ABSTRACT

SYSTRA conducted this study on behalf of the European Union Agency for Railways (ERA) in order (1) to provide a working definition of bearer independence in preparation for future work; and (2) to identify conditions for railway infrastructure, for vehicles, for spectrum, and for related equipment that could potentially enable European railways to achieve bearer independence.

The need for bearer independence

The introduction of GSM-R as a mandatory radio communication system for operational voice and ETCS data communication between infrastructure and on-board systems has provided a stable pillar for the single European railway area, based on a single radio technology and a single radio spectrum band. In recent years, it has however become clear that placing sole reliance on a single radio technology that is shortly becoming obsolescent is not a viable approach going forward. A more flexible approach is needed for the future.

With GSM-R, railway-specific functionality is directly integrated into the technical specification of the transmission technology. Features such as railway emergency calls and location dependent addressing (used for functional numbering) are an integral part of the GSM-R specification. Many of these application layer capabilities depend on capabilities of the underlying GSM-R network that would not necessarily be present in a general-purpose commercial wireless network. These network capabilities are specified together with the applications in the same GSM-R specifications.

As technology and requirements evolve, there is a widely recognised need to allow the use of alternative transmission technologies for track-to-train operational communications. There is a necessity to move beyond 2G technology (which at some point will no longer be maintainable), and there is also interest in supporting general purpose satellite or Wi-Fi technology. Operational rail applications will need to be able to run over transmission substrates that do not necessarily provide the same capabilities and features that GSM-R networks provide today.

Separating the *bearer* (the technical transmission technology aspects) from the *application* (railway functionality elements) therefore becomes a necessity. This separation is the essence of *bearer independence*. Multiple studies over the past few years[1] have recognised the need to evolve operational rail communications in order to achieve this separation.

A working definition of bearer independence

Bearer Independent Communications (BIC) are communications between two or more users and/or applications over a single access network or multiple heterogeneous access networks with no dependence on the availability of any bearer-specific features. Applications communications could in principle be supported over any IP-based bearer, whether commercial or private, without assuming that the bearer provides any capabilities beyond data transmission using the Internet Protocol (IP).

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Service continuity is required in both stationary and (high) mobility scenarios with the transparent use of one or more bearers.

Key findings

The study has identified a large number of findings and recommendations.

We identified two competing architectural models of multi-bearer support. The ***conservative view*** is based on 3GPP standards and specifications, and on services similar to those offered by Mobile Network Operators (MNOs). The ***flexible view*** is based on Over-the-Top (OTT) services using IETF and IEEE standards, and thereby potentially expands the set of bearers to include bearers such as Wi-Fi and satellite.

- The flexible solution should be preferred in the medium to long term. It is the solution that offers the broadest possibility to evolve operational rail communications over time.
- In the near term, there could however be benefit in implementing 3GPP-based solutions (the conservative view) as a stepping stone on the way to realisation of the flexible view. 3GPP-based solutions ultimately become one solution out of many[2].

Current standards do not enable the full realisation of bearer independence. Much promising work is going on that could potentially be reflected in bearer-independent standards, but further work will be required.

The shift to bearer independence implies the need for re-thinking of the ecosystem of rail operation transmission systems and rail operational applications. Both must be active in the market if rail operational communications are to be successful, and to evolve over time to benefit from technological and market evolution. There are, however, opportunities as well. The same de-coupling of transport from application that provides bearer independence could also potentially enable rail operational software by third party providers that are independent of the firms that provide the transmission equipment. In some cases, applications that have general commercial application might be used, with or without rail-specific enhancements, to meet operational rail communication needs.

Key recommendations

ERA should use its good offices to promote study of promising technological approaches, and engagement with relevant standards bodies where warranted. Candidates for further study or more active engagement include the ITxPT initiative, FirstNet in the US, the Cooperative-ITS (C-ITS) initiative, the Open Wireless Architecture (OWA), Software-Defined Radio (SDR), Software Defined Networks (SDN), Network Functionality Virtualization (NFV), and Multi Access Edge Computing (MEC).

Specific solutions are needed to address particular gaps. Full de-coupling of ETCS is called for, both in terms of specifications and of implementation. Solutions are needed for addressing (including number translation) and routing; for identifying the correct bearer(s) as the train moves. A security risk assessment based on major threat use cases, vulnerability of each assets, and potential impact is needed.

[2] It could be possible, however, that 3GPP specifications integrate also non-3GPP bearers in their portfolio; 5G may be the first step.

ERA's support for bearer independence should be undertaken in such a way as to make possible the development and deployment of third party operational rail applications. This implies that operational rail (on-board) equipment must be based on open and well documented operating systems and communication APIs so as to enable deployment of independently developed operational rail applications.

It will be necessary to evolve the certification and approvals process so as to support bearer independence in general and the introduction of third party applications in particular.

Migration plans to new bearers need coordination at European level, and must be harmonised with updates to the CCS TSI. A requirement at European, national or IM level will likely be needed to ensure that RUs upgrade by a predetermined and reasonable deadline, since RUs otherwise have little incentive to migrate.

ERA 2016 17 RS

25/07/2017

Reference number FR01T16H90_ERA_RS17_DLV_020

IMPLICATIONS OF BEARER INDEPENDENT COMMUNICATION CONCEPT

ERA 2016 17 RS

IMPLICATIONS OF BEARER INDEPENDENT COMMUNICATION CONCEPT

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The opinions expressed in this study are those of the authors and do not necessarily reflect the views of the European Union Agency for Railways (ERA).

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EXECUTIVE SUMMARY

This is the Executive Summary of the Final Report for "Implications of Bearer Independent Communication Concept", project ERA 2016 17 RS, which has been conducted on behalf of the European Rail Agency (ERA).

1 THE NEED FOR BEARER INDEPENDENCE

The introduction of GSM-R as a mandatory radio communication system for operational voice and ETCS data communication between infrastructure and on-board systems has provided a stable pillar for the single European railway area, based on a single radio technology and a single radio spectrum band. In recent years, it has however become clear that **placing sole reliance on a single radio technology that is on its way to becoming obsolete is not a viable approach going forward. A more flexible approach is needed for the future.**

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As technology and requirements evolve, there is a widely recognised need to allow the use of alternative transmission technologies for track-to-train operational communications. There is a necessity to move beyond 2G technology (which at some point will no longer be maintainable), and there is also interest in supporting general purpose satellite or Wi-Fi technology. Operational rail applications will need to be able to run over transmission substrates that do not necessarily provide the same capabilities and features that GSM-R networks provide today.

Separating the *bearer* (the technical transmission technology aspects) from the *application* (railway functionality elements) therefore becomes a necessity. This separation is the essence of *bearer independence*. Multiple studies over the past few years[3] have recognised the need to evolve operational rail communications in order to achieve this separation.

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2 GOALS OF THE STUDY

The overall objective of the study is identify the conditions for railway infrastructure, for vehicles, for spectrum, and for related equipment that can make feasible the concept of bearer independence for European railways.

In addition, the ERA's terms of reference call on the study team to answer a series of specific questions regarding the conditions necessary to successfully achieve bearer independence in terms of rolling stock, spectrum usage, infrastructure, the legal framework, and security. Our assessment of these aspects is summarised later in this Executive Summary.

3 A WORKING DEFINITION OF BEARER INDEPENDENCE

Bearer Independent Communications (BIC) are communications between two or more users and/or applications over a single access network or multiple heterogeneous access networks with no dependence on the availability of any bearer-specific features. Applications communications could in principle be supported over any IP-based bearer, whether commercial or private, without assuming that the bearer provides any capabilities beyond data transmission using the Internet Protocol (IP). Service continuity is required in both stationary and (high-)mobility scenarios with the transparent use of one or more bearers.

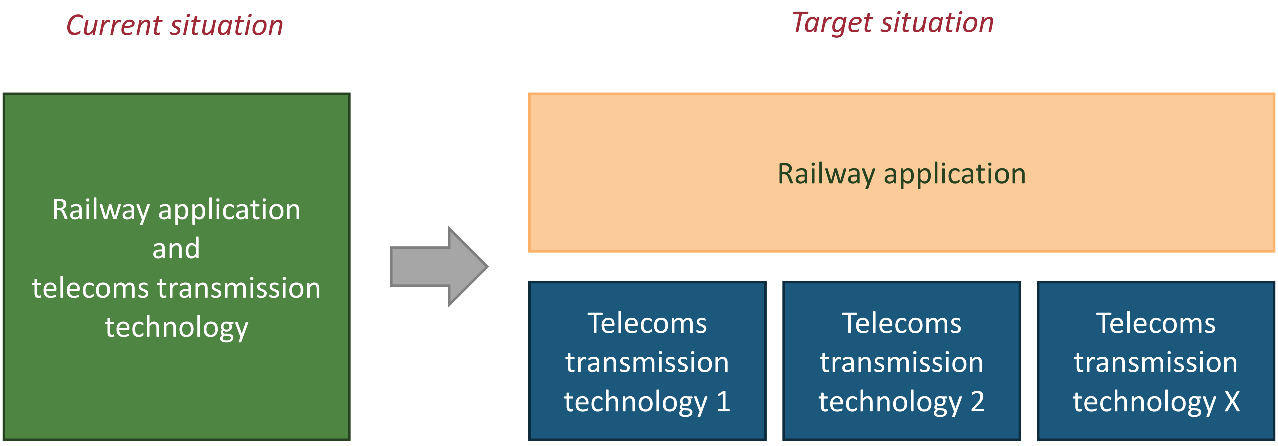

Figure 1: Bearer Independent Communications Concept

4 CATEGORISING THE FUNCTIONAL REQUIREMENTS

Based on our analysis of relevant use cases, we provide a *categorisation* or *taxonomy* of functional requirements (see Table 1) that enables us to group the requirements into interrelated clusters. We follow this structure throughout the report.

Category of Functional Requirements	Definition
INDEPENDENCE OF APPLICATION LAYER AND TRANSPORT	Any application must be able to communicate over one or more bearers without depending on any bearer-specific features, regardless of the application's characteristics or communication requirements (subject to quality of services requirements being fulfilled in terms of performance and security).
GUARANTEED CONNECTIVITY	Any application must be able to communicate at all times and at any supported location with a defined minimum quality of service that is appropriate to the requested operational rail service in terms of performance and security. This requires coverage, availability and sufficient capacity by at least one bearer at all supported locations.
MANAGEMENT OF MOBILITY	Service continuity needs to be maintained at all times and at any supported location for any authorised users or devices while ensuring end-to-end integrity of communications. This requires user authentication, authorisation, data integrity and confidentiality across hand-offs as a train moves from one bearer to another bearer.
ECOSYSTEM DEVELOPMENT	Full bearer independent communication systems will depend on new hardware and software components. This requires proper evolution of the market ecosystem. Given the relatively small size of the operational rail communications market, this may require policymakers to take special care.
DEPLOYMENT PLAN	Migration to fully bearer independent communication systems with full interoperability requires development and implementation of European and national deployment plans.
OPERATIONAL MANAGEMENT	Consistent and sustainable bearer independence requires integrated and comprehensive operational and maintenance management of all communication facilities (including both infrastructure and on-board equipment).

Table 1. **Categories of functional requirements**

Based on the identified use cases and our preliminary analysis of the functional requirements, a more detailed taxonomy or categorisation of key conditions for bearer independence can be derived and is presented in Table 2.

1	**INDEPENDENCE OF APPLICATION LAYER AND TRANSPORT**	System architecture			
		Standards and specifications			
2	**GUARANTEED CONNECTIVITY**	Radio Coverage	Traffic and QoS	Spectrum	
		Security-Availability *(incl. priority and preemption)*	Legal obligations		
3	**MANAGEMENT OF MOBILITY**	Subscriber authorisation	Subscriber location		
		Addressing			
		Seamless mobility *(incl. interworking with GSM-R, vertical handover and roaming)*			
		End-to-end security *(incl. authentication, integrity and confidentiality)*			
4	**ECOSYSTEM DEVELOPMENT**	Stakeholders	Products & Components		
		Traditional rail sector	New entrants	Hardware RF &	Software Applications
		Lifecycle & product availability			
5	**DEPLOYMENT PLAN**	European coordination	Legal Aspects		
		Vehicle RU	Infrastructure IM		
6	**OPERATIONAL MANAGEMENT**	Network Management	On-board communication devices maintainability		

Table 2. **Expanded view of the categories of functional requirements.**

5 FINDINGS

The findings address a range of issues including the goals and methodology of the study; the different visions of bearer independence, and their implications; standards and technology; network ownership and operational models; the management of mobility; the development of a bearer independent operational rail ecosystem addressing both transmission systems and operational rail applications; deployment plans; and operational management.

A numbered List of Findings appears at the beginning of the report, following the List of Figures and the List of Tables. For each finding, the List of Findings indicates the page on which the finding is initially derived.

For clarity of exposition, we present the findings in the most logical sequence, which is in a few instances a different sequence than that in which they appear in the text (thus causing a few of the Finding numbers to be out of sequence).

In terms of goals and methodology:

- Finding 1. Bearer independence can be introduced among new bearers, but full and comprehensive bearer independence is unlikely to be achieved until GSM-R has been decommissioned.
- Finding 2. The principal aims of introducing the Bearer Independent Communication Concept are (1) to allow flexibility in the implementation of new and diverse track-to-train radio services; (2) to facilitate the migration from one transmission technology to another; (3) to facilitate the maintenance of equipment; (4) to provide flexibility for the introduction, update, modification of, and maintenance of applications; (5) to provide flexibility for the introduction, update, modification and maintenance of the communications bearer; (6) to potentially provide better fall back or additional coverage offered by different networks and technologies; and (7) to provide flexibility in network capacity.
- Finding 3. In order to analyse conditions for success of the Bearer Independence Concept, it is helpful to categorise the conditions as relating mainly to (1) independence of the application layer and the transport; (2) guaranteed connectivity; (3) management of mobility; (4) ecosystem development; (5) the deployment plan; and (6) operational management.

Our findings as regards different visions of bearer independence (i.e. the *conservative view* versus the *flexible view*) and their relative desirability and sequencing:

- Finding 5. Stakeholders tend to gravitate to one of two architectural models of multi-bearer support. The *conservative view* is based on 3GPP standards, and on services similar to those offered by Mobile Network Operators (MNOs). The *flexible view* is based on Over-the-Top (OTT) services using IETF and IEEE standards, and thereby potentially expands the set of bearers to include bearers such as Wi-Fi and satellite.
- Finding 8. The flexible solution should be preferred in the medium to long term. Only the flexible solution offers full bearer independence. It is the solution that is most attuned to the likely long term evolution of the commercial market, where bearer independence has been taken for granted for many years. Moreover, the flexible solution is best positioned to support non-3GPP bearers such as Wi-Fi or SatCom in the medium or long term. It is the flexible solution that offers the broadest possibility to evolve operational rail communications over time.

- Finding 9. Short term implementation of the conservative view can be thought of as a stepping stone on the way to realisation of the flexible view. 3GPP-based solutions become one solution out of many.

Specific to the conservative view:

- Finding 4. Operational rail communications could potentially take advantage of the Mission-Critical Push-to-Talk (MCPTT) functionality that is an optional function in 3GPP Release 13 standards. It is unlikely, however, that Mobile Network Operators (MNOs) will deploy MCPTT unless they perceive sufficient demand for it from PPDR and/or operational rail. If MNOs do not demand these features, manufacturers will not implement them.
- Finding 36. *Wi-Fi calling* depends on 3GPP features. It is thus consistent with what we have referred to as the conservative view, but not with full bearer independence (i.e. the flexible view).

Specific to the flexible view:

- Finding 6. Full realisation of the flexible view would likely require the definition of new standards and protocols, with careful attention paid to performance and security. The bearers and applications are no longer bound to one another, but they effectively become an ecosystem where functionality and interoperability must be carefully planned for.
- Finding 7. Whether the conservative or the flexible view is ultimately followed, revisions to the various European instruments that ensure interoperability of rail communications (notably including the Technical Specifications for Interoperability (TSI)) are likely to be required.
- Finding 10. With bearer independence, we are seeking to deliver both voice and data operational rail communication services independently of underlying bearer-specific features. Today, it is routine for commercial data services to be fully bearer independent, and for voice services to ride on top of the bearer independent data services (as Voice over IP (VoIP)). This is the most natural approach for bearer independent operational rail communications to take.

As far as standards and technology in general:

- Finding 17. Current standards do not enable the full realisation of bearer independence.
- Finding 16. GSM-R has requirements beyond the standardised mandatory GSM capabilities required to support commercial mobile operations. The operational rail market is small, which implies that there is limited demand for equipment that can support GSM-R. This has led to delays in GSM-R standardisation and product availability, and additional cost within a niche market environment. Similar considerations might well apply to any future operational rail solutions that depend on specialised bearer-specific support in the transmission network.
- Finding 18. Current standards for many IP-based candidate bearers are potentially adequate for operational rail communications, once bearer-specific dependencies have been eliminated. Two areas that would nonetheless require intensive attention before incorporating any bearer into operational rail standards are (1) reliability and robustness requirements; and (2) QoS requirements, including end-to-end latency.

As regards potential or emerging technologies and standards that may be of interest in implementing bearer independence:

- Finding 15. Several emerging or developing technologies hold promise for the evolution of operational rail communications by potentially facilitating flexibility and infrastructure sharing. Among those that could be of interest are Open Wireless Architecture (OWA) and especially Software-Defined Radio (SDR), Network Functionality Virtualization (NFV), Software Defined Networks (SDN), and Multi Access Edge Computing (MEC).
- Finding 11. The IEC TCN communications architecture represents a valuable input as regards the safety of train operations.
- Finding 12. The ITxPT initiative provides a full ecosystem to deliver on-board plug-and-play IT systems to avoid vendor lock-in and foster the implementation of a standard IT on-board architecture.
- Finding 13. The First Responder Network Authority (FirstNet) that the US is in the process of deploying represents an interesting working example of a single network that provides communication services to both mission-critical safety and other non-mission-critical applications.
- Finding 14. Cooperative-ITS (C-ITS) is an Intelligent Transportation initiative that seeks to provide communication services between vehicles, infrastructures and other road users. It incorporates many of the same capabilities as those that are sought for bearer independent operational rail communications, including support for multiple bearers, transparent mobility management, and shared network resources.

As regards network ownership and operational models, and their implications:

- Finding 24. Spectrum options relevant for BIC provides a patchwork of models from legacy GSM-R model to a fully operated network model. This patchwork could be a major brake of putting into service standardised interference resilient products. Harmonised spectrum for railway applications could provide a framework to standardisation of interference resilient equipment, thus answering reliability figures of the FRMCS.
- Finding 26. The dedicated network is the preferred overall network model for GSM-R, but the alternative arrangements that are already in place demonstrate that other models may have value. The migration to fully bearer independent communications has the potential to facilitate the further evolution of other network operational models.
- Finding 27. The introduction of business and operational models other than dedicated GSM-R networks offers opportunities for rail operations, but it potentially also leads to considerably more technical and contractual complexity.
- Finding 25. With the move away from a single, dedicated GSM-R network, there is a need in many scenarios to establish clear Service Level Agreements (SLAs) in order to ensure that the necessary Quality of Service (QoS) is provided. Where multiple bearers operate in parallel, these SLAs might be tricky to implement.

As regards spectrum needs in order to achieve coverage in a bearer independent environment:

- Finding 19. Coverage is a fundamental requirement for operational rail communications. Ensuring coverage is a task for policymakers – it is not something that can be left to market mechanisms.
- Finding 23. The spectrum currently used for GSM-R is 876 MHz - 880 MHz for uplink, and 921 MHz - 925 MHz for downlink. The 4G mobile standards do not include these GSM-R bands. No additional spectrum has yet been designated for railways in Europe (to deal with migration to a successor to GSM-R, for example, for Member States that deploy dedicated networks). Many questions are not yet resolved as to how to best address the future evolution of operational

rail communications, but efforts to resolve them are already under way by the ECC Frequency Management Working Group.

- Finding 20. Whether dedicated spectrum is required for operational rail communications depends on whether the Member State has chosen to support rail operational communications using a private, dedicated network, a private network shared with other mission-critical applications such as PPDR, or a public commercial network provided by an MNO.
- Finding 21. If the Member State has chosen an approach to operational rail or passenger rail communications where coverage of rail routes by one or more commercial MNOs is needed, this could be achieved by means of coverage obligations in a future spectrum auction (for example, in the coming auctions for 700 MHz spectrum).
- Finding 22. For a dedicated network, whether dedicated exclusively to rail or shared with other mission-critical uses, it is the Member State's responsibility to ensure that the network is deployed.

As regards mobility management:

- Finding 31. Addressing and routing using rail-specific identities has not yet been specified in a manner consistent with bearer independence. Number translation is missing.
- Finding 32. The bearers available to on-board equipment will continually be in flux as the train moves. Full bearer independence makes this hand-off problem considerably more complex than it is today under GSM-R. The choice of bearer(s) might perhaps best be address by coordination between on-board equipment and infrastructure. This is not a solved problem.
- Finding 33. Mobility management has implications for security that are not yet well defined.

As regards the ecosystem for rail operational systems:

- Finding 37. The shift to bearer independence implies the need for re-thinking of the ecosystem of rail operation transmission systems and rail operational applications. Both must be active in the market if rail operational communications are to be successful, and to evolve over time to benefit from technological and market evolution.
- Finding 34. The same de-coupling of transport from application that provides bearer independence could also potentially enable rail operational software by third party providers that are independent of the firms that provide the transmission equipment. In some cases, applications that have general commercial application might be used, with or without rail-specific enhancements, to meet operational rail communication needs.
- Finding 35. If third parties are to be able to supply operational rail applications (especially in on-board systems), attention must be paid to ensure (1) open operating system platforms with well documented interfaces, (2) open well documented communications Application Programming Interfaces (APIs), (3) competitive constraints are not allowed to impede entry of new players, (4) the certification and approval process needs to carefully consider how to enable this kind of innovation without sacrificing safety, and (5) legal and regulatory requirements need to be fully thought through.
- Finding 38. Making it possible for third parties to provide applications potentially addresses a number of long-standing operational rail needs, including skill shortages for application developers and security experts.
- Finding 39. If 3GPP standardisation efforts were to fail to deliver the 3GPP features needed to fulfil railway functional requirements, an alternative will be needed. Fully bearer independent

PTT applications could provide the answer, and third party PTT apps might possibly be the most effective way to ensure availability of the necessary applications.

As regards network neutrality:

- Finding 28. If a commercial MNO were to support operational rail communications, network neutrality rules (Regulation 2015/2120) are inapplicable because operational rail communications do not provide access to the Internet, and do not serve the general public. Even if they were applicable, operational rail communications would clearly represent a *specialised service*. Network neutrality does not appear to pose an impediment to the use of public mobile networks for operational rail.
- Finding 29. Network neutrality (Regulation 2015/2120) does not appear to be applicable to rail passenger communications, as long as the services are offered only to passengers. To the extent that they are offered to the public at large (in train stations, for example), then the network neutrality rules might well be applicable.

As regards operational maintenance:

- Finding 40. End-to end management is a key enabler for the successful realisation of the bearer independence concept.
- Finding 41. Key goals in terms of vehicle maintenance are (1) to minimise the duration of human maintenance operations during periodic maintenance cycles; (2) to allow remote and secure maintenance operations outside periodic maintenance cycles without the need of standing vehicles at maintenance depots; and (3) to reduce OPEX. These are also the goals today under GSM-R. The introduction of bearer independence must not interfere without attainment of these goals.

6 RESPONSES TO THE QUESTIONS POSED IN THE ERA'S TERMS OF REFERENCE FOR THE STUDY

As previously noted, the Terms of Reference (TOR) of the study stipulate different questions to be addressed. The findings and recommendations developed in this study collectively answer the questions that were posed. A few key points are worth noting.

Question 1. Conditions for rolling stock

a. What may be needed to allow bearer independency: system architecture?

In terms of technical standards and systems architecture, ERA should use its good offices to ensure (1) that all relevant functional specifications are updated so as to eliminate dependence on bearer-specific capabilities beyond those embodied in basic transmission standards for most bearers; (2) that a gap analysis is conducted to identify capabilities that would need to be implemented at the Application Layer in order to provide necessary functionality going forward (presumably equivalent to that available under GSM-R today); and (3) that standards are developed that address the gaps identified. Where necessary and appropriate, ERA might ask the Commission to issue mandates to the European Standards Organisations (ESOs). Migration plans to new bearers may need coordination at European level, and must be harmonised with updates to the CCS TSI.

b. Availability of on-board applications to achieve the overall functionality.

This needs to be approached with a view of the operational rail ecosystem. The shift to bearer independence implies the need for re-thinking of the ecosystem of rail operation transmission systems and rail operational applications. Both must be active in the market if rail operational communications are to be successful, and to evolve over time to benefit from technological and market evolution. ERA's support for bearer independence should be undertaken in such a way as to make possible the development and deployment of third party operational rail applications. ERA should consult with stakeholders, and launch studies if appropriate, to determine how best to ensure that operational rail (on-board) equipment is based on open and well documented operating systems and communication APIs so as to enable deployment of independently developed operational rail applications. ERA should consult with stakeholders, and launch studies if appropriate, to determine whether actions at European level would be needed to ensure through standards and through IM and RU procurement policies that unnecessary barriers are not erected to market entry of third party operational rail applications.

c. Identification of possible constraints, such as:

- product availability in relation to the timing of the start of migration
- development and implementation costs
- delays in standardisation
- other economic constraints.

ERA should initiate a detailed study to explore a range of potential practical, legal and regulatory impediments to the future migration to bearers other than GSM-R. Potential impediments include

(1) the possible need for re-certification of the train; (2) legal and regulatory barriers; and (3) security concerns with over-the-air update of operational rail software.

d. Deployment plan of the RUs ("dual mode" or "single mode" on-board equipment; expected schedule for deployment): impact on the European implementation (coordinated migration scenario vs non-coordinated).

ERA should consider establishing a requirement at European, national or IM level for RUs to support NG (the Next Generation successor to GSM-R) by a predetermined and reasonable deadline, subject to the CCS TSI allowing the use of NG. A coordinated approach may be necessary, since RUs otherwise have little incentive to migrate.

*In previous work,[4] we identified the need for RUs to deploy dual-mode GSM-R / NG equipment **before** IMs deploy NG, and certainly before IMs phase out GSM-R.*

Question 2. Conditions for spectrum usage

a. What may be needed to allow bearer independency: reception of different spectrum bands and use of different technologies?

   The answers are generally the same as for Question 1, point (a).

b. Availability of radio terminal equipment to achieve the overall functionality: spectrum emission masks better than the ones currently available for LTE; prevention of blocking and intermodulation.

   Spectrum issues are very important for the migration to next generation operational rail technology, and on-board equipment with the ability to operate in the bands that will ultimately be used for the next generation successor should be deployed opportunistically as equipment is brought in for maintenance. The migration to bearer independence is, however, generally independent of the migration to next generation operational rail technology.

c. Identification of possible constraints, such as:
   - product availability in relation to the timing of the start of migration
   - development and implementation costs of radio terminals (SDR or others) that can use the GSM-R spectrum band and others
   - delays in standardisation (definition of the R-GSM band in the 3GPP rel14 and beyond)
   - dependency on the allocation of spectrum.

   The answers are generally the same as for Question 1, point (c).

d. Extreme spectrum scenarios: locations where not the full R-GSM band is available (at network borders).

[4] See for instance Systra (2016) Final Report ERA 2015 04 1 RS Study on migration of railway radio communication system from GSM-R to other solutions

Again, spectrum issues are very important for the migration to next generation operational rail technology. The migration to bearer independence is, however, generally independent of the migration to next generation operational rail technology.

e. <u>Possible deployment strategy: linked to the migration scenarios described (see Annex I), consider the benefits of using 1,4 MHz in the R-GSM band first and to use the full 3 MHz when GSM-R will be switched off; synergies with PPDR.</u>

   Again, spectrum issues are very important for the migration to next generation operational rail technology. The migration to bearer independence is, however, generally independent of the migration to next generation operational rail technology.

Question 3. Conditions for the infrastructure

a. <u>What may be needed to allow bearer independency: system architecture?</u>

   The answers are generally the same as for Question 1, point (a).

b. <u>Justification of the need to use dedicated networks, or under which circumstances could public networks be used</u>.

   In theory, public networks could be used to the extent that they meet the requirements of the relevant operational rail applications in terms of (1) coverage, (2) quality of service (including latency), (3) reliability and robustness, and (4) security. In practice, it may be either difficult or prohibitively expensive for commercial mobile networks to meet those requirements; at the same time, however, multi-bearer might facilitate solutions where commercial mobile networks play a complementary role to dedicated networks. In any solution where commercial networks contribute to the fulfilment of mission-critical operations, resource allocation and sharing between commercial versus mission-critical use will be challenging.

c. <u>Availability of applications to achieve the overall functionality with more than one network providing services (i.e. at least GSM-R and another one).</u>

   The answers are generally the same as for Question 1, point (b).

d. <u>Identification of possible constraints, such as:</u>
   - network management for various technologies/types of networks (i.e. at least GSM-R and another one)
   - subscriber management
   - international services (roaming)
   - relation to the timing to start the migration
   - development and implementation costs; other economic constraints.

   The answers are generally the same as for Question 1, point(c).

e. <u>Deployment plan of the IMs: impact on European implementation (coordinated migration scenario vs non-coordinated); conditions to stop GSM-R services in a region.</u>

ERA should consider establishing a requirement at European, national or IM level for RUs to support NG (the Next Generation successor to GSM-R) by a predetermined and reasonable deadline, subject to the CCS TSI allowing the use of NG. A coordinated approach may be necessary, since RUs otherwise have little incentive to migrate. Migration plans to new bearers may need coordination at European level, and must be harmonised with updates to the CCS TSI.

Question 4. Conditions for the legal framework

a. Different legal frameworks in the MSs related to telecommunication services and obligations, in particular regarding the provision of internet services and information to passengers.

   Legal and regulatory frameworks at European level and among the Member States have very little impact on bearer independence (and vice versa). As long as rail communications are either (1) operational or (2) delivered only to passengers but not to the public at large, they do not constitute Electronic Communication Services (ECS), and thus are not subject to most provisions of the Regulatory Framework for Electronic Communications (RFEC). Network neutrality is likewise inapplicable.

b. Additional regulation that may impose the rights of passengers to have access to wireless connections (to understand the possible impact on vehicle architecture).

   Whether imposed by regulation or not, passengers will increasingly demand wireless connections, and RUs will need to plan for them. The open question is whether it is cost-effective to deliver them using the same networks as operational services given the huge differences in bandwidth, latency, and reliability requirements between rail operations and passenger entertainment communications.

Question 5. Conditions related to security aspects

a. Justification of the need to use dedicated networks, or under which circumstances could public networks be used.
   In theory, as noted in the response to Question 3, point (b), public networks could be used to the extent that they meet the requirements of the relevant operational rail applications in terms of (1) coverage, (2) quality of service (including latency), (3) reliability and robustness, and (4) security. In practice, it may be either difficult or prohibitively expensive for commercial mobile networks to meet those requirements.

b. Considerations related to security to support the bearer independency for the applications and networks used (such as user management, security of the communication link, etc.).

   ERA should ensure that a security architecture for bearer independent operational rail communications is developed. A security risk assessment based on major threat use cases, vulnerability of each assets, and potential impact is needed. The results could be reflected in a future revision of the UIC User Requirements Specification (URS).

7 RECOMMENDATIONS

The study has generated nineteen recommendations, addressing standards and technology; the management of mobility; the development of a suitable ecosystem for operational rail transmission and applications; and the interaction of bearer independence with migration plans.

A numbered List of Recommendations appears at the beginning of the main report, following the List of Findings. For each recommendation, the List of Recommendations indicates the page on which the recommendation is initially presented.

Our recommendations in terms of the evolution of standards and technology are:

- Recommendation 1. The IEC TCN communication architecture may represent a good basis on which to design additional rail safety operations. Collaboration with IEC members should be considered in order to avoid redundant work on train to ground communication systems.
- Recommendation 2. Lessons learned from initiatives such as the ITxPT initiative should be considered by the rail sector as a means of overcoming the challenges of implementing SOA models.
- Recommendation 3. Lessons learned from initiatives such as the First Responder Network Authority (FirstNet) that the US is in the process of being deploying should be considered by the rail sector as a means of overcoming the challenges of implementing a single network that supports both mission-critical and non-mission-critical services.
- Recommendation 4. Lessons learned from initiatives such as the Cooperative-ITS (C-ITS) initiative should be considered by the rail sector as a means of overcoming the challenges of implementing bearer independent mission-critical communications.
- Recommendation 5. ERA should consider more detailed study of various network designs that are either being implemented or else are under consideration to determine the degree to which lessons learned are potentially applicable to European operational rail communications. Candidates for further study include the ITxPT initiative, FirstNet in the US, and the Cooperative-ITS (C-ITS) initiative.
- Recommendation 6. ERA should use its good offices to promote or encourage interaction between the operational rail communications community and the standards bodies responsible for technologies that are potentially of interest. Technologies where increased engagement may be warranted include the Open Wireless Architecture (OWA) and especially Software-Defined Radio (SDR), Network Functionality Virtualization (NFV), Software Defined Networks (SDN), and Multi-Access Edge Computing (MEC).
- Recommendation 7. In order to ensure that standards are in place to enable the full realisation of bearer independence, ERA should use its good offices to ensure (1) that all relevant functional specifications are updated so as to eliminate dependence on bearer-specific capabilities beyond those embodied in basic transmission standards for most bearers; (2) that a gap analysis is conducted to identify capabilities that would need to be implemented at the Application Layer in order to provide necessary functionality going forward (presumably equivalent to that available under GSM-R today); and (3) that standards are developed that address the gaps identified. Where necessary and appropriate, ERA might ask the Commission to issue mandates to the European Standards Organisations (ESOs).
- Recommendation 8. De-coupling of ETCS is called for, both in terms of specifications and of implementation. The introduction of middleware between the Euroradio Safety Layer and the Euroradio Communication Layer should be considered. ERA should consider launching studies as to how best to achieve the de-coupling.

In terms of the management of mobility, our recommendations are:

- Recommendation 9. ERA should use its good offices to ensure that a bearer independent solution is found that addresses the need for addressing (including number translation) and routing using rail-specific identities.
- Recommendation 10. ERA should ensure that technical solutions are found to identifying the correct bearer(s) as the train moves. A study might be appropriate as a first step.
- Recommendation 11. ERA should ensure that a security architecture for bearer independent operational rail communications is developed. A security risk assessment based on major threat use cases, vulnerability of each assets, and potential impact is needed. The results could be reflected in a future revision of the UIC User Requirements Specification (URS).ERA should use its good offices to ensure that a bearer independent solution is found that addresses the need for addressing (including number translation) and routing using rail-specific identities.

The development of a suitable ecosystem for operational rail transmission and applications requires special attention. The decoupling of the two offers many new opportunities.

- Recommendation 12. ERA's support for bearer independence should be undertaken in such a way as to make possible the development and deployment of third party operational rail applications.
- Recommendation 13. ERA should consult with stakeholders, and launch studies if appropriate, to determine how best to ensure that operational rail (on-board) equipment is based on open and well documented operating systems and communication APIs so as to enable deployment of independently developed operational rail applications.
- Recommendation 14. ERA should consult with stakeholders, and launch studies if appropriate, to determine whether actions at European level would be needed to ensure through standards and through IM and RU procurement policies that unnecessary barriers are not erected to market entry of third party operational rail applications.
- Recommendation 15. ERA should consider carefully, consulting with stakeholders and launching studies if appropriate, how to evolve the certification and approvals process so as to support bearer independence in general and the introduction of third party applications in particular.

In terms of the interaction of bearer independence with migration plans, our recommendations are:

- Recommendation 16. Migration plans to new bearers may need coordination at a European level, and must be harmonised with updates to the CCS TSI. Consider establishing a requirement at European, national or IM level for RUs to support NG (the Next Generation successor to GSM-R) by a predetermined and reasonable deadline, since RUs otherwise have little incentive to migrate.
- Recommendation 17. Consider expanding the register of infrastructure (RINF) tool and database to depict the routes where each of the bearers permitted under a future TSI is deployed, or is planned to be deployed.

- Recommendation 18. ERA should initiate a detailed study to explore a range of potential practical, legal and regulatory impediments to the future migration to bearers other than GSM-R. Potential impediments include (1) the possible need for re-certification of the train; (2) legal and regulatory barriers; and (3) security concerns with over-the-air update of operational rail software.**Error! Reference source not found.**

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ABBREVIATIONS

API	Application Programming Interface
2G	Second generation of wireless mobile telecommunications technology
3G	Third generation of wireless mobile telecommunications technology
3GPP	3rd Generation Partnership Project
4G	Fourth generation of wireless mobile telecommunications technology
5G	Fifth generation of wireless mobile telecommunications technology
3iBS	intelligent, innovative, integrated Bus Systems
ADL	Architecture Description Language
ANSSI	Agence nationale de la sécurité des systèmes d'information
AP	Access Point
APCO	Association of Public-Safety Communications Officials
ASCI	Advanced Speech Call Items
ATC	Automatic Train Control
BEREC	Body of European Regulators for Electronic Communications
BIC	Bearer Independent Communication
BSS	Base Station Subsystem
CAPEX	Capital Expenditure
CCS TSI	Technical Specifications for Interoperability relating to the Control-Command and Signalling subsystems of the trans-European rail system
CEPT	European Conference of Postal and Telecommunications Administrations
CER	Community of European Railway and Infrastructure Companies
CIM	Common Information Model
CMIP	Common Management Information Protocol
CS	Circuit-Switched
CSFB	Circuit-Switched Fall-Back
DMR	Digital Mobile Radio
dPMR	Digital Private Mobile Radio
DSD	Driver Safety Device
CSP	Communications Service Provider (including MNO, satellite and all kind of content and applications service providers)
DSRC	Dedicated Short Range Communications
E2E	End-to-End
EBSF	European Bus System of the Future
ECC	Electronic Communications Committee
ECO	European Communications Office
ECS	Electronic Communication Services
EDOR	ETCS Data Only Radio
EIM	European rail Infrastructure manager
ENISA	European Union Agency for Network and Information Security
EPC	Evolved Packed Core
ERA	European Union Agency for Railways
ER-GSM	Extended GSM-R
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
eTOM	enhanced Telecom Operations Map
ETSI	European Telecommunications Standards Institute

EU	European Union
FCAPS	Fault, Configuration, Accounting, Performance and Security
FDD	Frequency Division Duplex
FRMCS	Future Railway Mobile Communication System
FQDN	Fully Qualified Domain Name
FTS	Fixed Terminal System (dispatcher system)
GSM	Global System for Mobile Communications (refer to 2G)
GSM-R	Global System for Mobile Communications-Rail
IC	Interoperability Constituent
HTTP	HyperText Transfer Protocol
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IMS	IP Multimedia Subsystem
IM	Infrastructure manager
IOP	Interoperability
IP	Internet Protocol
ISO	International Organization for Standardization
IT	Information Technology
ITIL	Information Technology Infrastructure Library
ITS	Intelligent Transport System
ITU	International Telecommunication Union
ITU-R	ITU's Radiocommunication sector
ITxPT	Information Technology for Public Transport
KMS	Key Management System
KPI	Key Performance Indicators
LMR	Land Mobile Radio
LPWAN	Low-Power Wide-Area Network
LTE	Long Term Evolution
LTE-A	LTE Advanced (refer to 4G)
LTE-A Pro	LTE Advanced Pro
M2M	Machine-to-Machine
M(V)NO	Commercial Mobile (Virtual) Network Operator
MCG	Mobile Communication Gateway
MHz	MegaHertz
MIP	Mobile IP
MNO	Mobile Network Operator
MS	Member State
MSISDN	Mobile Station International Subscriber Directory Number
MTTR	Mean-Time-To-Repair
NEMO	Network Mobility
NG	Next Generation
NG2R	Next Generation Radio for Rail
NGTC	Next Generation Train Control
NMC	Network Management Center
NOC	Network Operations Center
NRA	National Regulatory Authorities
NSS	Network SubSystem
NXDN	Next Generation Digital Narrowband

OSI	Open Systems Interconnection
OMTS	On-board Multimedia and Telematic Subsystems
OTT	Over-The-Top
OWA	Open Wireless Architecture
P25	Project 25 (Refer to APCO)
PDT	Professional Digital Trunking
PMR	Private Mobile Radio - Professional Mobile Radio
PPDR	Public Protection and Disaster Relief
PRIME	Platform of Rail Infrastructure Managers in Europe
PS	Packet-Switched
PSCE	Public Safety Communication Europe
PT	Public Transport
PTToC	Push-To-Talk over Cellular
QCI	QoS Class Identifier
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
RCS	Rich-Communication Suite
S2R	Shift^{2}Rail
RAM	Reliability, Availability, and Maintainability
RAMS	Reliability, Availability, Maintainability and Safety
RED	Radio Equipment Directive
RINF	Register of INFrastructure
RU	Railway Undertaking
SATCOM	Satellite Communications
SALUS	Security And InteroperabiLity in Next Generation PPDR CommUnication Infrastructure
SDR	Software Defined Radio
SIP	Session Initiation Protocol
TDD	Time Division Duplex
TETRA	Terrestrial trunked Radio
SLA	Service Level Agreement
SMI	Structure of Management Information
SNMP	Simple Network Management Protocol
SOA	Service Oriented Architecture
TCMS	Train Control and Monitoring System
TCN	Train Communication Network
TMN	Telecommunications Managed Network
TOM	Telecom Operations Map
UIC	International Union of Railways
UMTS	Universal Mobile Telecommunications System
UNISIG	Union industry of signalling
ViLTE	Video over LTE
VoIP	Voice over IP
VoLTE	Voice over LTE
VoWiFi	Voice over Wi-Fi
WAPECS	Wireless Access Policy for Electronic Communications Services
WebRTC	Web Real-Time Communications

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1. INTRODUCTION

1.1 Scope and purpose of the document

This document is the Final Report of the study ERA 2016 17 RS entitled "Bearer Independent Communication Concepts" for railway radio communication systems. It identifies findings and the key conditions necessary for enabling bearer independent communications and provides recommendations on the way forward.

1.2 Context, scope and objectives of the study

1.2.1 Context

In September 2017, the European Union Agency for Railways contracted SYSTRA to carry out a study to understand the various implications of the "bearer independent communication" concepts related to railway specific voice and European Train Control System (ETCS) data applications and to security.

In terms of consistency of implementation, the current situation in Europe is diverse. On the one hand, only a single technology has been adopted and used, GSM-R, for operational voice and ETCS data communication, as mandated by the EU. On the other hand, there is a widespread roll-out of GSM-R network infrastructure and on-board equipment, as well as differences in the speed of introduction of ETCS, voice and other data applications. In addition, a variety of different contracting strategies, of additional radio systems for non-mandatory radio communication applications used by railways, and of system lifecycle management strategies can be seen.

The introduction of new technologies to replace GSM-R, which is expected to commence in 2022, will complicate this already diverse situation. In order to create more independence between on-board radio systems and the current and future trackside infrastructure, the concept of bearer independence aims at more flexible implementation, migration and maintenance during the lifetime of both on-board and trackside systems. This allows independent system and product roadmaps for the communication and application elements for both infrastructure and on-board equipment.

The concept of independence can only be successful when a number of conditions are fulfilled. This imposes a number of constraints on both the trackside infrastructure and the vehicle, such as support of different radio technologies while providing a single set of functions to the users in a seamless way. This implies the coexistence of various networks and technologies, which provide communication services that can be used through a terminal that is capable of switching between the available networks, using different spectrum bands in a seamless manner. Interruption of the end-user application when a change of network or technology occurs must also be prevented, thus making the architecture and design of both on-board and trackside architecture equipment a key condition for the success of the concept.

In Europe, there are already various initiatives in the rail sector related to using different bearers to complete GSM-R coverage for voice service. Several IMs and RUs have agreements with public operators on 2G networks for providing coverage on low traffic lines. Some of them have, or aim to have, a specific core network node to offer railway service for voice. But, note that these solutions include different bearers but are NOT bearer independent as the provided services/functionality differs. A recent initiative is the Finnish Transport Agency awarding a contract to use TETRA and a public network for operational communications. It was announced as a bearer-independent railway communication system but it need to be demonstrate because the solution is still under development and include 2G networks.

1.2.2 Scope and objectives of the study

The purpose of this study is to identify the conditions for railway infrastructure, vehicles, radio spectrum and related equipment that can make feasible the concept of bearer independence for European railways. This Final Report, containing a detailed analysis, main conclusions, and recommendations and underlying justification, is the main output of the study. It is intended that the European Union Agency for Railways uses the results of this study to support the Commission in the preparation of a strategy for the successor to GSM-R including the start of migration, future spectrum needs as well as the overall system architecture.

The Terms of Reference required that a number of areas be addressed:

1. Conditions for the vehicles

a. What may be needed to allow bearer independence: system architecture?
b. Availability of on-board applications to achieve the overall functionality.
c. Identification of possible constraints, such as:
    - product availability in relation to the timing of the start of migration
    - development and implementation costs
    - delays in standardisation
    - other economic constraints.
d. Deployment plan of the RUs ("dual mode" or "single mode" on-board equipment; expected schedule for deployment): impact on the European implementation (coordinated migration scenario vs non-coordinated).

2. Conditions for spectrum usage

a. What may be needed to allow bearer independence: reception of different spectrum bands and use of different technologies?
b. Availability of radio terminal equipment to achieve the overall functionality: spectrum emission masks better than the ones currently available for LTE; prevention of blocking and intermodulation.
c. Identification of possible constraints, such as:
    - product availability in relation to the timing of the start of migration
    - development and implementation costs of radio terminals (SDR or others) that can use the GSM-R spectrum band and others
    - delays in standardisation (definition of the R-GSM band in the 3GPP re114 and beyond)
    - dependency on the allocation of spectrum.

d. Extreme spectrum scenarios: locations where not the full R-GSM band is available (at network borders).
e. Possible deployment strategy: linked to the migration scenarios described (see Annex I), consider the benefits of using 1,4 MHz in the R-GSM band first and to use the full 3 MHz when GSM-R will be switched off; synergies with PPDR.

3. Conditions for the infrastructure

a. What may be needed to allow bearer independence: system architecture?
b. Justification of the need to use dedicated networks, or under which circumstances could public networks be used.
c. Availability of applications to achieve the overall functionality with more than one network providing services (i.e. at least GSM-R and another one).
d. Identification of possible constraints, such as:
    - network management for various technologies/types of networks (i.e. at least GSM-R and another one)
    - subscriber management
    - international services (roaming)
    - relation to the timing to start the migration
    - development and implementation costs; other economic constraints.
e. Deployment plan of the IMs: impact on European implementation (coordinated migration scenario vs non-coordinated); conditions to stop GSM-R services in a region.

4. Conditions for the legal framework

a. Different legal frameworks in the MSs related to telecommunication services and obligations, in particular regarding the provision of internet services and information to passengers.
b. Additional regulation that may impose the rights of passengers to have access to wireless connections (to understand the possible impact on vehicle architecture).

5. Conditions related to security aspects

a. Justification of the need to use dedicated networks, or under which circumstances could public networks be used.
b. Considerations related to security to support the bearer independence for the applications and networks used (such as user management, security of the communication link, etc.).

1.3 Main focus of the study

This study is part of enquiries led by the European Union Agency for Railways (hereafter ERA or the Agency) and the European Union, aiming at ensuring the future of a European interoperable railway radio communication service. It looks at the evolution of train control and communication systems and in particular the future of GSM-R and the bearer independence for ETCS data transmission. The aim is to provide technical advice to the European Commission, in particular on the feasibility and the possible ways for the adoption of new technologies whilst preserving functional interoperability requirements.

Consequently this study identifies key conditions for success of the bearer independent concept and conditions that can make this feasible for European railways in the areas that comprise the railway network, i.e. infrastructure, on-board equipment as well as other key topics that are radio spectrum, legal framework and security. Since the bearer independent concept is under development for railway applications, all these topics are addressed to identify possible constraints and availability. Other subjects that may have some impact on the development or deployment on the bearer independent concept are also analysed such as the provision of internet and information services to passengers or the need to use dedicated networks for railways.

The study identifies answers for each items according the following questions:

- What are the conditions for success?
- What is needed?
- Is the appropriate framework in place?
- Are we close to it? E.g. spectrum.

In order to identify the key conditions in a logical manner the study is structured in the following way:

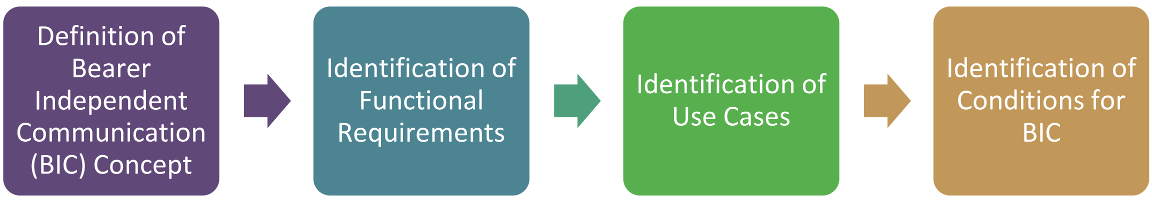


Figure 1. Study structure

The study starts by defining the concept of bearer independent communications. A working definition is provided in Chapter 2 to help facilitate the readability of the study and a final definition is provided in Chapter 10.

Functional requirements for track-to-train communications are then identified in Chapter 3, based on current (EIRENE) and future (FRMCS) requirements. The study concentrates on critical and performance services categories of the UIC URS as a minimum for bearer independence analysis and linked constraints and conditions. Business applications are deemed less important for this analysis because there is no direct impact on interoperability.

Later in Chapter 3 the study goes on to develop five operational use cases which help to classify the functional requirements implied by Bearer Independence.

Based on this classification of functional requirements, Chapters 4 to 9 of the study identify conditions and constraints that need to be met to make the BIC concept feasible. A detailed analysis on different areas implicated in the bearer independent concept is carried out resulting in key findings and recommendations defining conditions for success of the bearer Independency.

Finally, a summary of the findings and recommendations is presented in Chapter 10.

1.4 Other related studies

This Bearer Independent Concept study is the one of a series of studies undertaken by the Agency in the field of operational communications. Some of these studies have been used as an input for this current study in order to help in the identification of the conditions:

- A study on migration of railway radio communication from GSM-R to other solutions, carried out by SYSTRA.[5] Its principal objective was to identify main business drivers for migration and potential migration scenarios as well as to create a model to analyse the economic impact of different migration scenarios.
- A study on co-existence of GSM-R and other radio technologies in the current railway radio spectrum, produced by LS Telcom.[6] Its key objective was to study the technical and operational coexistence of another communication system with GSM-R in the current harmonised spectrum for railways during the transition period.
- A study on the feasibility of satellite communications for railway applications, written by INDRA/ALG.[7] The aim of this study was to assess the potential feasibility for railway applications of an integrated communication architecture including not only terrestrial radio networks but also current and future commercially available satellite communication services and products.
- A study on operational communications for the evolution of the railways communications system produced by Analysis Mason,[8] introduced bearer independence as key considerations for future railway communication. Bearer independence can be seen in a multi technology

[5] Systra (2016) Final Report ERA 2015 04 1 RS Study on migration of railway radio communication system from GSM-R to other solutions

[6] LS Telecom (2016) Study on co-existence of GSM-R and other radio technologies in the current railway radio spectrum

[7] INDRA/ALG (2017) Study on feasibility of satcom for railway applications

[8] Analysys Mason (2014), Final report of the study for the evolution of the railways communications system

approach and as a separation between application and bearer from an architectural point of view. This study presents and evaluates 6 options of evolution from the current situation: (1) retain GSM-R, (2) new technology with same band, (3) new technology with new band, (4) new technology with third party, (5) multiple prescribed technologies; and (6) multiple technologies without prescription.

- The IDATE report[9] on the GSM-R evolution refers to bearer independent applications capable of operating over a chosen range of bearer technologies either already available or future ones.

A selection of findings of the above studies relevant to this study are highlighted below:

- GSM-R will continue to be used for many years. The successor system will consequently need to coexist with the current system.
- There is interest in using satellite communications and Wi-Fi as suitable bearers for track-to-train communication despite them not supporting a number of key operational features which are inherently part of GSM-R (e.g. Railway Emergency Calls).
- In the coming decades, there is unlikely to be a single technology or system, but rather a dynamic, hybrid, continuously evolving ecosystem.
- A flexible on-board architecture will be the key for successful migration.
- There is a need to have relevant specifications to ensure operational interoperability including GSM-R and its successor.
- There is possibility for the rail sector to use networks with no specific features for rail applications but still with end-to-end performance and reliability requirements. It is still important to provide the communication bearer in a safe and secure way when it is required.
- To maintain interoperability, CCS TSI would specify a number of radio bearers, enabling Member States or Infrastructure Managers to choose one or more of them.
- Participants of IDATE workshop would like to have IP-based bearer-independence that offers independence between the radio bearer and application layer. For that, the industry needs to develop IP suitable voice and ETCS application platforms.
- Bearer independence is presented as a one of the principal issues for evolution and ETCS over (E)GPRS and IP telephony development can be seen as a first step of this evolution.
- Specification of error performance and latency is important for the future bearer.

These findings demonstrate the need to investigate in greater detail the bearer independent concept.

[9] IDATE (2015), Evolution of GSM-R, FINAL Report

1.5 Study methodology

For this study SYSTRA followed a methodology inspired by the European Commission's Guidelines for Better Regulation,[10] including Chapter VIII of the "Better Regulation Toolbox" (methods, models and costs and benefits) that complements the Guidelines.

The project was divided into a number of steps:

Figure 2. Project steps

Step 0: Inception: The aim of this step was to ensure alignment and agreement between the project team and ERA on specific details on planning and methodology approach. The objective was to set the basis to ensure the project direction and management. It included preparation, organization and participation of kick-off meeting with the Agency and a kick-off meeting report.

Step 1: Data collection: This step consisted of two components:

- The objectives of the **Data collection for BIC concept definition** were:
  - ✓ To define the key principles of the bearer independent communication concept;
  - ✓ To make an overview of the different bearer independent concepts;
  - ✓ To elaborate a common view of the bearer independent communication concept.
- The objectives of the **Data collection for conditions** were:
  - ✓ To make an overview of exhaustive conditions to be met to achieve Railway Interoperability;
  - ✓ To make an overview of use cases;
  - ✓ To make an overview of conditions to make BIC concept feasible.

Details of the data sources can be found in Section 12.2 Annex B – Input data sources.

Step 2: Data analysis and definition of conditions: The objective was to identify the conditions and constraints to make BIC feasible. The identification was based on analysis of different areas based on previous data collection:

- ✓ Technical (including security and standardization) for on-board and trackside;
- ✓ Legal and regulatory;

[10] European Commission (2015), SWD (2015) 111.

- ✓ Spectrum.

Step 3: Assessment of conditions: The objective was to assess the impact on cost and delays of the identified conditions.

Chapters 2 to 9 focus on the steps above.

Step 4: Formulation of findings and recommendations: The objective was to summarise the main findings and provide recommendations, and to provide an answer to the question defined in the tender specification. Chapters 3 through 9 each conclude with sections dealing with findings and with recommendations, respectively, while Chapter 10 provides an overall summary of findings and recommendations.

1.6 Sources of information

For this study, SYSTRA used different sources of information. The first sources were previous studies conducted on related subjects and listed in the bibliography chapter at the beginning of this report. They helped to understand the different issues. Another source of information was the available output of international bodies. Additionally, a questionnaire on Bearer Independent Concept, sent in November 2016 and presented in the annexes, provided useful input.

1.6.1 International bodies

We note that the Bearer Independence Concept for rail is being studied by several international bodies, including:

- Standardisation bodies (such as ETSI TC RT and TC CYBER, 3GPP, 5G PPP, ITU-R, UIC FRMCS, CEPT/ECC)
- Sector representatives (Railway Users (CER and EIM)
- Railway Industry Group (ROCIG)
- UNISIG, EU Commission Agencies (ERA, ENISA, ESA)
- Others such as BEREC, PPDR, RSPG on spectrum field or Research and Development Programme such as NGTC, SHIFT2RAIL, University of Birmingham (formal security analysis of ERTMS)

These groups have published a range of documents including position papers, communications, analysis, public deliverables, standards, and more. The BIC concept study relies in part on the results of the work of these bodies. We note, however, that there are limited sources of information about security aspects of operational rail communications.

For further details of the work undertaken by these bodies, please refer to the Annexes (section 12.2 of this report).

1.6.2 Questionnaires and interviews

A questionnaire entitled "The concept of bearer independence: Questionnaire regarding your vision of the Concept" was produced as part of this study to address different questions on principles and other topics to a selected number of stakeholders involved in relevant activities. The aim was to collect information in order to define the key principles of bearer independence. The questionnaire and the Agency introduction letter are presented in Chapter 12.3 Annex C.

The questionnaire was sent out on the 24th of November 2016 to different representatives that participate in projects or groups where the Bearer Independent Concept is discussed (17 projects or companies, 31 individuals), including:

- UIC FRMCS-AT members
- ESA
- Ansaldo STS
- Siemens
- Frequentis
- Shift2Rail IP2 TD2.1
- Funkwerk
- SBB
- DB Netz

SYSTRA received and analysed 15 answers. A second round was organized and sent on the 20th of December 2016 to ERA Coordination Group representatives:

- CER,
- ETSI
- ERTMG UG
- ROC IG
- ERFA
- EIM
- UNISG
- UTP

A wide variety of responses were received and are detailed enough to provide useful information for this study; several answers gave interesting additional references and highlighted major concerns. It should be noted that in some cases there was no consensus for a particular topic.

2. WHAT IS BEARER INDEPENDENCE?

With GSM-R, railway-specific functionality is directly integrated into the technical specification of the transmission technology. Features such as railway emergency calls and functional numbering are an integral part of the GSM-R specification. Many of these application layer capabilities depend on capabilities of the underlying GSM-R network that would not necessarily be present in a general-purpose commercial wireless network. These network capabilities are specified together with the applications in the same GSM-R specifications.

As technology and requirements evolve, there is a widely recognised need to allow the use of alternative transmission technologies for track-to-train operational communications. There is a necessity to move beyond 2G technology (which at some point will no longer be maintainable), and there is also interest in supporting general purpose satellite or Wi-Fi technology. Operational rail applications will need to be able to run over transmission substrates that do not necessarily provide the same capabilities and features that GSM-R networks provide today.

Separating the *bearer* (the technical transmission technology aspects) from the *application* (railway functionality elements) therefore becomes a necessity. *This separation is the essence of bearer independence.* Multiple studies over the past few years[11] have recognised the need to evolve operational rail communications in order to achieve this separation.

A full definition of a bearer is provided in the Section 12.1 (Annex A).

[11] See for instance Analysys Mason (2014), Final report of the study for the evolution of the railways communications system; and IDATE (2015), Evolution of GSM-R, FINAL Report.

Figure 3 illustrates the concept of separating the bearer from the application.

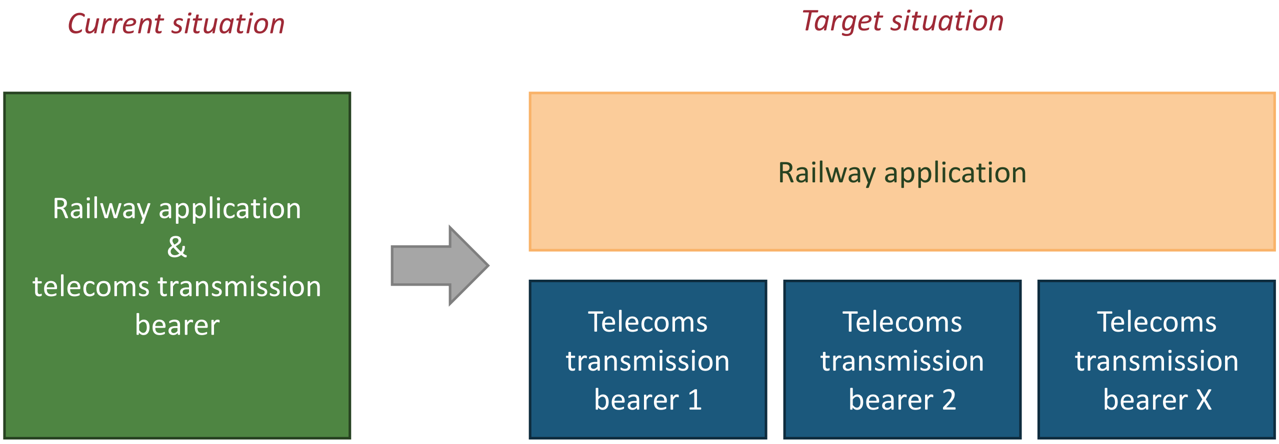


Figure 3. Bearer independence communication concept

Whilst a formal definition will be presented at the end of this Final Report (Chapter 10.2), it is important to define at an early stage what we mean by *bearer independence*.

2.1 Different terminologies

Prior to providing a working definition of the concept of Bearer Independent Communication, it is important to note that similar issues are being discussed by various parties, some of whom have differing terminologies. The following organisations have been identified as working on similar concepts

- European Union Agency for Railways: "Bearer Independent"
- Shift2Rail: "Technology Independent"
- European Space Agency: "Multi-Bearer"
- Next Generation Train Control System (NGTC): "Multi-Vector Architecture"

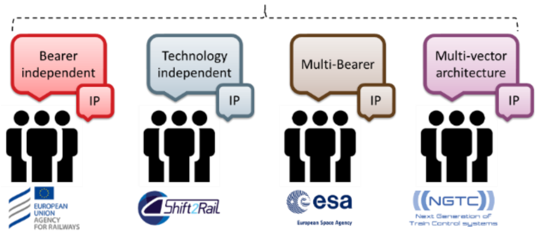


Figure 4. Different terminologies

The main scope of the NGTC project is to analyse the similarities and differences of the required functionality of ETCS and CBTC systems, and to determine the achievable common level of architecture, hardware platforms and system design. NGTC will directly contribute to the Shift²Rail project. It involves manufacturers as well as a number of railway and urban RUs.

Shift²Rail is a large European research and innovation initiative on a variety of subjects covering rolling stock, infrastructure and signalling. The principal objective is to increase attractiveness of rail in Europe. The Innovation Programme (IP2) dedicated to Advanced Traffic Management & Control Systems includes development of prototypes in labs with the "Technology Demonstrators" (TDs) and to deliver on adaptable train-to-ground communications system usable for train control applications. The project includes multi-bearer solutions for the demonstration.

Whilst the scope of the aforementioned initiatives vary considerably, one common element links them all: each of them refer to Internet Protocol (IP) as the technology enabling their chosen concept to become a reality.

As identified as a requirement in many of the previous studies, interworking with GSM-R (which is not IP-based) during migration to a bearer independent architecture, is a must (see Section 1.4). Bearer independence can be introduced among new bearers, but the need for co-existence implies that full and comprehensive bearer independence cannot be achieved until GSM-R has either been extensively altered or (much more likely) decommissioned.

Finding 1. Bearer independence can be introduced among new bearers, but full and comprehensive bearer independence is unlikely to be achieved until GSM-R has been decommissioned.

2.2 Working definition

A working definition of the bearer independence concept is provided below:

- There is a separation between the transport and application layers for both on-board equipment and for network infrastructure.
- The Bearer Independence Concept (BIC) allows for a vehicle to communicate through different bearers or networks (which implies the use of various networks and technologies).
- The BIC allows for seamless communications from a user's point of view, i.e. the user is unaware that the communication bearer has changed (which implies on-board capabilities including automatic switching or hand-over, together with end-user application continuity).
- The "catalogue" of bearers can be changed without impact on the applications and vice versa.

2.3 What is to be achieved with BIC?

The principal aims of introducing the Bearer Independent Communication Concept are to:

- Allow flexibility in the implementation of new and diverse track-to-train radio services.
- Facilitate the migration from one transmission technology to another.
- Facilitate the maintenance of equipment.

- Provide flexibility for the introduction, update, modification of, and maintenance of applications.
- Provide flexibility for the introduction, update, modification and maintenance of the communication bearer.
- Potentially provide better fall back or additional coverage offered by different networks and technologies.
- Provide flexibility in network capacity.

There are, however, a number of challenges that will need to be addressed if BIC is to become a reality. These include:

- New feature introduction and on-board architecture.
- New feature introduction and network architecture.
- How to ensure interoperability.
- How to ensure end-user application continuity (where there is a change of network).
- How to ensure the security of communications.

Compared to the current situation, where there is only one authorised technology, the Bearer independent Communications concept entails a number of strengths, weaknesses, opportunities, and threats (SWOT). A high-level SWOT analysis is presented in Table 3:

STRENGTHS	WEAKNESSES
Improves new radio technology implementation flexibility	Introduces technical complexity (e.g. call and subscription management)
Improves new application implementation flexibility	Introduces complexity in migration (compared to a single new technology)
Decreases spectrum constraints	
Increases number of possible applications for rail	
OPPORTUNITIES	**THREATS**
Provide additional solutions to increase communication availability, coverage and robustness	Interoperability: success dependent on coordination at a European level
Increase flexibility and sustainability for future evolution	ETCS compatibility needs to ensure for all candidate bearers for the concept to work
Allow new entrants (software & hardware suppliers) to the rail market	Success dependent on agreement with others stakeholders (MMO, PPDR, satcom operator…)
Create a new market in safety-critical applications	Other vertical markets and 5G may be less promising than expected (e.g. more time, fewer features, market modifications)
Facilitate the introduction of new services for passengers	

Table 3. **BIC SWOT analysis**

A detailed analysis of the merits of the Bearer Independence concept is outside the scope of this study, which is primarily focussed on identifying key conditions for success of the concept.

2.4 Findings

Based on the considerations discussed in this chapter, we have identified two key findings:

Finding 1. Bearer independence can be introduced among new bearers, but full and comprehensive bearer independence is unlikely to be achieved until GSM-R has been decommissioned.

All stakeholders agree that bearer independence must be achieved on the basis of Internet Protocols (IP). GSM-R, which is not based on IP, will co-exist with new bearers for years to come. It seems highly unlikely that GSM-R in its present form could cost-effectively be modified to make it fully bearer independent. Consequently, we assume that non-bearer-independent GSM-R will need to co-exist with new facilities created using the principle of bearer independence until such time as GSM-R can be fully phased out.

Finding 2. The principal aims of introducing the Bearer Independent Communication Concept are (1) to allow flexibility in the implementation of new and diverse track-to-train radio services; (2) to facilitate the migration from one transmission technology to another; (3) to facilitate the maintenance of equipment; (4) to provide flexibility for the introduction, update, modification of, and maintenance of applications; (5) to provide flexibility for the introduction, update, modification and maintenance of the communications bearer; (6) to potentially provide better fall back or additional coverage offered by different networks and technologies; and (7) to provide flexibility in network capacity.

The need to migrate to a successor to GSM-R is the most immediate driver for a migration to bearer independence, but the flexibility provided by the shift to bearer independence offers many other benefits as well (see Section 2.3).

2.5 Recommendations

The material in this chapter did not, in and of itself, prompt us to make any specific recommendations; however, these findings influence many of the recommendations that we present later in this report.

3. FUNCTIONAL REQUIREMENTS AND USE CASES

Prior to defining the conditions of success for the Bearer Independent Communication (BIC), it is necessary to first identify the various functional requirements. Following this, use cases are presented in this report to help classify the functional requirements. The advantage of use cases is that they help to identify real-life scenarios involving uses of different bearers within a single railway network or between different railway networks.

Only once the functional requirements have been classified can a list of conditions be derived.

Based on our analysis of the use cases, we provide a *categorisation* or *taxonomy* of functional requirements that enables us to group the requirements into interrelated clusters. We follow this structure throughout the balance of the report.

3.1 Functional requirements

The UIC decided to create in 2012 the Future Railway Mobile Communication System (FRMCS) project to prepare the necessary steps towards the introduction of a successor to GSM-R. The first step started is now achieved with the delivery of "User Requirements Specification". This document describes all the applications and functionalities for rail and is a key input for the start of standardisation work.

The URS defines three categories of applications:

1. Critical
2. Performance
3. Business

This document incorporates the GSM-R functional requirements as detailed in the EIRENE FRS.

In addition to these traditional operational functional requirements, stakeholders are also interested in new railway radio needs and applications such as on-board internet connectivity, transmission of CCTV images, and commercial applications. These types of requirements are not considered essential for the Bearer Independent Concept, however it is useful to list them for completeness.

The situation is summarised in Table 4:

Current and future railway radio functions		
Essential functional requirements	Data (ETCS Level 2)	Pre-emption and priority No other specific functions
	Voice	Functional Numbering / Addressing
		Location Dependent Addressing (LDA / eLDA)
		Railway emergency Call (REC)
		Voice Group call Service (VGCS)
		Shunting mode
		Pre-emption and priority
Non-essential functional requirements	On-board Internet connectivity	
	Transmission of CCTV images	
	Business applications	

Table 4. **Railway functions**

Each functional requirement can be classified as either "essential" or "non-essential". This method will help to define the key conditions for the Bearer Independent Concept at the end of this chapter.

The two main applications that we have explicitly considered are ETCS and operational voice communications (a.k.a. train radio). They have been chosen as they are classified under **critical** applications as described in UIC FRMCS URS introducing the concept of categories for voice, data, and video applications.

To have a clear separation of applications and bearers, it is necessary to characterise applications in terms of communication attributes. In the UIC FRMCS URS document, applications are characterised with following communication attributes in Figure 5:

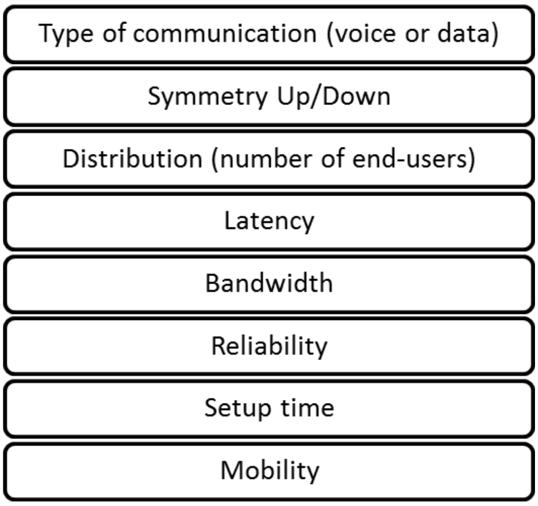


Figure 5. FRMCS URS Communication attributes for application

3.2 Examples of operational use cases

The simplest way in which to understand the functional requirements implied by Bearer Independence is by means of assessing specific use cases. Doing so enables us to understand how bearer independent communications could potentially be implemented for railways in national and international contexts (including interoperability and border crossing).

This chapter discusses *operational use cases*. Here, we are addressing the simpler and more usual use cases. These use cases enable us to classify the functional requirements. Five uses cases are presented, all in a consistent manner:

- What the use case involves: countries (MS), networks (IM), operators (RU), and operational areas.
- Description of the use case.
- Diagram illustrating the use case.
- Identification of the Essential and Non-Essential functional requirements.

In order to implement a use case, all Essential functional requirements must be satisfied. On the other hand, Non-Essential functional requirements are not deemed to be critical to the implementation of the use case (these could be classified as being "nice to have").

The use cases below are developed in detail in Sections 3.2.1 through 3.2.5:

1. Migration
2. Border crossing
3. Operational areas
4. Multi-bearers
5. Shunting yard, depots or railway stations

Note: Radio technologies are referred to in use cases as examples to help understand the situation. Their reference should not be interpreted as an endorsement of a particular bearer technology in this study.

3.2.1 Use case 1: Migration

The first use case consists of migrating from legacy GSM-R bearer to a new appropriate bearer for critical and performance applications on a national basis.

This use case involves:

- ✓ Same country (same Member State)
- ✓ Same railway network (same Infrastructure Manager)
- ✓ Different or same Train Operators (same or different Railway Undertakings)
- ✓ Same operational area (it could be a dispatcher area or an RBC area depending on application operational requirements)

Based on lessons learnt from analogue to GSM-R migration, different options of implementing bearers in a migration scenario are possible depending on which sub-system, on-board or infrastructure, will be the "heart" of the concept:

- ✓ **Multi-bearer on-board**: At least one appropriate bearer is available on trackside at all times. GSM-R is removed gradually on trackside (operational areas are migrated by blocks to the new system). The new on-board cab radios can switch between GSM-R (with legacy applications and protocols) and new bearers depending on whether the line is covered by legacy GSM-R trackside infrastructure or a new bearer.
- ✓ **Multi-bearer infrastructure**: At least two appropriate bearers (including legacy GSM-R) are available on trackside for a single application. Trains are either equipped with legacy GSM-R cab radios or cab radios capable of operating on more than one bearer. Eventually all trains will be equipped with the new cab radios at which point the legacy GSM-R trackside infrastructure can be switched-off.

<u>Description of the use case:</u>

- ✓ A train driver (train operator with legacy GSM-R system on-board) launches a voice group call (train radio) to connect to the dispatcher area. The voice call connects to the train driver, dispatcher, and all train drivers located in dispatcher area (which could be other train operators with either legacy GSM-R system on-board either a new bearer such as

LTE-Advanced) regardless of the options of implementing bearers (multi-bearer on-board or multi-bearer infrastructure). The performance target must be met for all attendees of the call.

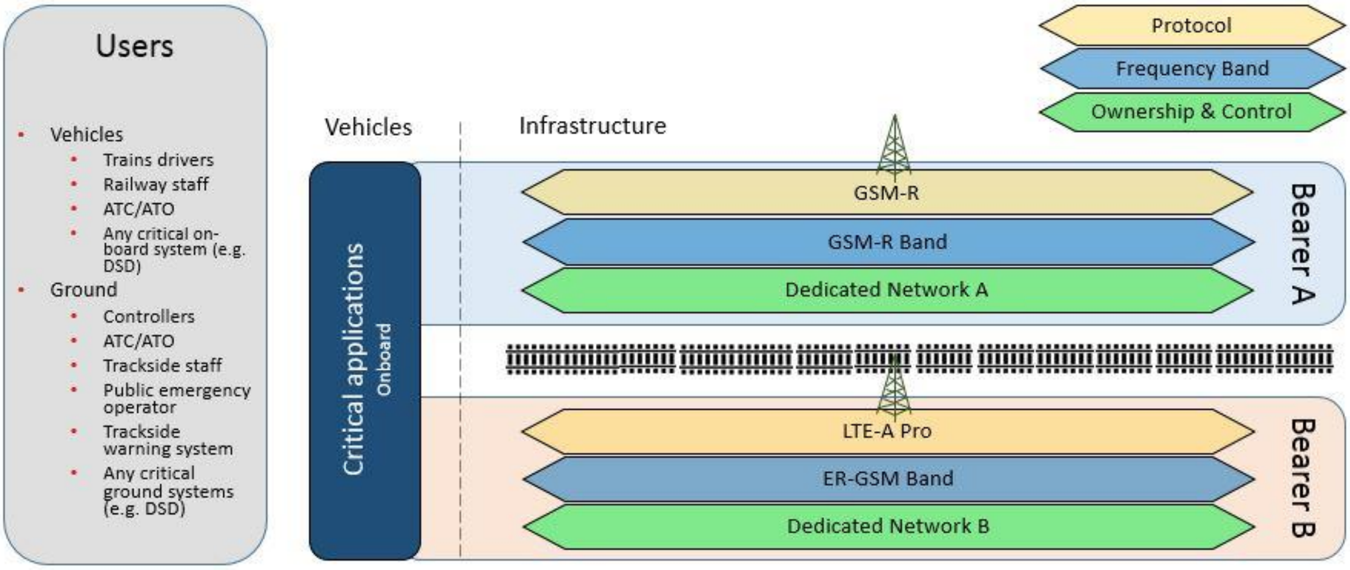


Figure 6. Example of Migration use case with multi-bearer infrastructure

IDENTIFICATION OF ESSENTIAL REQUIREMENTS

Category	Sub-category	Comments
INDEPENDENCE OF APPLICATION LAYER AND TRANSPORT	System architecture	
MANAGEMENT OF MOBILITY	Seamless mobility	*Only for multi-bearer on-board*
	Subscription management	*Common subscription management between bearers*
	End-to-end security	*From application over bearer A to application over bearer B (and vice-versa)*
ECOSYSTEM DEVELOPMENT	Application ecosystem	*Possibility to have same or different software applications to deliver same service*
DEPLOYMENT PLAN	Coordination	
OPERATIONAL MANAGEMENT	Network and on-board management	

Table 5. Essential Requirements for Migration use case

3.2.2 Use case 2: Operational areas and sub-networks

This use case consists of moving from one operational area to another one covered with different bearers. This use case involves:

- ✓ Same country (same Member State)
- ✓ Same railway network (same Infrastructure Manager)
- ✓ Different or same Train Operators (same or different Railway Undertakings)
- ✓ Different operational areas (e.g. RBC, dispatchers)

<u>Description of the following use case:</u>

- ✓ A train connected to RBC area A (bearer is satellite communication, owned and managed by Telecom Network Operator A) is moving to RBC area B (bearer is LTE-Advanced Pro, owned and managed by Telecom Network Operator B) within the same country. At least one appropriate bearer is available on area B for a single application. The data connection between train and RBC A and B is automatic and guaranteed without service interruption when moving from different bearers. The performance target must be met for all participants of the call.

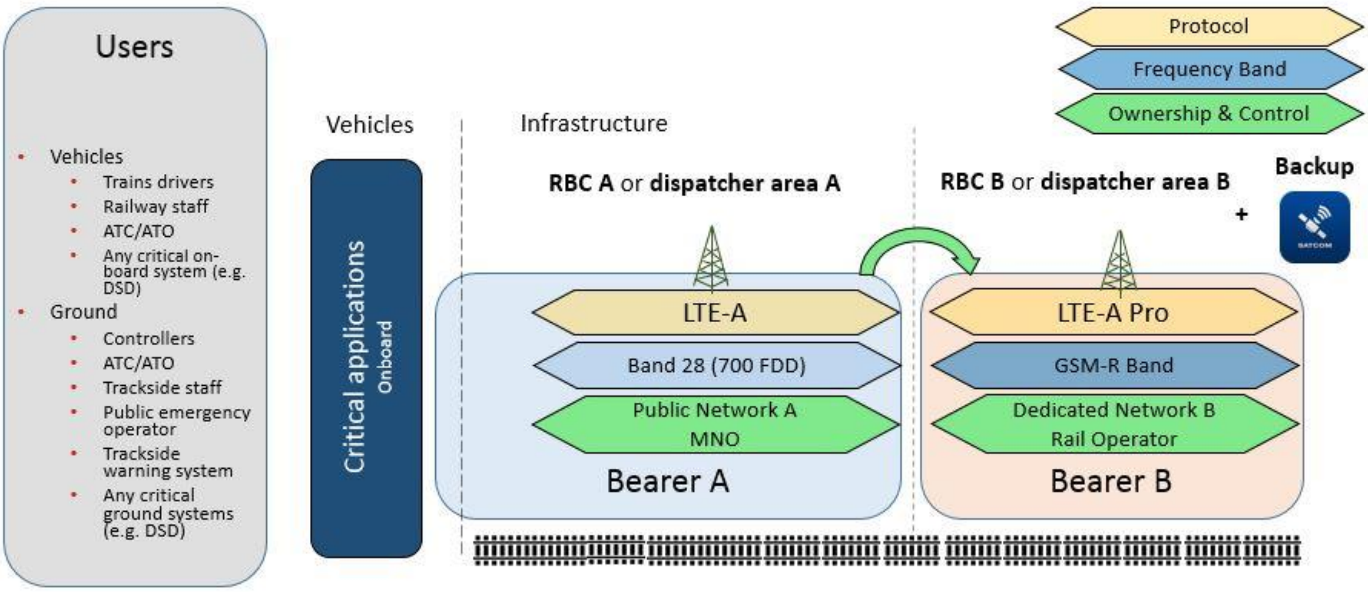


Figure 7. Example of Operational use case

IDENTIFICATION OF ESSENTIAL REQUIREMENTS

Category	Sub-category	Comments
INDEPENDENCE OF APPLICATION LAYER AND TRANSPORT	System architecture	
GUARANTEED CONNECTIVITY	On-board multi-bearer support	*For a defined and known list (on-board or remote)*
	Traffic and QoS	
	Coverage	
MANAGEMENT OF MOBILITY	Seamless mobility	
	Subscription management	*Common subscription management between bearers*
	End-to-end security	*From application over bearer A to application over bearer B (and vice-versa)*
ECOSYSTEM DEVELOPMENT	Application ecosystem	*Possibility to have same or different software applications to deliver same service*
	Services	
	Transport	
DEPLOYMENT PLAN	Legal aspect	
OPERATIONAL MANAGEMENT	Network and on-board management	

Table 6. **Essential Requirements for Operational areas and sub-networks use case**

3.2.3 Use case 3: Border Crossing

The next use case consists of crossing the border from Country A to Country B (and vice-versa). This use case involves:

- ✓ Different countries (different Member States)
- ✓ Different railway networks (different Infrastructure Managers)
- ✓ Different or same Train Operators (the same or different Railway Undertakings)
- ✓ Different or same operational area(s) (e.g. emergency calls in areas covered by countries A and B)

Different options of implementing bearers in countries A and B are possible among:

- ✓ From GSM-R (country A) to at least one appropriate bearer available on trackside for a single application (country B)
- ✓ Same bearer in countries A and B (roaming use case).
- ✓ From one bearer (country A) to another bearer (country B) - at least one appropriate bearer available on trackside for a single application.

<u>Description of the following use cases:</u>

- ✓ A train driver (train operator A) moving from country A to country B launches a voice call (train radio) to connect to dispatcher area (country A). This dispatcher area A is also linked to dispatcher area B (country B) to manage emergency situations at borders. The voice call must connect to train driver A, dispatcher A, dispatcher B and train drivers of dispatcher area B (could be train operator B) regardless of the options of implementing bearers in countries A and B. The performance target must be met for all participants of the call.
- ✓ A train connected to ETCS Radio Block Centre (RBC) RBC area A (country A) is moving to RBC area B (country B). At least one appropriate bearer must be available on area B (country B) for a single application. The data connection between train and RBC A and B is automatic and guaranteed without service interruption when moving from different bearers. The performance target must be met for all participants of the data call.

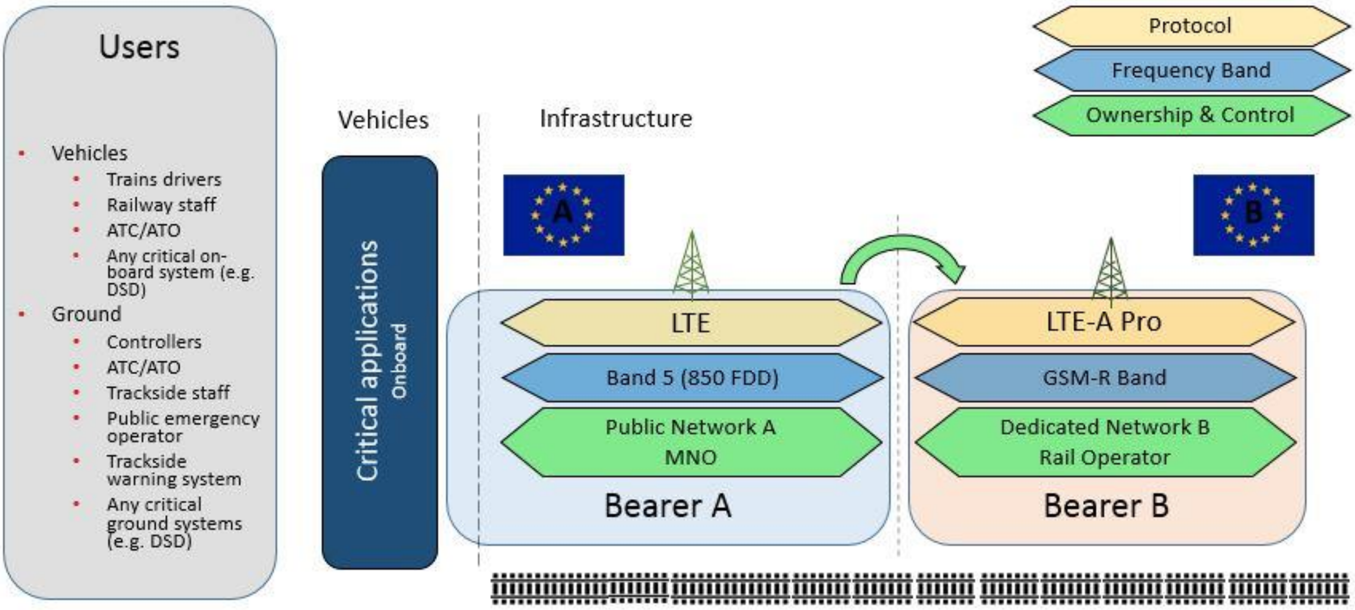


Figure 8. Example of Border-crossing use case

IDENTIFICATION OF ESSENTIAL REQUIREMENTS

Category	Sub-category	Comments
INDEPENDENCE OF APPLICATION LAYER AND TRANSPORT	System architecture	
GUARANTEED CONNECTIVITY	On-board multi-bearer support	*For a defined and known list (on-board or remote)*
	Traffic and QoS	
	Coverage	
MANAGEMENT OF MOBILITY	Seamless mobility	
	Subscription management	*Common subscription management between bearers*
	End-to-end security	*From application over bearer A to application over bearer B (and vice-versa)*
ECOSYSTEM DEVELOPMENT	Application ecosystem	*Possibility to have same or different software applications to deliver same service*
DEPLOYMENT PLAN	European coordination	
OPERATIONAL MANAGEMENT	Network and on-board management	

Table 7. **Essential Requirements for Border Crossing use case**

3.2.4 Use case 4: Multi-bearers

This use case consists of moving from one bearer to another bearer within the same operational area. This use case involves:

- ✓ Same country (same Member State)
- ✓ Same railway network (same Infrastructure Manager)
- ✓ Different or same Train Operators (same or different Railway Undertakings)
- ✓ Same operational area (e.g. RBC, dispatchers)

Description of the following use case:

✓ A train driver (train operator A) moving from bearer A (bearer is satellite communication, owned and managed by Telecom Network Operator A) to bearer B (bearer is LTE-Advanced Pro, owned and managed by Telecom Network Operator B) launches a voice call (train radio) to connect to dispatcher area (covered by two different bearers). The voice call connects to train driver A, dispatcher, and train drivers under coverage of bearer B (could be train operator B). The performance target must be met for all participants of the call.

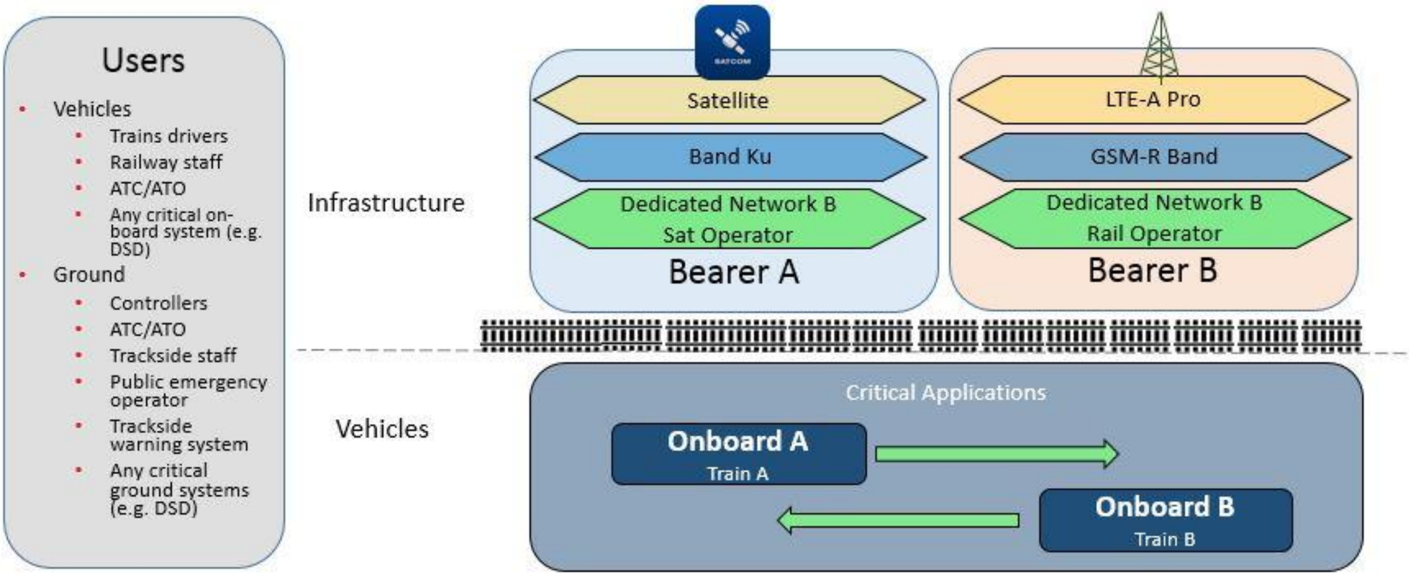


Figure 9. Example of Multi-bearer use case

IDENTIFICATION OF ESSENTIAL REQUIREMENTS

Category	Sub-category	Comments
INDEPENDENCE OF APPLICATION LAYER AND TRANSPORT	System architecture	
GUARANTEED CONNECTIVITY	On-board multi-bearer support	*For a defined and known list (on-board or remote)*
	Traffic and QoS	
	Coverage	
MANAGEMENT OF MOBILITY	Call management	
	Subscription management	*Common subscription management between bearers*

	End-to-end security	*From application over bearer A to application over bearer B (and vice-versa)*
ECOSYSTEM DEVELOPMENT	Application ecosystem	*Possibility to have same or different software applications to deliver same service*
DEPLOYMENT PLAN	Coordination	
OPERATIONAL MANAGEMENT	Network and on-board management	

Table 8. **Essential Requirements for Multi Bearer use case**

3.2.5 Use case 5: Shunting yard, depots and railway stations

Another possible use case consists of using a different bearer in Shunting yard than the ones used in operational areas to use specific services such as direct peer-to-peer communications without any infrastructure.

A further use case could be in railway stations where non-mission critical data applications need more capacity as an offloading solution. This use case involves:

- ✓ Same country (same Member State)
- ✓ Same railway network (same Infrastructure Manager)
- ✓ Same or different Train Operators (same or different Railway Undertakings) choosing different appropriate bearers
- ✓ Same operational area

<u>Description of the following shunting use case:</u>

- ✓ A train driver (train operator B) moving from bearer B (bearer is LTE owned and managed by Telecom Network Operator B) to bearer A (bearer is Wi-Fi, owned and managed by a Company A, unlicensed spectrum usage) initiates a voice shunting group call (train radio) to connect to shunting members and Controllers. The voice shunting group call connects to train driver A, all shunting members and in some case the Controller A. The performance target must be met for all participants of the call in particular to know who is connected because it relates to each shunting member's safety. Seamless mobility between the two areas may be not required. A critical on-board system is required (e.g. DSD).

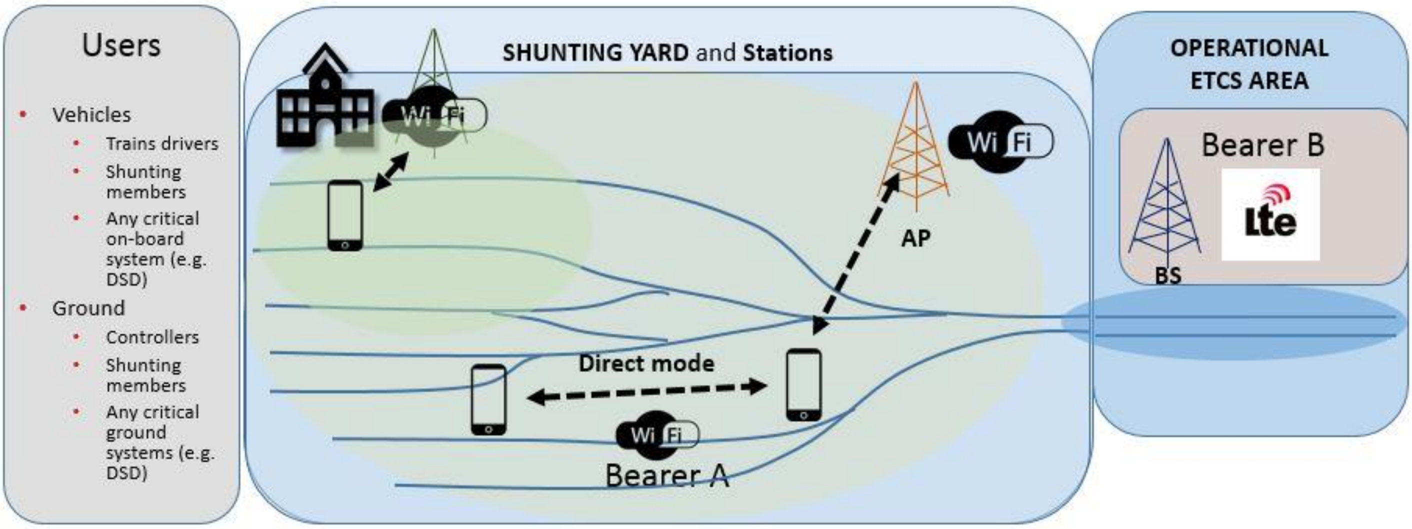


Figure 10. Example of Shunting Yard and Stations use case

IDENTIFICATION OF REQUIREMENTS

Category	Sub-category	Comments
INDEPENDENCE OF APPLICATION LAYER AND TRANSPORT	System architecture	
GUARANTEED CONNECTIVITY	On-board multi-bearer support	*For a defined and known list (on-board or remote)*
	Coverage	
MANAGEMENT OF MOBILITY	Subscription management	*Common subscription management between bearers*
	End-to-end security	*From application over bearer A to application over bearer B (and vice-versa)*
	Seamless mobility	
ECOSYSTEM DEVELOPMENT	Application ecosystem	*Possibility to have same or different software applications to deliver same service*
DEPLOYMENT PLAN		*No specific requirement here*
OPERATIONAL MANAGEMENT	Network and on-board management	

Table 9. Requirements for Shunting Yard and Stations use case

3.3 Identification and definition of conditions for success

All of the functional requirements identified in the previous five use cases can be grouped together into six categories as seen in the previous tables. These categories form the basis of the key conditions that will be developed in the following six chapters. A brief definition of each is provided in Table 10.

Category of Functional Requirements	Definition
INDEPENDENCE OF APPLICATION LAYER AND TRANSPORT	Any application must be able to communicate over one or more bearers without depending on any bearer-specific features, regardless of the application's characteristics or communication requirements (subject to quality of services requirements being fulfilled in terms of performance and security).
GUARANTEED CONNECTIVITY	Any application must be able to communicate at all times and at any supported location with a defined minimum quality of service that is appropriate to the requested operational rail service in terms of performance and security. This requires coverage, availability and sufficient capacity by at least one bearer at all supported locations.
MANAGEMENT OF MOBILITY	Service continuity needs to be maintained at all times and at any supported location for any authorised users or devices while ensuring end-to-end integrity of communications. This requires user authentication, authorisation, data integrity and confidentiality across hand-offs as a train moves from one bearer to another bearer.
ECOSYSTEM DEVELOPMENT	Full bearer independent communication systems will depend on new hardware and software components. This requires proper evolution of the market ecosystem. Given the relatively small size of the operational rail communications market, this may require policymakers to take special care.
DEPLOYMENT PLAN	Migration to fully bearer independent communication systems with full interoperability requires development and implementation of European and national deployment plans.
OPERATIONAL MANAGEMENT	Consistent and sustainable bearer independence requires integrated and comprehensive operational and maintenance management of all communication facilities (including both infrastructure and on-board equipment).

Table 10. **Categories of Functional Requirements**

The categories of conditions for success identified in Table 10 represent the organising principle for all of the analysis in the remainder of the report

Finding 3. In order to analyse conditions for success of the Bearer Independence Concept, it is helpful to categorise the conditions as relating mainly to (1) independence of the application layer and the transport; (2) guaranteed connectivity; (3) management of mobility; (4) ecosystem development; (5) the deployment plan; and (6) operational management.

Based on the identified use cases and our preliminary analysis of the functional requirements, a more detailed taxonomy or categorisation of key conditions for bearer independence can be derived and is presented in Table 11.

Table 11. **Detailed taxonomy/categorisation of key conditions for success of the Bearer Independence Concept**

1	**INDEPENDENCE OF APPLICATION LAYER AND TRANSPORT**	System architecture
		Standards and specifications
2	**GUARANTEED CONNECTIVITY**	Radio Coverage; Traffic and QoS; Spectrum
		Security-Availability *(incl. priority and preemption)*; Legal obligations
3	**MANAGEMENT OF MOBILITY**	Subscriber authorisation; Subscriber location
		Addressing
		Seamless mobility *(incl. interworking with GSM-R, vertical handover and roaming)*
		End-to-end security *(incl. authentication, integrity and*
4	**ECOSYSTEM DEVELOPMENT**	Stakeholders: Traditional rail sector; New entrants
		Products & Components: Hardware RF & Interfaces; Software Application
		Lifecycle & product availability
5	**DEPLOYMENT PLAN**	European coordination; Legal Aspects
		Vehicle RU; Infrastructure IM
6	**OPERATIONAL MANAGEMENT**	Network Management; On-board communication devices maintainability

3.4 Findings

Based on our analysis of the use cases, we developed a taxonomy of functional requirements that drives our analysis throughout.

Finding 3. In order to analyse conditions for success of the Bearer Independence Concept, it is helpful to categorise the conditions as relating mainly to (1) independence of the application layer and the transport; (2) guaranteed connectivity; (3) management of mobility; (4) ecosystem development; (5) the deployment plan; and (6) operational management.

3.5 Recommendations

The material in this chapter did not, in and of itself, prompt us to make any specific recommendations; however, the categorisation developed in this chapter permeates our analysis throughout the report and can be useful for further case studies.

4. INDEPENDENCE OF APPLICATION LAYER AND TRANSPORT

For the Bearer Independence Communication Concept to work every application must be allowed to communicate over one or multiple bearers without calling upon any specific bearer feature, regardless of the applications' characteristics and communication attributes. This chapter focusses on this condition for success of the concept and is structured in the following manner:

- Conditions and areas of study
- Setting the scene
- Key challenges (and opportunities, if any)
- Findings
- Recommendations

Table 12 presents the scope of the condition:

1	INDEPENDENCE OF APPLICATION LAYER & TRANSPORT	System architecture
		Standards and specifications

Table 12. Scope of Independence of Applications Layer & Transport

4.1 Conditions and areas of study

This chapter will assess the Independence between the Application Layer and the transport to understand why it is a condition for success of the bearer independent communication concept. Areas of study which are impacted by the Independence are outlined in the Table 13 (marked with an "X"):

	Vehicles	Spectrum	Infrastructure	Legal framework	Security aspects
Independence of Application & Transport	X	X	X	X	X

Table 13. Areas of study of the Independence of Applications Layer & Transport condition

4.2 Setting the scene

A major condition of success of the Bearer Independence Concept is to have a full independence between the transport and the application layers in the design, in the standards, in the specifications and in the final products.

Before analysing what may be needed to allow bearer independency referring to the future communication architectures that can influence and facilitate the BIC introduction, key principles of the bearer independence communication concept are outlined in the following section.

4.2.1 Principles of bearer independence communication concept

4.2.1.1 A bearer independent communication

Literally speaking, a **bearer independent communication** means that an end user or device (for example, a high-level application such as ETCS) using a communication service to exchange information (voice, data, or video) with a third party must not be aware of which underlying bearer(s) is used to provide that communication service.

To progress further in the definition of the concept of bearer independence communication, we now focus on the different objectives related to the evolution of radio communication system coming from different sources, which are outlined below:

- ✓ "Flexible implementation, migration and maintenance, with the possibility of having independent system and product roadmaps for the communication part and the application part for both Infrastructure and On-board". Source: ERA.
- ✓ "ETCS as an application […] be unaffected by developments in communication technology. […] the specification of the ETCS application should be separated from the transmission layer (bearer specifications)". Source: EC SWD(2014) 48.
- ✓ "Cheaper and plug-and-play ETCS products […] relying on IP […] GSM-R is simply not available as the data carrier for most ETCS projects outside the EU". Source: EC SWD(2014) 48.
- ✓ "[…] telecommunication systems usually have a much shorter life cycle than signalling systems. For this reason, it should be possible to replace the 'telecommunications part" of on-board equipment without this having an impact on the "safety critical signalling part". For this reason, the ETCS specifications will be made totally independent of the transmission media, including aspects such as performance requirements and testing". Source: MOU EC/ERA/Sectors – 2012.
- ✓ "In order to facilitate future upgrades of the on-board radio component, an internal interface, between the so-called Euroradio Safety Layer and the Euroradio Communication Layer, will be defined. This interface should take an "FFFIS form" to ensure that adaptations of the EDOR can be carried out independently of the ETCS supplier". Source: MOU EC/ERA/Sectors – 2012.
- ✓ "Consider forward and backward compatibility and Co-existence to ensure viable migration." Source: MOU EC/ERA/Sectors – 2012.
- ✓ "Consider Spectrum and Interferences, Security, and legal aspects." Source: ERA – Tender specifications.
- ✓ "Ensure Railway Interoperability." Source: EC/ERA – Tender specifications.

The first point of agreement is that development of application and bearer specifications for both infrastructure and on-board should be made without any cross-references.

The product roadmaps and life cycles of the different communication technologies must also be considered when introducing support of multiple bearers. The coexistence of many generations of multiple technology standards must be considered when defining the system architecture.

The second point of agreement is that applications needs to be based on IP. This implies that bearers should be packet-based technology supporting transmission of IP datagrams. But this finding is detailed in the following sections.

4.2.1.2 Interoperability

The European Commission has already expressed its views whilst dealing with independence:

- ✓ "ETCS as an application […] be unaffected by developments in communication technology. […] the specification of the ETCS application should be separated from the transmission layer (bearer specifications)". *Source: EC SWD(2014) 48.*
- ✓ "The basic goal is that the on-board ETCS, EVC, is installed once (with an IP interface) and not affected by any change in the communication technology." *Source: EC SWD(2014) 48.*
- ✓ "Therefore, the specifications of the ETCS application should be separated from the transmission layer (bearer specifications)." *Source: EC SWD(2014) 48.*

The independence requirement could be translated to all railway applications (critical, performance and business categories) and implies that:

- ✓ ETCS, train voice radio, shunting (etc.) specifications must not reference any bearer.
- ✓ Products roadmaps must be independent between applications and bearers.

However, bearer independence communication should continue to ensure interoperability throughout Europe. Interoperability concerns both applications and the legal framework. This subject will be addressed in the relevant chapters of this report.

4.2.1.3 Support of multiple bearers

The second principle consists of supporting a list of potential candidate bearers and establishing conditions and restrictions to that list. Many open questions need to be answered by the rail sector together with industry:

- ✓ Which bearers are candidates for the evolution of radio technology?
- ✓ Which characteristics must we consider to make a bearer as a candidate for the evolution of radio technology?

- ✓ Is a bearer candidate for a dedicated application or a category of applications?
- ✓ Do the TSI need to reference any bearer?
- ✓ Which system authority is responsible for considering a bearer as candidate if applications are fully independent of underlying bearers?

Some answers are already provided by the European Commission in the Commission staff working document on the state of play of the implementation of the ERTMS deployment plan (*reference SWD(2014)48 final – 14.2.2014*) giving some directions for this study:

- ✓ "The system should be flexible enough to allow the use of multiple technologies. One could consider several (IP-based) bearers: GSM-R (GPRS/EDGE), Wi-Fi, LTE, satellite, etc., but also simple digital (and cheap) technology. This could also foster the expansion of ETCS to other regions of the world".
- ✓ "The following characteristics are important to be able to decide on the suitability of a candidate solution: QoS, capacity, availability (especially in dense areas), standardised solution (no "-R"), harmonious coexistence with public communication networks (resilience to interferences), affordability".
- ✓ "Network ownership (and control) will have to be considered. There are various models possible, such as having a national dedicated network, a European dedicated network, or a public network. What is important is that the network (bearer) will have to fulfil the ETCS requirements, regardless of who owns (and control) it".

Based on the questionnaire and the European Commission requirements, the following principles could be considered:

- ✓ Multiple bearers must be suitable for a given application.
- ✓ The need for support of multiple, but limited number of, technologies. Scalability must be considered.
- ✓ Flexibility needs to be provided when a new bearer is introduced. A new bearer must not invoke changes in the application framework. The product roadmaps and life cycles of the different communication technologies need also be considered when introducing support of multiple bearers. The coexistence of many generations of multiple technology standards must be considered when defining the system architecture.
- ✓ At least one appropriate bearer needs to be available wherever and whenever an application need communication services.
- ✓ Specific rail services (functional numbering, location based services…) must be provided.

If we consider the European Commission requirements, many bearers need to be considered as possible candidates based on evaluation of functionality, level of service, technical feasibility, and economic aspects.

A picture of possible candidates from terrestrial (3GPP, IEEE, ETSI and other local standardization bodies – ARIB/TTC, TTA, CCSA, ATIS, TSDSI) to satellite technology standards could be the following (only packet-based technology standards are considered) as presented Figure 11.

Figure 11. Possible bearer candidates

Bearers need to meet the minimum requirements in order to be considered as part of the BIC. Whilst outside the scope of the study, for completeness it is useful to briefly mention examples of technical and economical requirements used to consider a bearer as possible candidates. Some examples of requirements to be considered could be the following:

- ✓ Mobility and Doppler resistance for high-speed trains (up to 500 km/h)
- ✓ Geographic coverage (including free space tracks, stations/depots/shunting yards, undergrounds, tunnels, hilly terrains, and forests)
- ✓ Throughput
- ✓ Robustness to interferences and noise
- ✓ CAPEX/OPEX
- ✓ Time-to-market…

Requirements need to be defined for a single application for each category (critical, performance and business applications). Additional criteria inherent to the bearer (network models and spectrum access schemes) must also be considered, including:

- ✓ Resiliency and availability, related to architecture engineering (redundancy of key entities)
- ✓ Security (physical and cyber-security)
- ✓ Packet delay, packet error rate…

After defining requirements, a mapping process needs to be considered to make a bearer suitable to delivering requested communication services to an application.

The on-going 3GPP work item called "Study on Future Railway Mobile Communication System" (acronym: FS_FRMCS) intends, amongst other things, to analyse the gap between railway applications characteristics (communication services and railway specific services, performance, and other criteria) and existing 3GPP functions and specifications (draft document 3GPP TR 22.989 available on 3GPP website). As an example, UIC/3GPP S1-170034 document identifies application performance criteria based on UIC FRMCS URS to determine if 3GPP technologies can guarantee these levels of services by providing appropriate Quality of Service.

A study led by the Agency on the feasibility of satellite communications (SatCom) for railway applications has been published on the ERA website beginning of 2017. The purpose of this study is to provide a conclusion on the suitability of using SatCom as a candidate bearer as wells as defining the conditions. The main conclusion of the study is that none of the SatCom solutions available and analysed is fully compliant with the whole set of criteria identified (i.e. SatCom to support the whole set of railway applications simultaneously). This study was not conducted in the context of a bearer independent communication concept. Within the BIC concept, applications could be supported by different bearers with different communication profiles based on different application characteristics. Within that concept, SatCom could be considered for some of the railway applications if conditions for success such as regulatory framework, railway certifications, the use of communication standards, geographical constraints and some other technical implications, have been dealt with suitable solutions.

These initiatives need to be considered to assess every candidate bearer as transport system for all or a subset of railway applications.

Stakeholders expressed different views on the support of multiple bearers. Two different views are emerging, which could be characterised as the *conservative view* (see Section 4.2.1.3.1) and the *flexible view* (see Section 4.2.1.3.2).

4.2.1.3.1 **Conservative view**

The conservative view limits the number of supported bearers to avoid intensive use, verification and integration work to be done by vendors and operators. Some stakeholders even recommended to reference one single dedicated bearer as Mandatory for Interoperability and Mandatory applications (mission-critical applications) and apply the concept only to non-mission critical applications.

The first vision comes from the mobile network ecosystem (telco carrier industry) which is based on the 3GPP framework. The 3GPP framework provides a *partial independence* of bearer to upper layers by enabling basic and advanced IP communication services with appropriate quality of service over a dedicated bearer. The voice and conversational services based on IMS core network and SIP control plane are called Voice over LTE (**VoLTE**), Voice over Wi-Fi (VoWiFi), Video over LTE (ViLTE) to enable mobile multimedia calls using appropriate QoS with QoS Class Identifier (QCI). They are not fully carrier independent. Interworking with a limited number of bearers are already provided in the 3GPP framework such as Wi-Fi.

Since March 2016, Mission-critical push-to-talk (MCPTT) functionality is part of the 3GPP LTE Release 13 standard. MCPTT-capable devices should be available when Release 13 is scheduled to be implemented as early as 2018. This feature is provided by the infrastructure through an Application Server. MCPTT is an optional functionality in 3GPP Release 13 meaning that only interested manufacturers will develop and propose in their roadmaps. Only interested MNO will buy them to offer services to their professional subscribers if and only if the business model is sustainable enough, adding values as a new business opportunity. Professional customers such as PPDR users could foster MCPTT.

Functionalities requested by the rail sector on mission critical communications especially for voice with location-based services may be implemented in the same way in 3GPP and then to be integrated through specific rail application servers connected to mobile core network. Through this type of architecture, it can be possible to create Mobile Virtual Network Operator able to manage their subscribers and offer services through different 3GPP networks such as it is done for mobile operators today.

Finding 4. Operational rail communications could potentially take advantage of the Mission-Critical Push-to-Talk (MCPTT) functionality that is an optional function in 3GPP Release 13 standards. It is unlikely, however, that Mobile Network Operators (MNOs) will deploy MCPTT unless they perceive sufficient demand for it from PPDR and/or operational rail. If MNOs do not demand these features, manufacturers will not implement them.

4.2.1.3.2 Flexible view

The flexible view opens the concept to multiple bearers to foster the expansion of ETCS, even exporting the concept to other railway markets outside the European Union. We could hold Professional Digital Trunking – PDT – as an example of China's private network communication standard. This standard provides an all-IP network, independent control and carrier, large coverage area, with lots of similarities with European railway operational needs. Flexibility could also mean exporting the concept to other verticals like ITS (including appropriate digital communication standards).

The second vision on communication architecture provides *full independence* between applications and bearers. It comes from the internet and web domain and is based primarily on IETF and IEEE standards. The architecture is based on open internet communication protocols to replace legacy operator controlled services offered by MNO. The voice and conversational services are called Voice over IP (VoIP) providing voice, video, voice and video group calls. VoIP is fully carrier independent by providing basic and advanced communication services over any IP network (i.e. any IP-based bearer). Third-party service providers (also called Over-the-Top – OTT – communication service providers) are well-known content and application providers in the mobile industry, which disrupt the traditional business model of telecoms operators. Amongst them, we can list OTT apps like Facebook, WhatsApp (OTT instant messaging), Viber or Skype (OTT voice calling). Up to now OTT solutions are not interoperable. For instance, Skype user A and Viber user B cannot communicate together. They need the same App to access to communication services over Internet. Additionally, they do not include performance target such as Grade of Service, they usually provide best effort services. Such ecosystem represents a limitation for any future usage in professional area especially such as railway in Europe. New standards and protocols need likely to be defined while fostering a new ecosystem. Performance and security are also important in that context.

Finding 5. Stakeholders tend to gravitate to one of two architectural models of multi-bearer support. The *conservative view* is based on 3GPP standards, and on services similar to those offered by Mobile Network Operators (MNOs). The *flexible view* is based on Over-the-Top (OTT) services using IETF and IEEE standards, and thereby potentially expands the set of bearers to include bearers such as Wi-Fi and satellite.

Finding 6. Full realisation of the flexible view would likely require the definition of new standards and protocols, with careful attention paid to performance and security. The bearers and applications are no longer bound to one another, but they effectively become an ecosystem where functionality and interoperability must be carefully planned for.

4.2.1.3.3 Implications of the conservative view and the flexible view for interoperability

These two views have different conditions and impacts. One of the main conditions is the availability of products to support bearer independence concept (time to market, product integration, cost etc.).

Both flexible and conservative views will have major or minor impacts depending on European Interoperability directives: the implications of defining a list of approved bearers or not in the Technical Specifications for Interoperability (TSI) need to be assessed.

The impact on legal framework (Interoperability Directive, Technical Specification for Interoperability, interoperability Control-Command & Signalling sub-systems, Interoperability Constituents) will be further analysed in this study.

If no cross-reference to any bearer is made in the specifications of ETCS, a list of defined and appropriate bearers are likely be essential to support ETCS on the TEN-T network and critical voice service for border crossing to allow interoperability for on-board equipment. Otherwise, on-board complexity should be assessed as a high risk to achieve interoperability.

Finding 7. Whether the conservative or the flexible view is ultimately followed, revisions to the various European instruments that ensure interoperability of rail communications (notably including the Technical Specifications for Interoperability (TSI)) are likely to be required.

4.2.2 System architecture

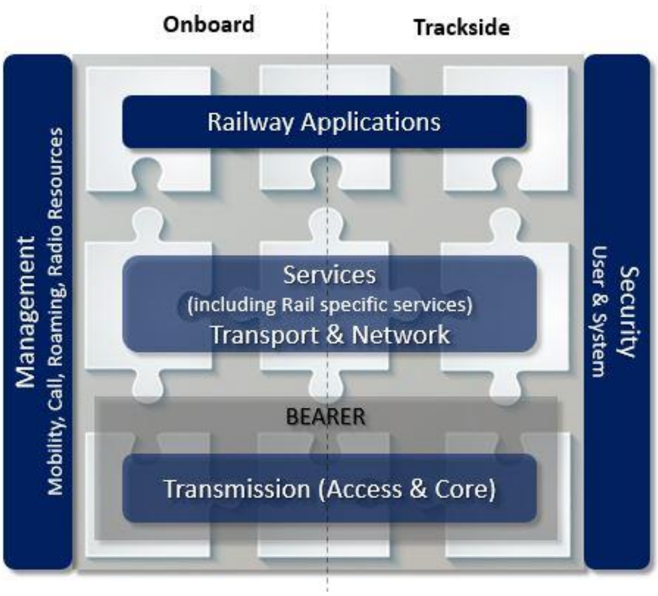
4.2.2.1 Definition

IEC 42010:2011 systems and software engineering standard defines **architecture** as "the fundamental organization of a system embodied in its components, their relationships to each other and to the environment, and the principles guiding its design and evolution".

The communication system architecture of a railway mobile system focuses on communication services provided to train and to ground components in order for them to communicate with each other, provides interfaces with applications and services (such as location-based services), imposes conditions on design and evolution of the system (i.e. scalability).

4.2.2.2 High-level functional architecture

To help us understand the complexity of the communication model, we propose to define the following high-level functional architecture both for on-board and trackside entities (based on ITS communications architecture for vehicles and infrastructure which is quite similar to the rail sector needs – *source: ETSI standards*):



Source: ETSI

Figure 12. High-level functional architecture

Railway applications (e.g. ETCS and train radio) need **communication services** to exchange data between system entities (e.g. RBC to send Movement Authority to on-board/EDOR as data messages). Railway applications also need **advanced railway communication services** like group calls, functional roles, location based services, specific address schemes, etc. Together with the communication service itself, applications need **quality of service** (e.g. bandwidth, reliability, availability, priority, etc.) and **security** requirements (e.g. authentication, ciphering, integrity of Movement Authority to be guaranteed, etc.). In the bearer independency communication concept, railway applications are not aware of underlying bearers. But they need a communication service layer in charge of delivering voice, data, and video services together with advanced railway communication services like Push-to-Talk services (referring to ETSI Advanced Speech Call Items) or location-based services (referring to EIRENE features).

In the current railway standards, these services are part of the GSM-R standard and could not be seen as independent of application layers.

To provide full independence between applications and bearers, some additional functionalities have to be defined to provide full interoperability between supported railway applications and supported bearers. Most stakeholders emphasize that introducing Internet Protocol (**IP**) in railway communications is key to bearer independency. IP is a layer 3 protocol as defined by the OSI model and may or may not be included in the bearer definition. Two main ways of implementing IP in railway communication framework are possible which are linked to the conservative and the flexible visions already outlined in the previous paragraph:

- ✓ **Full independence** between applications and the bearer using standardized protocols over IP such as SIP and RTP over TCP/IP to implement Voice over IP (VoIP) services (e.g. Over-The-Top voice applications – OTT – such as Skype, Viber, and WhatsApp). A data packet channel is used for either voice, data, or video communication, independently of applications, combining Quality of Service (QoS) profile with specific rail services. This is the flexible vision.

- ✓ **Partial independence** using for example 3GPP communication framework to provide interworking mechanisms to non-3GPP access networks like Wi-Fi.
  Many standardised versions of Wi-Fi-based wireless systems are currently available from IEEE, and many categories are derived from Wi-Fi for dedicated verticals like IEEE 802.11p as the basis of European standard for vehicle communication known as ETSI ITS-G5. All wireless standards must be clearly considered.
  3GPP standards are using equivalent voice over IP mechanisms but including a different level of service, called Voice over LTE (VoLTE). On that point, a new terminology has been used by UIC recently "bearer flexibility", to allow a certain level of independence between railway applications and the underlying transport system. Bearer flexibility is only referring to different access types within the 3GPP system architecture framework. The decoupling of applications depends on the application and the expected service requirements (including communication services, performance, and security requirements). Flexibility when adding a new bearer included or not in the 3GPP framework has to be considered. This is the conservative vision.

Both implementations have technical, economic and planning advantages and disadvantages with different levels of service.

The 3GPP framework, providing services such as VoLTE, is sustainable since it is an existing ecosystem comprised of many stakeholders (dominated by MNOs). Non-3GPP bearers such as SatCom however are not directly integrated into this framework, but work is on-going to fill this gap.

Only the flexible solution offers full bearer independence. Moreover, the flexible solution is best positioned to support non-3GPP bearers such as Wi-Fi or SatCom in the medium or long term. It is the flexible solution that offers the broadest possibility to evolve operational rail communications over time. It is the solution that is most attuned to the likely long term evolution of the commercial market, where bearer independence has been taken for granted for many years. For all of these reasons, we conclude that the flexible solution should be preferred in the medium to long term.

Long term implementation of the flexible view is not incompatible with short term implementation of the conservative view, which can be thought of as a stepping stone on the way to realisation of the flexible view. 3GPP-based solutions become one solution out of many.

The flexible, fully independent solution depends, however, on the creation of a valuable and sustainable ecosystem for rail-specific application. This topic will be addressed Chapter 7.

Finding 8. The flexible solution should be preferred in the medium to long term. Only the flexible solution offers full bearer independence. It is the solution that is most attuned to the likely long term evolution of the commercial market, where bearer independence has been taken for granted for many years. Moreover, the flexible solution is best positioned to support non-3GPP bearers such as Wi-Fi or SatCom in the medium or long term. It is the flexible solution that offers the broadest possibility to evolve operational rail communications over time.

Finding 9. Short term implementation of the conservative view can be thought of as a stepping stone on the way to realisation of the flexible view. 3GPP-based solutions become one solution out of many[12].

4.2.2.3 System architecture description

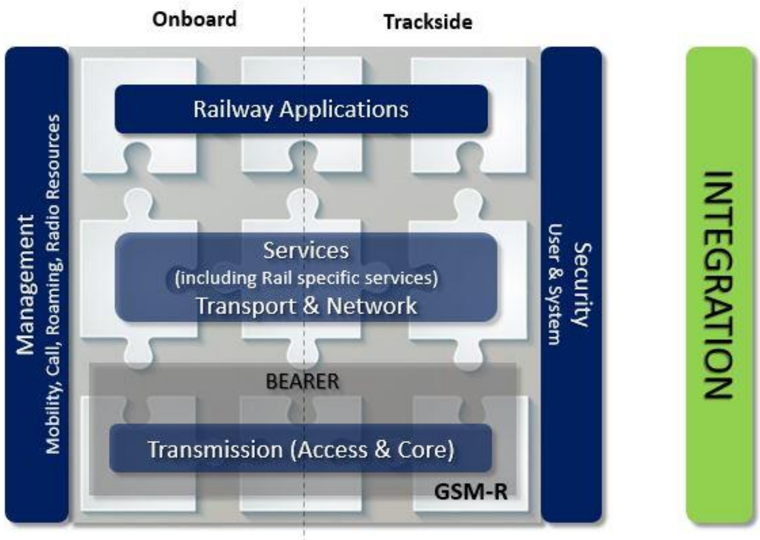
In this study, on-board (i.e. train) architecture is considered of primary concern in the concept of bearer independence. Two major reasons can be outlined to explain this.

Firstly there is a lack of infrastructure/networks integration to provide roaming and seamless connectivity between bearers with different access technologies. Some of them, such as commercial cellular technologies, are already standardised by 3GPP with primary focus on providing interfaces and roaming capabilities between old and new technologies such as 2G and 4G for instance. But this capability is not foreseen *between bearers standardised by different organisations (e.g. 3GPP and IEEE)*.

[12] It could be possible, however, that 3GPP specifications integrate also non-3GPP bearers in their portfolio; 5G may be the first step.

Two different approaches defining the co-existence with legacy GSM-R system are detailed from stakeholders in the questionnaire, which are challenging issues to be addressed by the rail sector and outlined below:

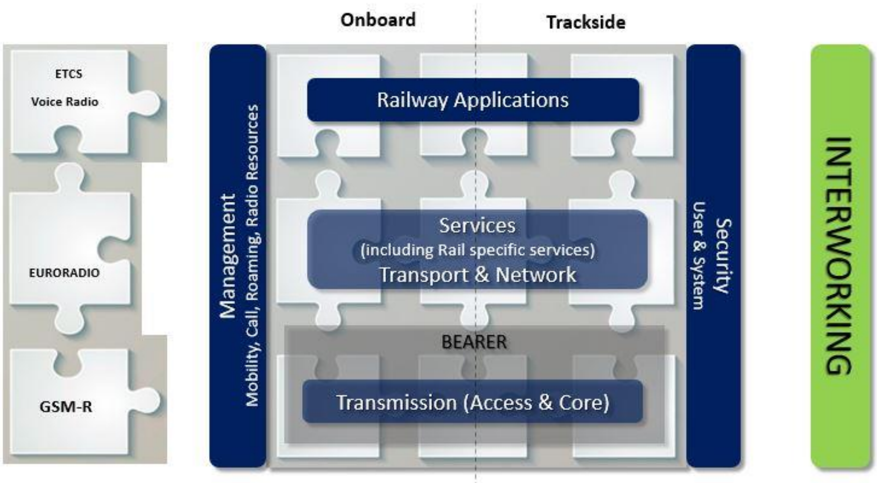
- ✓ **Integration**: GSM-R is part of the bearer independent concept. Adaptation layers have to be studied.



Source ETSI

Figure 13. High-level functional architecture integrating GSM-R

- ✓ **Interworking**: GSM-R is a separate entity. Interworking domains have to be studied. This is the preferred option from UIC.

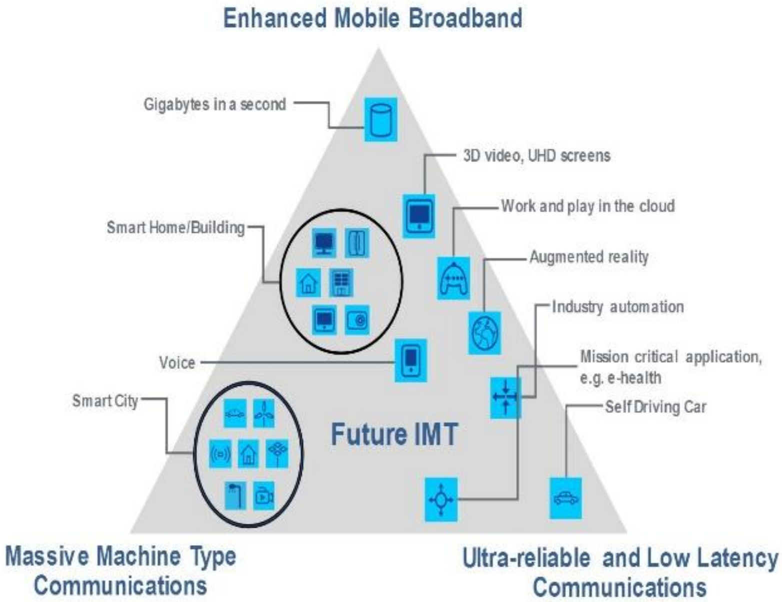


Source ETSI

Figure 14. High-level functional architecture with interworking for GSM-R

The second reason is the purpose of the bearer, i.e. what it has been designed for. Bearer specifications fulfil different requirements, and so have been standardised and designed in different ways with different objectives set by different standards bodies. We can highlight key communications requirements for the following bearers:

- ITU-T **2G** such as GSM: ITU-T defines specifications of the second generation (2G) of digital cellular systems. Key criteria were mainly to provide digital voice services to be covered in a wide area (country) with roaming capabilities across countries and continents. Low-rate data transmission with SMS and MMS were also defined. Quality of service for voice services was included in the communication technology.
  GSM networks are still operated today by MNOs to deliver voice services with QoS by-design (i.e. circuit-switch mode providing dedicated end-to-end resources).
- ITU-T **4G** such as LTE-Advanced and WirelessMAN-Advanced (a.k.a. WiMAX): IUT-T defines the fourth generation of digital cellular systems with particular interest on broadband data. 4G networks deliver broadband data in packet-switch mode with QoS by-design in the radio layers. The SAE bearer service was introduced to guarantee end-to-end QoS for data communication services. The radio access layer can tune protection, protocols, radio resources capacities and other radio parameters based on upper layer communication needs such as class of service, guaranteed bit rate, transfer delay, priority and pre-emption. Mainly European MNOs are using 4G for broadband data and implement fall back to circuit-switch mode (2G networks) when users need voice communication services. But this implementation choice is to be re-evaluated because of MNOs outside Europe having already shutting down their 2G networks by routing all users' traffic (voice and data) to 4G networks. For instance, at the beginning of January 2017, AT&T was one of the first MNO on the North American continent to shut down its legacy 2G GSM 850/1900 MHz network. 4G technologies could then be introduced in 850/1900 MHz spectrum bands, refarming from 2G.
- ITU-T **5G** (IMT-2020): ITU-T defines overall objectives of the fifth generation of digital cellular system, as outlined in the ITU "target" and "triangle" in Figure 15 below and with target performance in Figure 16:



Source: ITU

Figure 15. 5G overall objectives

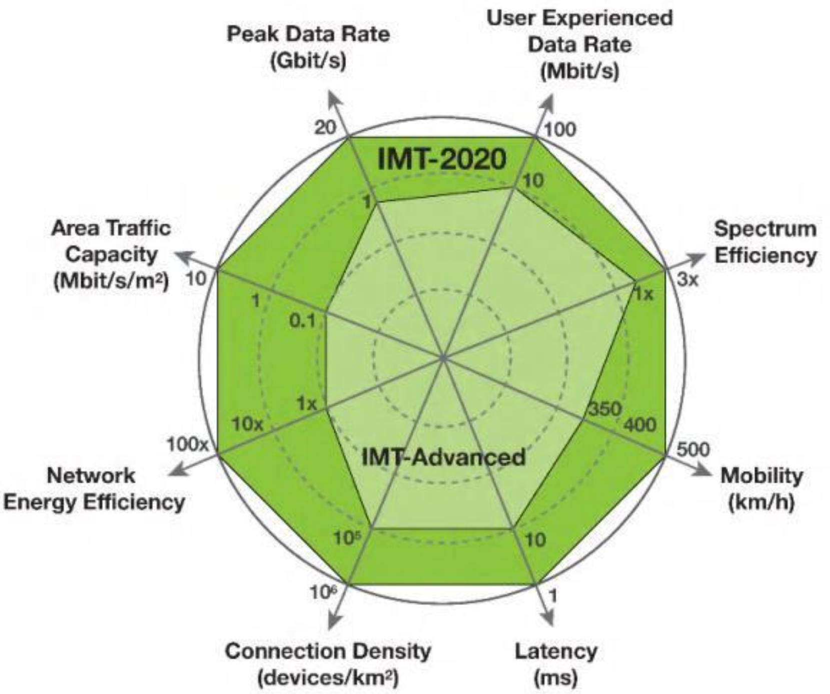


Figure 16. 5G performance target

Key criteria are enhanced broadband data, with massive connectivity (industrial IoT use case), and ultra-reliable and low latency performance.

- **SatCom**: three categories of services are provided by SatCom: Broadcast, Fixed and Mobile services. Main objectives of SatCom were to deliver TV/Radio broadcasting, voice telephony, internet access, news gathering, and narrowband/broadband data with particular interest on global or continental outdoor coverage. Performance characteristics depend mainly on the type of satellite orbit, GEO, MEO or LEO, and weather events (e.g. rain could have major degradation impact on radio signal quality).
- IEEE **802.11** (“**Wi-Fi**”): Wi-Fi has been designed primarily for data connectivity in public local areas (short-range coverage also known as hotspots or Access Point - AP) on a best-effort approach. QoS is not guaranteed due to service delivery in unlicensed spectrum, shared equally by all authorised users, with no QoS-by design in the radio layers. Wi-Fi networks provide a wide range of difference of performance. Wi-Fi networks are already used by public urban transport operators to offload high volumes of data such as CCTV in stations or depots or to add capacity capabilities by means of load sharing.
  But voice over Wi-Fi is one new trend in Wi-Fi services. VoWi-Fi is becoming popular to carry IP voice traffic.
- **LPWAN** such as LoRa, SigFox, NB-IoT etc.: LPWAN is a type of digital wide-area communication network designed to perform long range data communications at low-bit rate with low power consumption. It has been designed for IoT domain to provide connectivity for massive number of sensors using batteries.

As previously highlighted in this section, bearers have been designed with different objectives and communication requirements in mind. In the concept of bearer independence, we want to deliver voice and data communication services independently of underlying bearer specific features.

Therefore, we need to find a convergent element as a condition for success of the concept. The convergent element is the **data** connectivity. All kind of bearers have been designed to deliver at least data services with or without guaranteed, seamless and secure connectivity. That's why we would like to consider further in this study, infrastructure as a **data pipe** or **data channel** to allow effective bearer independent communications. Infrastructure must be seen as a route to connectivity only. Infrastructure or networks provide content-independent services to end users. Content-dependent railway services are provided by upper layers.

Bearers seen as data pipes with different traffic volume densities are outlined in the Figure 17:

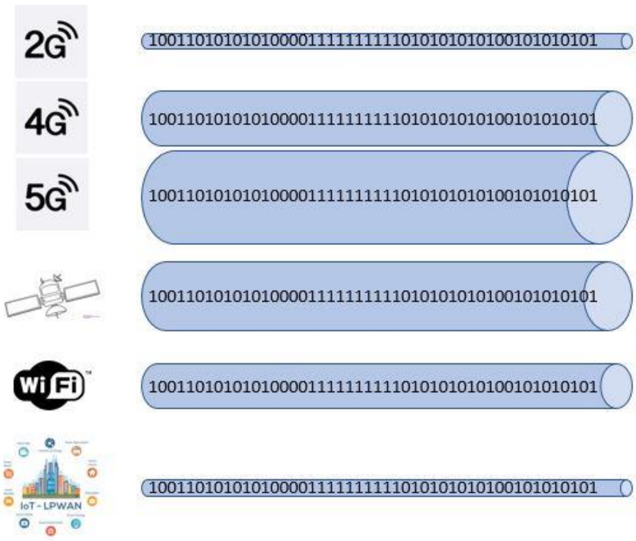


Figure 17. Bearers seen as data pipes with different traffic volume densities

Finding 10. With bearer independence, we are seeking to deliver both voice and data operational rail communication services independently of underlying bearer-specific features. Today, it is routine for commercial data services to be fully bearer independent, and for voice services to ride on top of the bearer independent data services (as Voice over IP (VoIP)). This is the most natural approach for bearer independent operational rail communications to take.

4.2.2.4 A former architecture : GSM-R on-board architecture

The current GSM-R on-board architecture provides minimum legal obligations on communication services to support ETCS and train radio (a.k.a. train-to-ground radio). There is not a single communication system architecture for both applications, even if they are using the same bearer, which is GSM-R. Communication system architectures are defined in silos by different bodies for ETCS and train radio with independent communication entities/devices:

- Signalling organisations define ETCS-Data only radio (i.e. EDOR) with circuit-switched and packet-switched data communication capabilities for on-board European Vital Computer (EVC).

- CabRadio provides voice and non-safety data communication capabilities for train drivers, dispatchers, and all kind of railway staff communication needs, as defined in EIRENE standards.

In the following, we will present trends on on-board/mobile communication system architecture in railway domains and other safety-related sectors with similar principles as bearer independence concept provides. We address how those architecture could bring benefits and opportunities to the evolution of railway radio for ETCS and train radio and highlight conditions for success in the context of BIC.

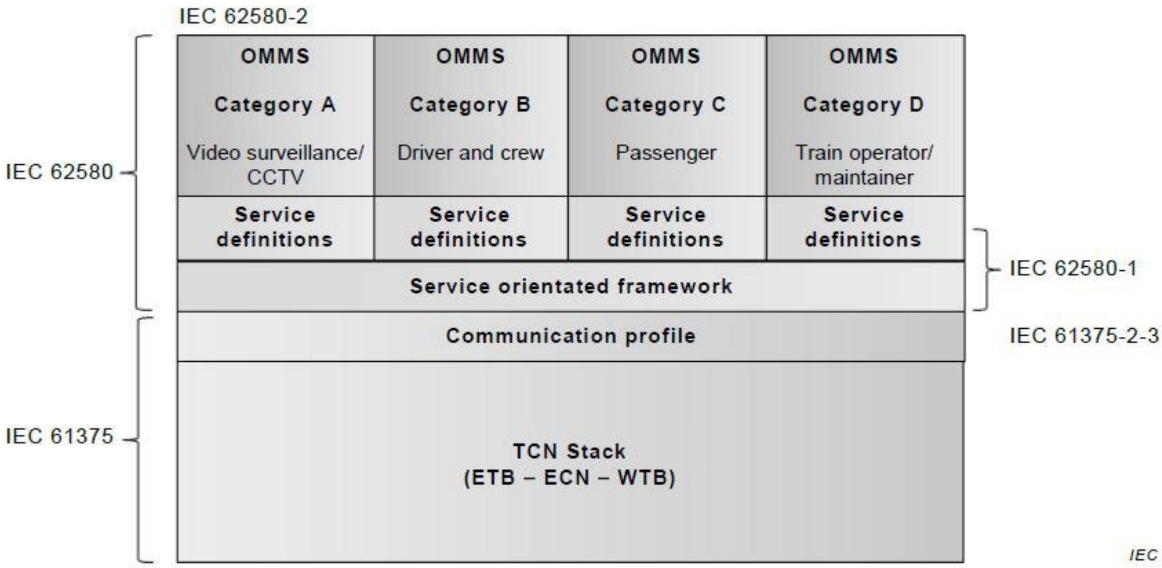
4.2.2.5 An example of new on-board Architecture: The Train Control and Monitoring, Telemetry and multimedia

The IEC 62580-1 standard defines the general architecture of the **On-board Multimedia and Telematic Subsystems (OMTS),** so as to achieve compatibility between subsystems in the same vehicle and between subsystems on-board of different vehicles in the same train.
On-board communication and on-board-to-ground communication are specified by the IEC 61375 series, where on-board-to-ground communication is intended as a generic link, with no assumption on the underlying technology (cellular, satellite or others).
The general architecture of OMTS is specified in terms of services, that's why a **Service-Oriented Architecture (SOA)** has been de facto chosen. The main benefit of services oriented architecture addressed in this standard is to decouple applications from communications, to ensure that applications compliant with IEC 62580 series are compatible with protocols compliant with IEC 61375 series irrespective of evolutions in both releases.

Note: Only one category of services – category A: CCTV services – are specified yet (refer to IEC 62580-2 standard). Other categories of services such as driver/crew oriented services will be addressed in the future.

It has to be noted that this standard will soon be referenced in ENE TSI. The on-board Energy Measurement System (EMS) will be supported as a Category B service (driver and crew services) to exchange data with the ground energy data collecting system.

OMTS deal with electronic production, coding/decoding, processing and exchange of information which is not directly relevant for train operation (i.e. non-critical data).



Source: IEC

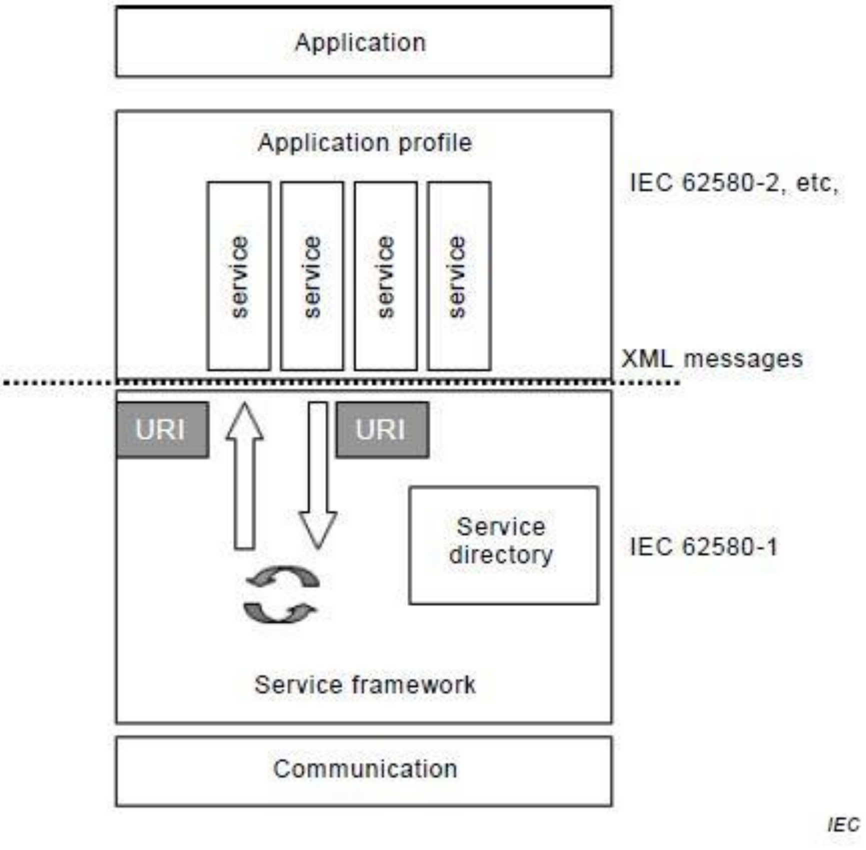
Figure 18. General OMTS service-orientated architecture

Applications implement the functional requirements. Communications provide data transfer services and should be considered as “data pipelines”.
To decouple applications from communications, the concept of middleware has been introduced in SOA to provide a uniform and complete interface to all kind of applications.
The middleware is split into two sub-layers:

- A communication independent **application profile:** the application profile adapts the communication services to the needs of a specific application category (e.g. critical, performance and business).
- An application independent **communication profile: t**he communication profile maps the communication services with mechanisms depending on required level of service.

These sub-layers are dealt in detail in IEC 61375-2-3 and future 61375-2-4.

The IEC 62580 series deals with interoperability between OMTS at application level, defining how applications exchange information. It is assumed that a bearer, specified in IEC 61375 series, is available to applications for communication services.
Each category of applications (or OMTS) can be seen as a set of cooperating services, producing and consuming messages. Services allow to describe interfaces at application-level:



Source: IEC

Figure 19. OMTS service-based interface

Some services can be used for other applications or subsystems such as TCMS.
Examples of such services, provided by the application profile, are:

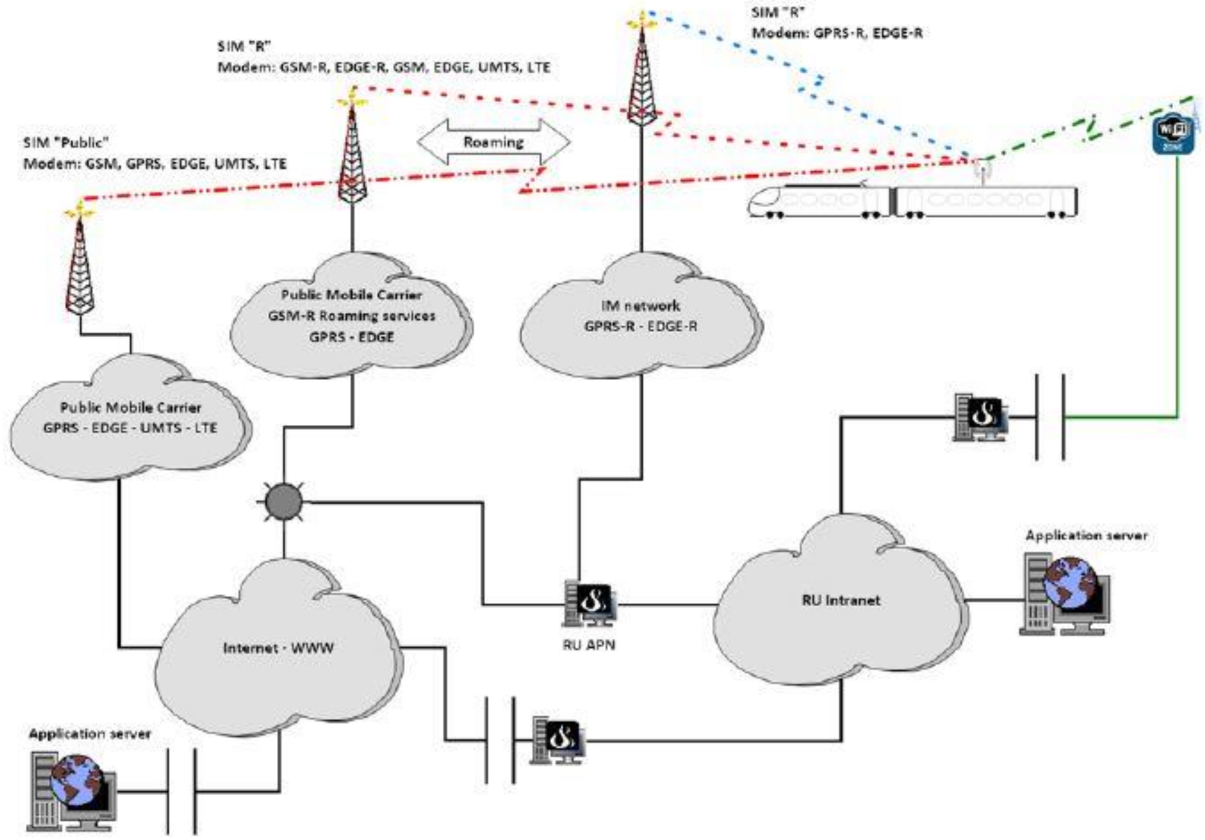
- Security services (authentication, data integrity and confidentiality)
- Location service (position of the train)
- Time service (UTC information)

The IEC 61375 standard defines interfaces so as to achieve plug-in compatibility between equipment within same or in different vehicles. This standard defines these interfaces as connections to a data communication network, called the **Train Communication Network (TCN).**
The IEC 61375-2-6 standard defines on-board to ground communication requirements to:

- Use available radio technology based on QoS application profile;
- Provide secured communication services to TCMS and OMTS functions (for non-critical data communication services);

The on-board to ground communication is provided through a shared Mobile Communication Gateway (MCG) which is an on-board device or through a dedicated communication interface.

Choosing between multiple bearers is then possible. The choice of bearer(s) is dependent of strategic and economic criteria from the Infrastructure Manager and/or Communication Service Provider (CSP). Cellular systems and Wi-Fi are mentioned as possible examples but radio link interfaces must be specified by ITU and/or ETSI. The selection of the appropriate bearer for communication needs of a single application is application dependent. It is based on QoS application profile mapped on QoS communication profile. The selection is also based on the required level of security and the train state (i.e. operation/automatic, maintenance, or commissioning states).



Source: IEC

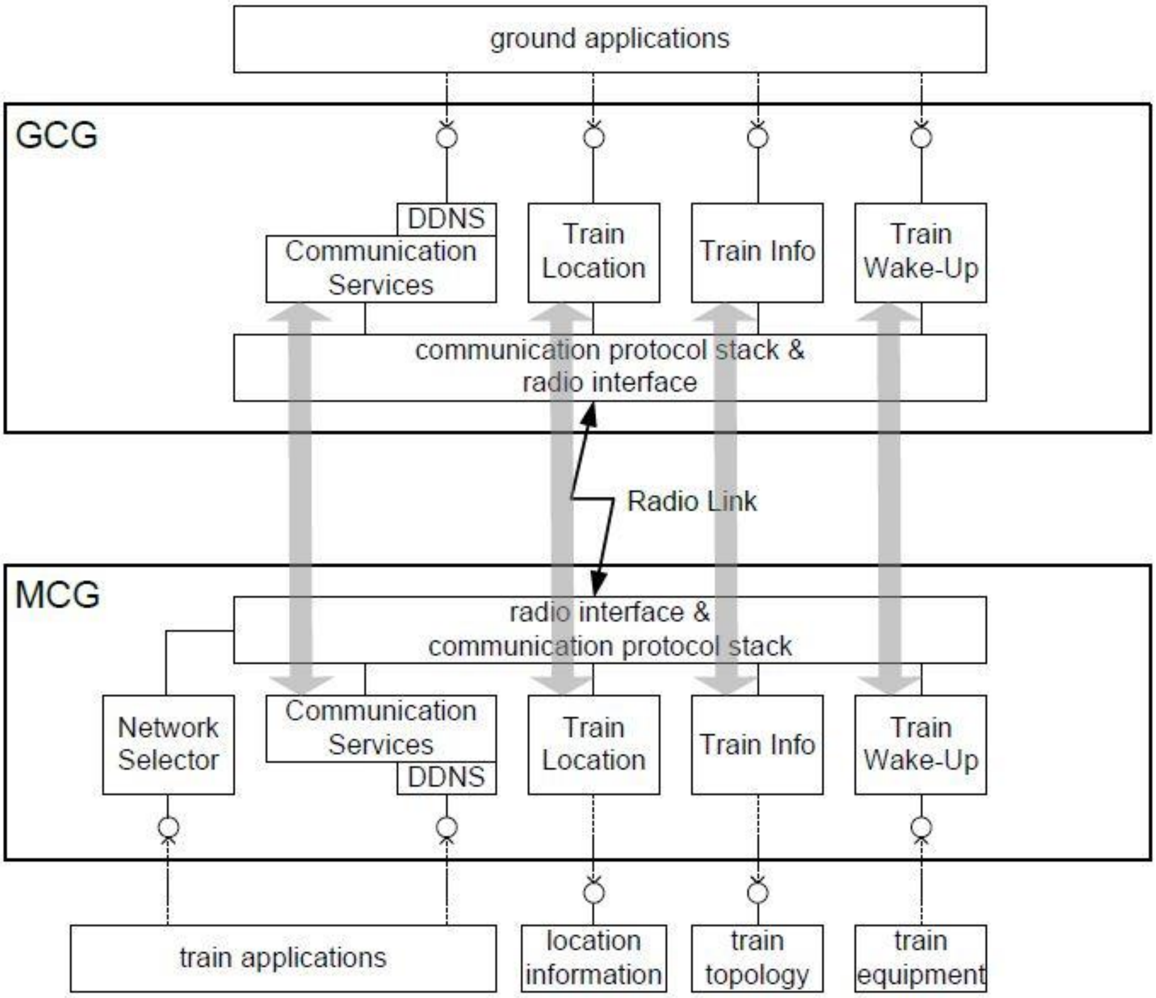
Figure 20. TCN track-to-train communication: interface to multiple bearers

The shared MCG provides security capabilities (authentication, integrity and confidentiality), which could alternatively be provided at application level. The security architecture of the communication system is modelled with the concept of zones and conduits as defined by the IEC 62443 series. A zone is defined as a grouping of logical or physical assets that share common security requirements. If equipment in a zone has a security level not equal or higher that the required level, extra security measures need to be taken. The concept is to protect functions with high level of security requirements (safety zones) from non-safety related functions. Then to map those safety and non-safety zones to appropriate closed or open communication systems as on-board network, as defined by the IEC 62280 series. The MCG is required to be compliant with the highest level of security requirements.

Availability is in the scope of the application layer by means of communication redundancy. Redundancy handling is performed by duplicating physically the communication device: the MCG is duplicated, and selection of active device is made based on cold or warm stand-by.

4.2.2.5.1 Train Communication Network On-board and ground system service architecture

Figure 21 provides an overview of the ground and the on-board TCN system service architecture.



Source: IEC

Figure 21. TCN system service architecture

GCG is the Ground Communication Gateway. MCG and GCG provide train-to-ground communication services to OMTS and TCMS, together with additional services such as:

- Train location: current train location coming from a positioning system (e.g. GNSS receiver, odometry)
- Train info: train data on train status (e.g. traction, brakes, door control as defined in UIC leaflet 556)

We will not go into details of the whole system architecture but focus on communication services and network selector (to control data transmission and selection of bearer) which are clearly in the scope of this study.

4.2.2.5.2 Communication services

Before transmitting data, the communication services will be in charge of providing interfaces to the bearer for:

- Radio link establishment: the implementation depends on bearers and is outside the scope of this standard
- IP address handling: the implementation depends on bearers and is outside the scope of this standard
- DNS registration (i.e. similar to functional registration in EIRENE)
- Authentication provided by appropriate function

When the communication channel is established between on-board and ground, applications are ready to send data. Three kind of data communication services are available for upper layers (applications) depending on functional requirements:

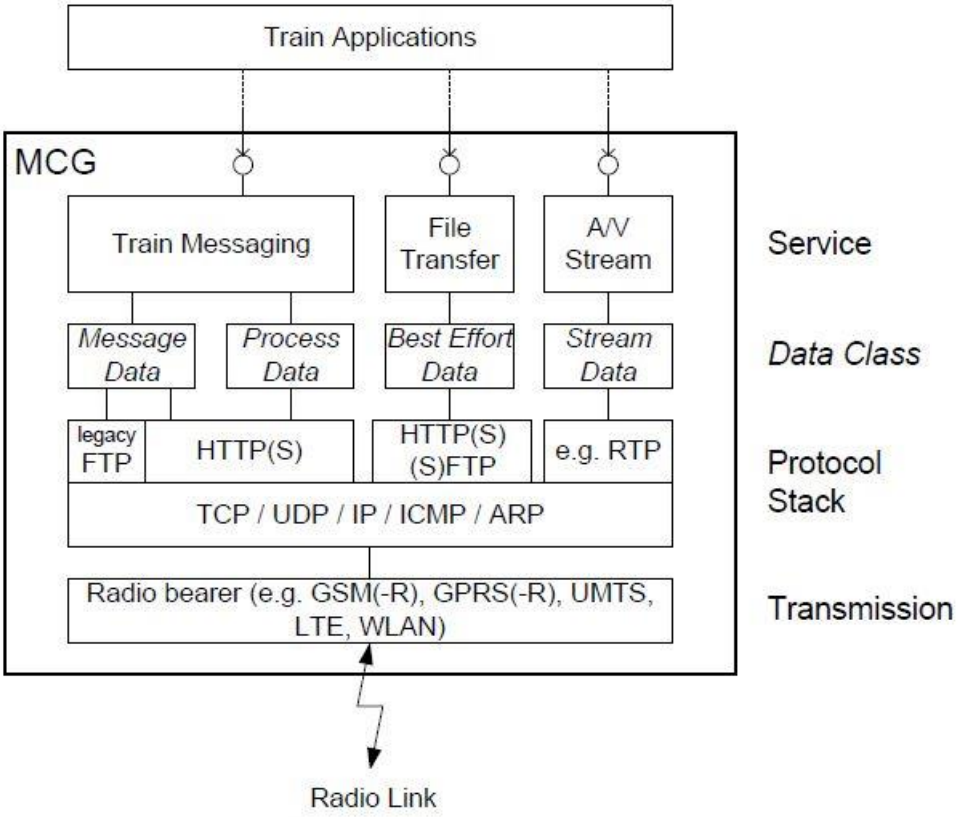
1. **Messaging service** for event-based information exchange
2. **File transfer service** for complete data files
3. **Streaming service** for continuous data exchange

Those services are then mapped to data classes depending on functional requirements. Data classes are defined with a list of service parameters and appropriate values such as:

- Data packet size
- Data packet rate
- Latency
- Jitter
- Data integrity (i.e. bit error rate).

Depending on data classes, appropriate communication protocols are used. The following standardised internet communication protocols are described:

- HTTP as the basic communication protocol
- HTTPS if security requirements are needed in addition to basic communication service
- FTP for file transfer
- SFTP if security requirements are needed in addition to file transfer service
- RTP for real-time communication services



Source: IEC

Figure 22. MCG communication architecture

4.2.2.5.3 Network selector

When data transmission is requested and during transmission, bearers are dynamically and automatically selected by means of on-board entity. The selection is based on link quality metrics coming from the radio link layers, but also on cost constraints and user policies.

Examples of radio link quality metrics are:

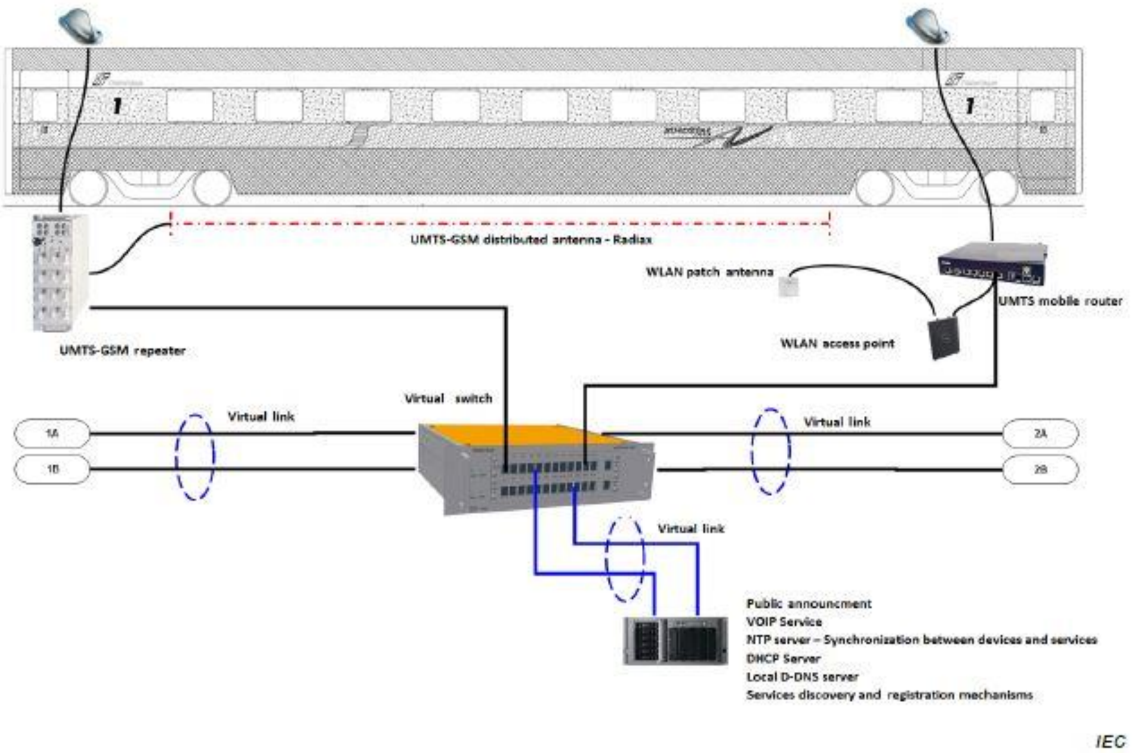
- data rate
- signal strength.

An example of user policy and cost is:

- Transfer video only when WLAN is available.

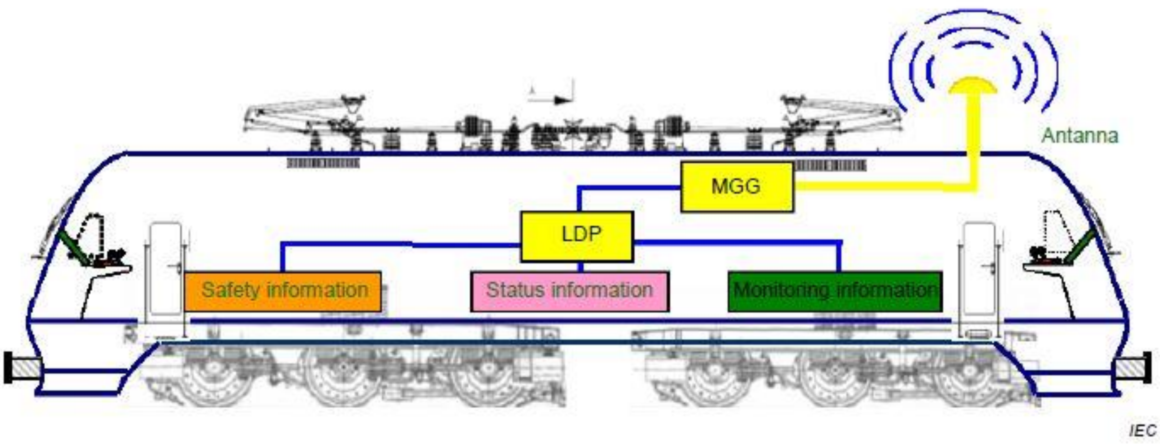
When the train is moving to a new bearer or when quality of active bearer is degraded, the network selector must provide automatic and seamless re-selection by using suitable vertical handover technologies such as the ones defined in IEEE 802.21. The IEEE 802.21 standard defines functions and protocols to optimise services when networking between IEEE 802 and cellular networks. Seamless is defined in this standard as lossless and without connection loss (for TCP sessions only).

Here are pictures of MCG use cases by different train operators in International countries:



Source: IEC

Figure 23. Italian high-speed train MCG



Source: IEC

Figure 24. Chinese train MCG

4.2.2.6 *Assessment of TCN architecture for critical communications*

Is the TCN on-board to ground communication architecture suitable to railway critical data communications?
This question is of particular interest for this study. Current applications supported by the TCN do not intend to use on-board to ground communication services for safety operations (e.g. control of brakes or doors). Communications of safety related commands are out of the scope of the IEC TCN standard series.

To perform a high-level assessment of communication architecture as a suitable architecture for safety train operations, requirements on critical data communication characteristics need to be established first.

High reliability, high availability and **a high level of security** are key attributes to design a proper communication system architecture for safety applications.
Redundancy is a well-known design technique to prevent failures, together with remote proactive failure monitoring. Redundancy could efficiently give answers to achieve high reliability and high availability requirements by means of load aggregation or warm stand-by techniques.
IEC TCN communication redundancies are already defined by means of duplicated functions, devices (MCG and bearers), local networks, and interfaces (radio interfaces).

Priority and pre-emption are features that makes network resources available to mission-critical communication services at any time when needed, even if the network is congested. This is not related to the definition a high-available on-board architecture but as indirect impact. This feature is conventionally implemented as a network feature such as eMLPP in GSM-R system. eMLPP can control network resources and allows priority users to pre-empt resources when network is congested. This feature could also be design differently. Consider all applications with communication needs using a single point of communications such as the MCG of the TCN: the MCG is then able to control and arbitrate the flows of each application. The MCG could consider non-safety applications flows to be routed to congested bearer or simply rejected while safety applications flows are routed to available bearer with guaranteed access to network resources.
The concept of bearer independence needs to consider priority and pre-emption as network agnostic features.

Security is another key attribute to design communication architecture for critical applications. IEC TCN system architecture already provides a full of set of security measures by means of firewalls, authentication techniques, encryption based on already well established internet standards. The standard also introduces the concept of zones already defined in IEC 62443. A zone is defined as a set of functions with common security requirements. Safety zones are defined for safety functions.

To conclude, we can say that IEC TCN communication architecture is a good basis to design additional safety (train) operations and should be considered as a valuable input. A collaboration with IEC members also needs to be considered in order to avoid redundant work on train to ground communication systems.

Finding 11. The IEC TCN communications architecture represents a valuable input as regards the safety of train operations.

Recommendation 1. The IEC TCN communication architecture may represent a good basis on which to design additional rail safety operations. Collaboration with IEC members should be considered in order to avoid redundant work on train to ground communication systems.

4.2.2.7 Train recording system

The EN 62625-1 standard has been prepared under a mandate given to CENELEC by the European Commission and the European Free Trade Association. The standard covers all relevant essential requirements as given in Annex III of the EU Directive 2008/57/EC on Rail interoperability.
This standard elaborates specification of on-board juridical data recording system to ensure interoperability of trains inside EU. Juridical data are monitored to control the right operations of trains including Automatic Train Protection and Automatic Train Operation events and could be used for post-accident and post-incident survey, or for drivers' behaviour monitoring.

One of the option to get on-board recorded data for further analysis is to use the communication system. The preferred implementation of the communication system is the Mobile Communication Gateway (MCG) specified in IEC 61375, previously described. A typical use case is to download over-the-air the recorded data when trains are standing at stations or depots using Wi-Fi hotspots for instance as connectivity channels. The system must also provide on-board diagnosis and remote maintenance (remote monitoring of trains, remote control of trains, over-the-air downloading of software, firmware and configuration files) by the mean of the MCG and train location service (GNSS or odometry).

We would like to highlight to the railway community involved in the definition of the evolution of railway radio that a convergent communication architecture has been defined by IEC to support a number of non-safety related data applications. It is recommended to start to work on a common basis to provide a communication layer independent from applications.

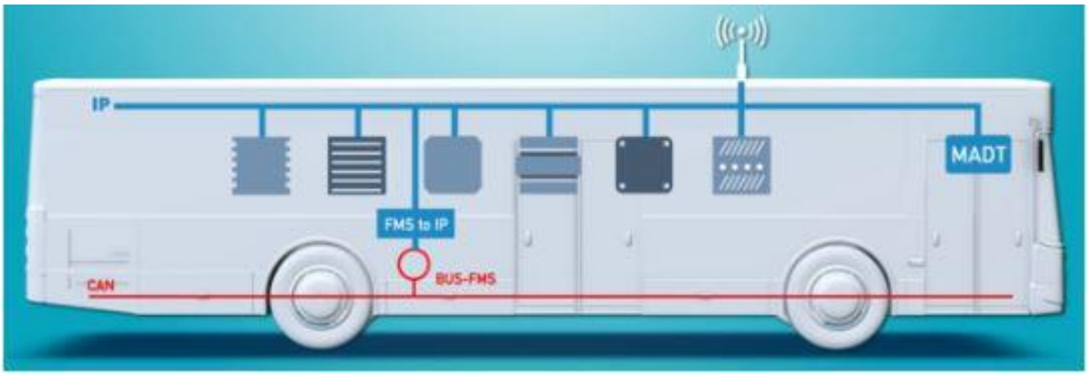
4.2.2.8 Independent bearer communication architectures in other markets

In similar markets development frameworks, work is under way in a number of areas linked to bearer independence. Whilst the scope of these initiatives vary, they provide useful information to this study. Three examples are described below and of particular interest for this study:

- Urban Public Transport and the ITxPT (Information technologies for Public Transport) initiative
- PPDR and the FirstNet in the US
- Intelligent Transport Systems: connected and autonomous vehicles

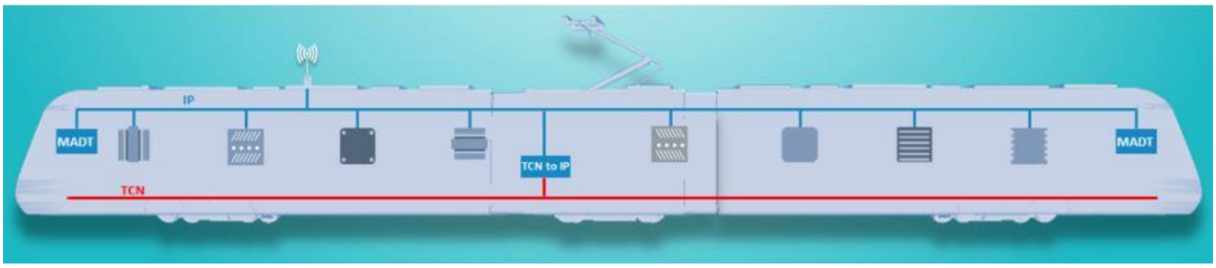
4.2.2.8.1 Urban Public Transport: ITxPT initiative

As of 4th of May 2016, Information Technology for Public Transport (ITxPT) has been officially incorporated by the Belgian Ministry of Justice as an international non-profit association under Belgian law. The mission of the ITxPT Initiative is to support the deployment of standards and practices for on-board plug-and-play IT systems for public transport by developing standard IT on-board architecture.
This architecture specifies communication protocols and hardware interfaces to offer a full interoperability of IT systems (on-board and back office) for PT applications.
Based on open technologies, it gives the possibility to implement and interface IT systems with common mechanisms, standard rules, and protocols. As from now, parts of these IT architecture specifications are included in EN 13149-7/8/9 standards for on-board part in the scope of CEN/TC 278 (Intelligent transport systems)/WG 3 (Public Transport) standardization group. This IT architecture is suitable for buses and is under extension to other types of PT like tramways.
ITxPT is pushing the requirements to have a full IP-based architecture. A full IP architecture follows different technologies and implementations covering areas such as: integrity, security, reliability, routing, addressing scheme, etc...
In ITxPT, the "Multi-Application Driver Terminal" (MADT) allows the driver to access or control multiple applications connected to the IT architecture on an integrated, shared HMI (Human-Machine Interface). It offers the possibility to be connected through different bearers. This equipment is comparable, in the railway environment, to a possible future bearer independent cab radio/ATO related DMI functions.



Source: ITxPT

Figure 25. ITxPT architecture for bus



Source: ITxPT

Figure 26. ITxPT architecture for light-rail

Examples of current IP communications technologies in the scope of ITxPT are the followings:

- For long range coverage
  - 3GPP Cellular technologies (e.g. GPRS, EDGE, UMTS, 3G, 4G)
  - WiMAX
- For short range coverage
  - Wi-Fi
  - WiGiG

Communications needs may vary depending on the type of applications using the media and therefore various numbers and types of networks may be used in combinations.

Typical bus system applications such as AVLS (Automated Vehicle Location System), DPI (Dynamic Passenger Information), and Ticketing can be satisfied with simple mechanisms such as request/response, multicasting, or servicing/publishing. All modules may need a back-office communication, so ITxPT recommends avoiding antenna redundancies by implementing a single Vehicle Communication Gateway. But emerging applications in Bus Systems such as streaming multimedia, Voice Over IP, IPTV bring the concept of Quality of Service (QoS). QoS must be taken into account to build the IT architecture.

On-board modules should be easily installed and configured, requiring minimal manual intervention. **Zero Configuration Networks technologies** for home networks (IETF zeroconf http://www.zeroconf.org/) should be considered, where each on-board module must implement such technologies.

The communication components are:

- The Back-office IP network: it includes all networks that are not in a vehicle, such as "PTO Network", "PTA Network". It can be developed at different organization levels like "Regional Network", "National Network" or "European Network"
- The Onboard IP network: it includes all embedded IP networks in a vehicle ("Onboard IP network" and "Onboard backbone IP network").
- The Onboard to BackOffice IP Link: it includes all media types (and associated modules) used for the communication between back-office and vehicles (i.e. list of supported bearers).

All these networks must use IP as a standard protocol for communication and a secured protocol to prevent data loss, intrusion on networks and to ensure reliability on data.

The ITxPT architecture is based on **Service-oriented Architecture** (SOA) model, composed of Modules exchanging services to communicate on an IP network. Modules are capable of recognising each other and discovering every service without any prior configuration. Sharing communication and location resources by all modules is now part of the architecture design. SOA has been designed for IT industry to provide interoperability, scalability and cost-efficiency based on standard IP protocols.

ITxPT also provides **integration and testing platforms**. Manufacturers can therefore verify their products compatibility with EN 13149 standards under operating conditions. PTA and PTO can confirm that their IT architectures are consistent as a whole, by ensuring modules from different suppliers could work well together in plug-and-play mode.

Next step for ITxPT in the European context (cooperative project called European Bus System of the Future – EBSF) is to study the potential of "**Smart garage**" with particular attention on telediagnosis giving real-time access to vehicle's technical data to optimise maintenance. Telediagnostics relies on standardised technical data provided by modules and sensors in the vehicle giving access to innovative maintenance processes and reducing operational costs (reducing time to repair).

The ITxPT initiative provides a full ecosystem to deliver on-board plug-and-play IT systems to avoid vendor lock-in and foster the implementation of a standard IT on-board architecture. Lessons learnt from such initiatives should be considered by the rail sector to overcome challenges of implementing SOA models.

Finding 12. The ITxPT initiative provides a full ecosystem to deliver on-board plug-and-play IT systems to avoid vendor lock-in and foster the implementation of a standard IT on-board architecture.

Recommendation 2. Lessons learned from initiatives such as the ITxPT initiative should be considered by the rail sector as a means of overcoming the challenges of implementing SOA models.

4.2.2.8.2 PPDR: example of FirstNet in the US

The US Congress decided in 2012 to initiate the design, build and run of a new, nationwide, interoperable broadband network for public safety (also known as PPDR) communications by creating the First Responder Network Authority (FirstNet). The US Federal Communications Commission (the FCC, the national telecoms regulator) assigned a licence to FirstNet with a 2x10 MHz in the 700 MHz band (FirstNet LTE band 14). The first goal of FirstNet is to carry data communications, and voice as an option.

Before FirstNet is available all over the US, public safety communities are turning to multiple bearer communication systems for their in-vehicle communications such as Wi-Fi, public and private cellular networks, or SatCom. The applications supported by in-vehicle communication systems are considered to be mission-critical. Seamless connectivity and service continuity must be guaranteed by means of high performance and full coverage including mobility.

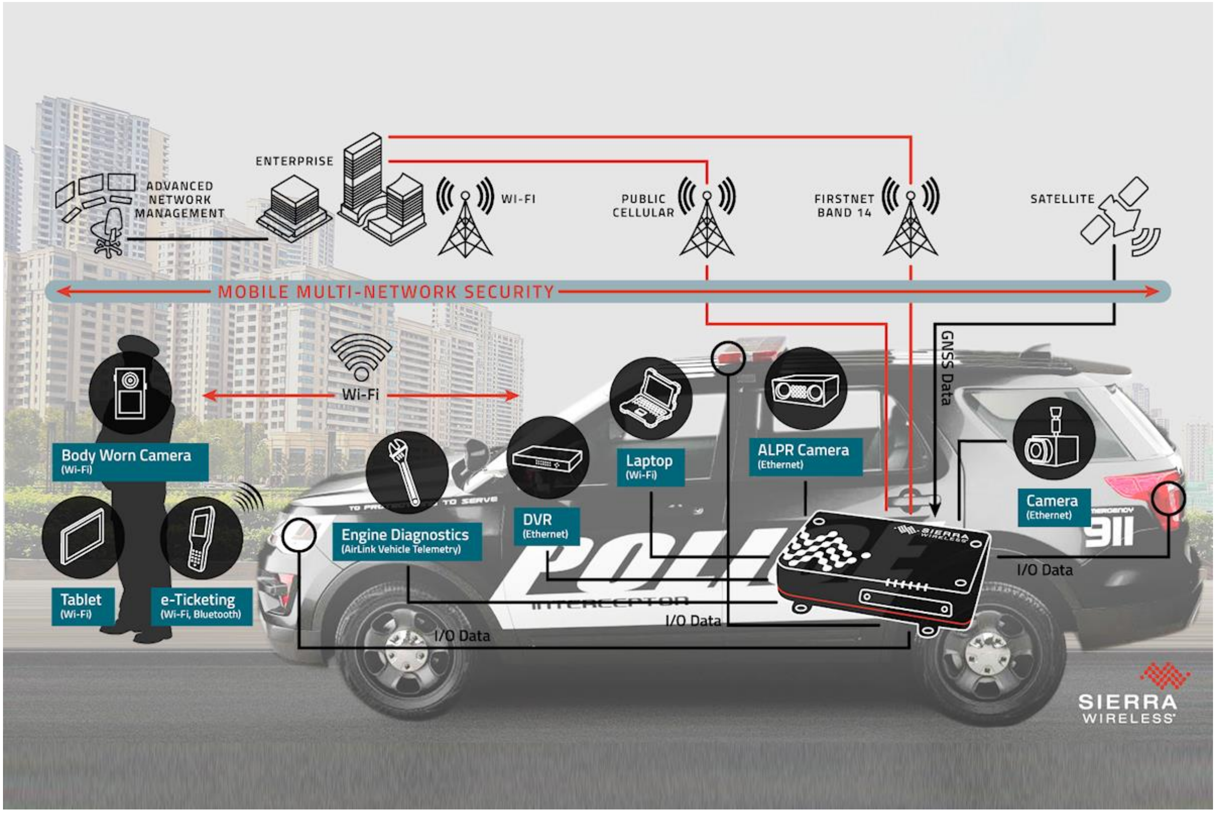
Dynamic and automatic selection of the bearer needs to be provided in the following use cases:

- Moving from Wi-Fi to cellular network (and vice-versa) when vehicles are leaving or returning to a station or depot
- Switching between cellular networks when vehicles are moving and quality of service is badly affected (e.g. out of coverage)

Criteria for selection are network priority list, availability, signal strength, vehicle location or time of the day.

Reliability and availability requirements are met by introducing resilient communications through multiple bearers and automatic selection so as to ensure service continuity.

Security requirements are also considered for transmission of sensitive data between vehicles and back-end systems. Internet standards are provided to meet authentication, integrity and confidentiality of data while maintaining session continuity when the vehicle selects a new bearer.



Source: Sierra Wireless

Figure 27. Example of FirstNet in-vehicle communication architecture

This example of **on-board** communication architecture needs to be considered by the rail sector to outline pros and cons to provide communication services to safety and non-safety applications, especially when considering migration scenario.

Finding 13. The First Responder Network Authority (FirstNet) that the US is in the process of deploying represents an interesting working example of a single network that provides communication services to both mission-critical safety and other non-mission-critical applications.

Recommendation 3. Lessons learned from initiatives such as the First Responder Network Authority (FirstNet) that the US is in the process of being deploying should be considered by the rail sector as a means of overcoming the challenges of implementing a single network that supports both mission-critical and non-mission-critical services.

4.2.2.8.3 Intelligent Transport System: connected and autonomous vehicles

One of ITS domain that may be of interest for the development of future railway communication system is Cooperative-ITS (a.k.a. C-ITS). C-ITS provides communication services between vehicles, infrastructures and other road users to improve safety of future automated vehicles and their full integration in the transport domain.
ITS safety applications such as emergency brakes, priority of public safety vehicles, or speed control need communication services to control the overall environment.

Security is also clearly needed to avoid wrong messages to be sent across the network providing wrong safety information.

Lessons learnt from the public transport domain such as bus domain have been taken into considerations in the design of C-ITS, where each application with communication needs is considered in silo with its own communication protocols, standards and interfaces.
Note: ongoing ITxPT initiative is looking to change this silo's vision.

To avoid development of services in silo, a common ITS communication architecture has been defined by standardised bodies ISO and ETSI. This architecture is suitable for different categories of applications (road safety, traffic efficiency, infotainment) through a diversity of access technologies or bearers such as 3GPP cellular systems, Satellite, or IEEE 802.11 standards.

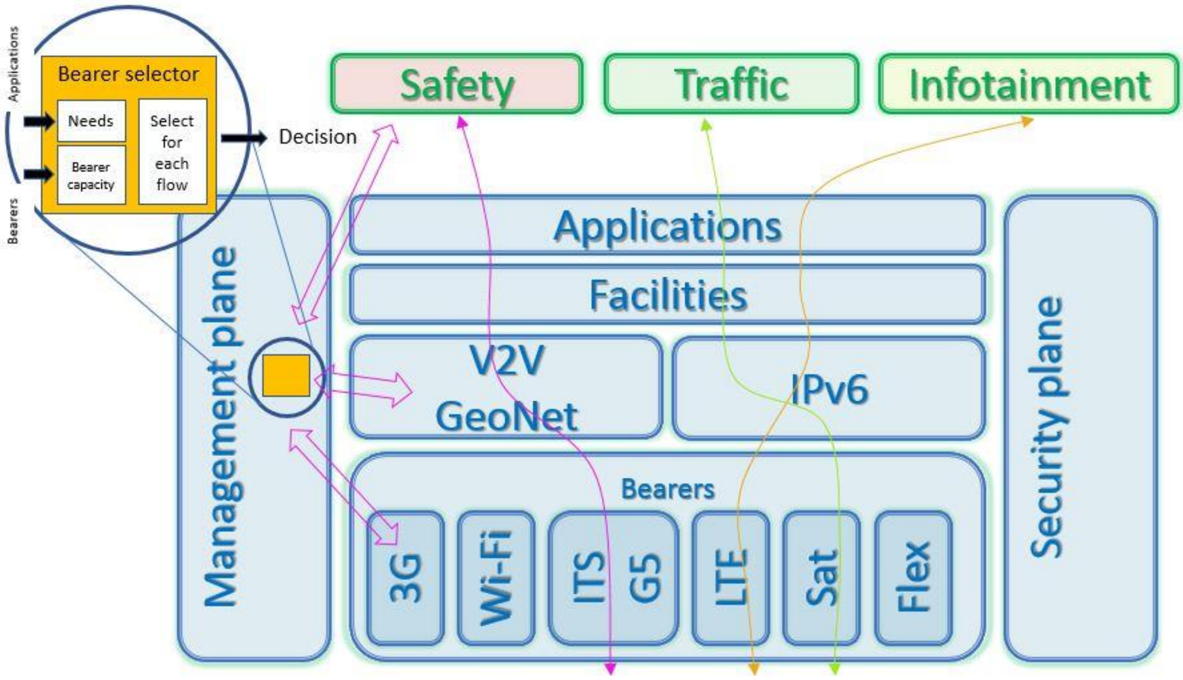
The support of a variety of access technologies of different characteristics allows great flexibility to connect ITS on-board entity (called mobile ITS station) to one another and to the Internet, at any given time or any given location (i.e. guaranteed connectivity, also called ubiquitous connectivity). Since no single access technologies is deployed everywhere, mobile ITS stations can use whatever access technologies is available in a certain area. These bearers could be used simultaneously, and vary according to the category of ITS station and its purpose. The communication flows must also be transferred from one bearer to another without breaking ongoing session (i.e. while performing vertical handovers).

Applications need to be **access technology independent** so that the best available access technology can always be used. The most optimal access technology is selected according to the application flow requirements and current bearer characteristics. However, some application providers or authority may prefer or request the use of a specific access technology for a given or set of applications. For doing so, applications must provide their communication requirements so that the network protocol can always select the best access technology.

To support any given access technologies, a new standard specifies the parameters and functions so that the access technology could be recognised by the ITS station. Currently, the support of several wireless access technologies (infrared, microwave, millimetre waves, 2G/3G and wired access technologies - Ethernet) is already specified, in either ISO or ETSI standards. More access technologies could be supported in the future, without any impact on the other layers of the ITS station reference architecture. It is of course not required for a given deployment to implement neither all these access technologies nor to implement the specific functions required to support all these access technologies.

So, the purpose of the standard is to specify how a given access technology, if needed, can be integrated into the ITS station.

The selection of the bearer depends on the application needs and the bearer capacity. The selection is made for each communication flow. An example of communication flows are outlined in Figure 28 below:



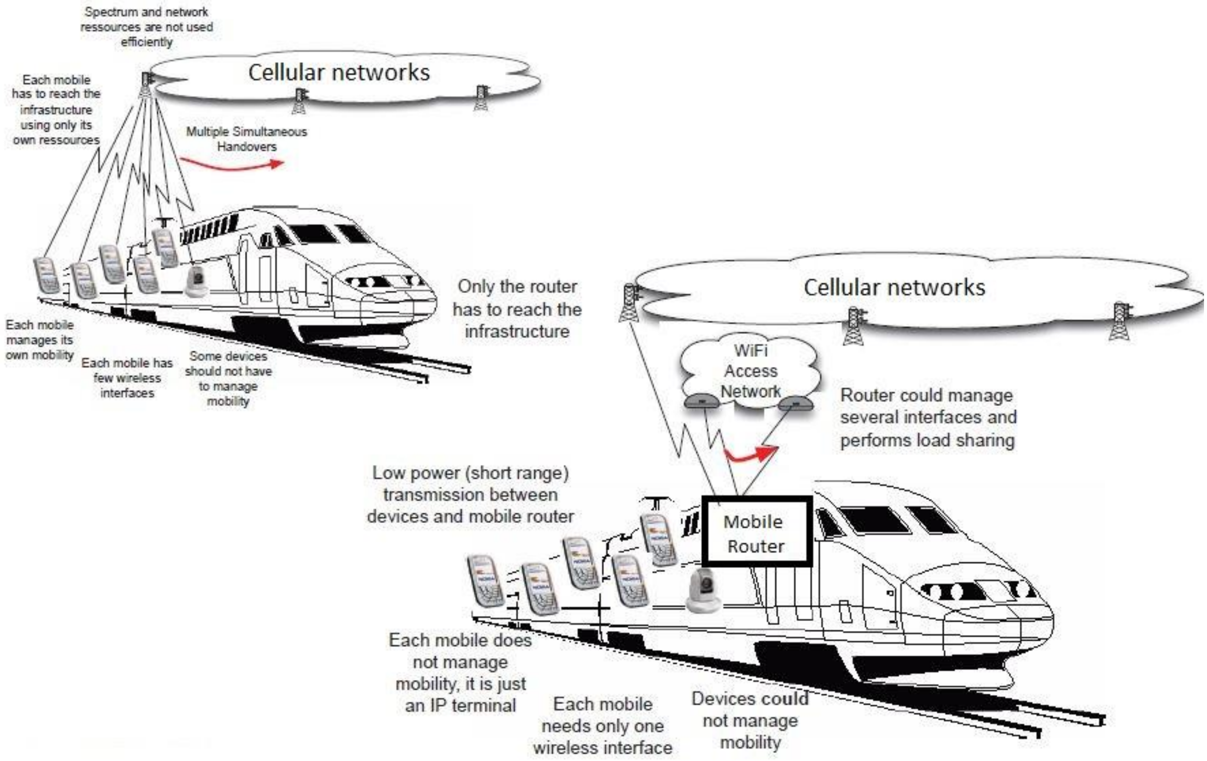
Source: IMT Atlantique

Figure 28. ITS station architecture defined by ISO and ETSI using multiple bearers

The ITS station architecture introduces the concept of mobile router. The concept is quite similar to the TCN Mobile Communication Gateway (MCG) by sharing network resources from a single communication device. The concept of mobile router provides the following benefits:

- Sharing network resources: a single on-board device (i.e. the mobile router) performs communication services for all categories of on-board applications
- Multiple bearers: mobile router performs access to multiple bearers simultaneously, using load sharing techniques
- Mobility Management: standardised Mobility protocols such as Mobile IPv6/MIPv6 and NEMO are used to manage devices and networks mobility
- Transparent Mobility: applications are not aware of mobility when for instance performing vertical handovers between bearers.

The benefits of mobile router are outlined in Figure 29:



Source: IMT Atlantique

Figure 29. ITS station mobile router

This additional example of **on-board** communication architecture must be considered by the rail sector to outline pros and cons to provide communication services to safety and non-safety applications. Lessons learnt from this initiative must be considered by the Rail sector in the design of the future radio system to support BIC and to overcome challenges of implementing such model.

Finding 14. Cooperative-ITS (C-ITS) is an Intelligent Transportation initiative that seeks to provide communication services between vehicles, infrastructures and other road users. It incorporates many of the same capabilities as those that are sought for bearer independent operational rail communications, including support for multiple bearers, transparent mobility management, and shared network resources.

Recommendation 4. Lessons learned from initiatives such as the Cooperative-ITS (C-ITS) initiative should be considered by the rail sector as a means of overcoming the challenges of implementing bearer independent mission-critical communications.

Recommendation 5. ERA should consider more detailed study of various network designs that are either being implemented or else are under consideration to determine the degree to which lessons learned are potentially applicable to European operational rail communications. Candidates for further study include the ITxPT initiative, FirstNet in the US, and the Cooperative-ITS (C-ITS) initiative.

4.2.2.9 Other architecture trends to foster BIC concept

4.2.2.9.1 New radios architecture: RRS, SDR and cognitive radios convergence using OWA

The Open Wireless Architecture (OWA) approach, supporting various standardised wireless air interfaces in an open architecture platform, must be considered with attention by the rail sector.
OWA is a promising architecture to provide additional benefits such as cost-effective and spectrum effective high speed wireless transmission. Future devices must be capable of operating in several frequency bands and with different bandwidths (requiring improved RF modules). Devices should have the potential of dealing with different systems (multi-modes) and should also implement interference management to improve transmission capacity and performance (enhanced sensitivity and strategies for interference suppression). Therefore, the future terminal should provide an open RF architecture which is reconfigurable and portable for various air interfaces and frequency bands. The terminal must be multi-standards, multi-modes, multi-bands, and multi-medias.

Software-Defined Radio (SDR), which is categorised in the area of radio convergence, is one form of OWA.

We do not recommend a "wait-and-see" approach concerning OWA and especially SDR, but rather suggest instead that the rail industry initiate collaboration with standardisation bodies such as ETSI (referring to ETSI TC RRS working group) to assess the capabilities of OWA and SDR technology to support multiple bearers and as a solution to fulfil conditions for success of the concept of bearer independence for rail.

4.2.2.9.2 Telcos trends

We can observe interesting new trends in standardization bodies such as ETSI and 3GPP in the telecom industry providing new opportunities for future evolution architecture in transport and rail in particular. Some key evolutions are presented below with highlight on challenges still to be overcome.

4.2.2.9.2.1 Network Functionality Virtualization (NFV) and Software Defined Network (SDN)

Network Functionality Virtualization (NFV) and Software Defined Network (SDN) propose to create evolved packet core network in transferring all software of core network to common servers, switches and storage, which could be located in data centers, network nodes or at the end user's premises. This evolution will provide agile management of the core network functionality and services.

Announced benefits of NFV/SDN are:

- ⇨ Put together the apps (like smartphones)
- ⇨ Tailored deployments for vertical industries
- ⇨ Commodity servers

On the contrary, main challenges for NFV are time processing (latency), software licenses and interoperability.

4.2.2.9.2.2 Multi Access Edge Computing (MEC)

Another evolution intended to complement and build upon the concept of NFV is **Multi Access Edge Computing (MEC).** MEC is a network architecture concept that enables cloud computing capabilities and an IT service environment at the edge of the cellular network (i.e. in the Radio Access Network). The basic idea behind MEC is that by running applications and performing related processing tasks closer to the cellular customer, network congestion is reduced and applications perform better. MEC technology is designed to be implemented at the cellular base stations, and enables flexible and rapid deployment of new applications and services for customers. Combining elements of information technology and telecommunications networking, MEC also allows cellular operators to open their radio access network (RAN) to authorised third-parties, such as application developers and content providers (*Wikipedia and ETSI web site source*). Technical standards for MEC are being developed by ETSI. MEC will offer rapid deployment of new services and optimization of service delivery but before to be a reality interoperability should be achieved in order to let applications from different providers run on the mobile-edge platforms offered by the various vendors. ETSI created a Group to specify the MEC application-platform with open APIs, to promote this high-level architecture and develop favourable market conditions. Demonstrations with Proofs of Concepts (PoCs) are encouraged. A number of technical challenges need to be addressed including security, application portability, network integration, performance and resilience.

MEC is a promising technology for transport and rail. In particular MEC will enable applications and services (Layers 4 and above as defined by the OSI model) to be hosted 'on top' of the mobile network elements, i.e. above the network layer. These applications and services can benefit from being in close proximity to the customer and from receiving local radio-network contextual information.

Finding 15. Several emerging or developing technologies hold promise for the evolution of operational rail communications by potentially facilitating flexibility and infrastructure sharing. Among those that could be of interest are Open Wireless Architecture (OWA) and especially Software-Defined Radio (SDR), Network Functionality Virtualization (NFV), Software Defined Networks (SDN), and Multi Access Edge Computing (MEC).

Recommendation 6. ERA should use its good offices to promote or encourage interaction between the operational rail communications community and the standards bodies responsible for technologies that are potentially of interest. Technologies where increased engagement may be warranted include the Open Wireless Architecture (OWA) and especially Software-Defined Radio (SDR), Network Functionality Virtualization (NFV), Software Defined Networks (SDN), and Multi-Access Edge Computing (MEC).

4.2.3 Standards and specifications

We limit the scope of our discussion in this standards and specifications section to on-board and trackside applications covered under the CCS TSI sub-systems of the Rail interoperability EU directive, namely ETCS and train voice radio.

4.2.3.1 The current situation

GSM-R is the communication standard in Europe for both ETCS and train voice radio applications.
CCS TSI Annex A refers to a set of mandatory specifications to which products for ETCS, train voice radio and GSM-R must comply. The work that has been delivered to publish those specifications has been completed by different railway organisations such as ERA, UNISIG, EEIG ERTMS Users Group, Morane, UIC, and the ROC Industry Group (former GSM-R industry group) with additional work on communication layers (i.e. GSM-R) from telco standardisation bodies such as ETSI and 3GPP.

The full list of mandatory specifications are available on the ERA website (http://www.era.europa.eu/Core-Activities/ERTMS/Pages/Current-Legal-Reference.aspx).

ETCS and train radio functional requirements are based on specific bearer features with direct references to standards and specifications features in the CCS TSI.

Moreover, most of those bearer features are implementation options in the communication standards. The consequence is that products compliant to railway standards and specifications are not commercial-off-the-shelf (COTS) products but additional options compared to MNO networks implementations already deployed for business to consumers purposes, with the effects of additional delays in standardisation and product availability, and additional cost within a niche market environment.

Finding 16. GSM-R has requirements beyond the standardised mandatory GSM capabilities required to support commercial mobile operations. The operational rail market is small, which implies that there is limited demand for equipment that can support GSM-R. This has led to delays in GSM-R standardisation and product availability, and additional cost within a niche market environment. Similar considerations might well apply to any future operational rail solutions that depend on specialised bearer-specific support in the transmission network.

4.2.3.2 Objectives to make BIC feasible

Current standards do not enable the full realisation of bearer independence. In order to make the concept feasible, a number of actions would need to be committed by the rail sector in terms of standards and specifications:

- **Functional requirements**
  The rail sector must specified functional requirements together with performance and security characteristics for each application without cross-references to any bearer. Security attributes must be defined. This issue will be addressed later in this report (refer to section 6.3.3.4).

- **Data connectivity**
  As previously outlined in the "system architecture" section, the convergent element of all kind of bearers is data connectivity. Infrastructure and networks must be seen as data pipes.
- **Mandatory set of standard features**
  If the bearers are considered to be simple data pipes, all features beyond basic data transmission that were previously implemented in the GSM-R standard must be supported by upper layers, on top of the transport layer. Each bearer would need to be defined in terms of basic, mandatory features of the corresponding communications standards without any optional features. This allows the use of commercial-off-the-shelf (COTS) communications products for on-board and infrastructure elements. Doing so reduces technical complexity and CAPEX, and helps to ensure product availability for early adopters.

We recommend that a gap analysis between functional railway requirements (i.e. User Requirement Specification – UIC FRMCS URS) and the common transport layer standard protocols (i.e. IP and above) be undertaken. This will help to identify the work that is left to be done by standards organisations in order to fill the gap. Regarding ETCS specifications, an internal interface such as a middleware between the Euroradio Safety Layer and the Euroradio Communication Layer should likely be further studied and specified by the rail sector.

Finding 17. Current standards do not enable the full realisation of bearer independence.

Recommendation 7. In order to ensure that standards are in place to enable the full realisation of bearer independence, ERA should use its good offices to ensure (1) that all relevant functional specifications are updated so as to eliminate dependence on bearer-specific capabilities beyond those embodied in basic transmission standards for most bearers; (2) that a gap analysis is conducted to identify capabilities that would need to be implemented at the Application Layer in order to provide necessary functionality going forward (presumably equivalent to that available under GSM-R today); and (3) that standards are developed that address the gaps identified. Where necessary and appropriate, ERA might ask the Commission to issue mandates to the European Standards Organisations (ESOs).

Recommendation 8. De-coupling of ETCS is called for, both in terms of specifications and of implementation. The introduction of middleware between the Euroradio Safety Layer and the Euroradio Communication Layer should be considered. ERA should consider launching studies as to how best to achieve the de-coupling.

4.3 Key challenges and opportunities

4.3.1 Key challenges

The biggest challenges when designing the future communication system architecture that we have identified and have to be overcome by industry to allow bearer independence are the following:

- **Voice communication services**

Voice communication service revenues are in decline for many MNOs, but voice services are crucial for operational rail communications.

Note that even if a shift to messaging is be expected in the future, it is likely that voice will still be considered as the most appropriate communication means in abnormal, degraded or danger situations.

Voice is used in unicast, broadcast and multicast modes of transmission. Traditional professional mobile radio voice services must be provided to railway users such as:

- ✓ **Group calls** with push-to-talk functionality: a set of users in an area can communicate to each other. Users need a token (via PTT feature) to have the right to talk, and thus to avoid confusion of all the noise in a multicast environment.
- ✓ **Priority and pre-emption**: categories of users are defined to allow priority to have the right to talk and pre-empt radio resources when maximum capacity has been reached.

Specific railway services must also be delivered such as:

- ✓ **Functional addressing:** railway users are identified by a functional identity instead of subscriber number or IP address. This functional identify is related to their role in the railway domain, such as train drivers.
- ✓ **Location dependent addressing:** train drivers should be able to communicate with appropriate ground dispatcher based on the train location. Dispatchers are responsible of their operational area. When trains are entering their area, they should be able to join the dispatcher without knowing their identity (e.g. subscriber number or IP address) but only using global functional identity such as "primary controller".
    - o The system must be able to provide high accuracy of train locations to guarantee detection of train on the right track. It must be accurate enough to distinguish between parallel or adjacent tracks, together with accurate detection in closed environment such as indoor sections or tunnels.

Today's solutions to deliver professional mobile radio and railway voice communication services are digital communication technology specifically design to meet operational rail requirements. Radio layers are specified to fulfil voice requirements, but they are not bearer independent.

This big challenge is addressed in the following paragraphs, highlighting briefly standardised and proprietary voice solutions such Voice over IP (VoIP), PTT over IP, Over-the-Top (OTT) communication services, application servers etc. Conditions for success are also addressed in the "ecosystem development" paragraph with special care on new entrants and recommendations on how to foster this ecosystem.

Key challenges include (1) reliability and (2) quality of service.

- **Reliability**

Many commercial IP-based networks are able to provide data services suitable to critical applications such as ETCS that require only low throughput; some struggle, however, to provide the necessary reliability and robustness,[13] while others may be unable to meet requirements for end-to-end latency. Delivering data pipes with high throughput capabilities is the main concern when designing IP-based MNO commercial services for consumers. The primary challenge for operational rail data connectivity is to guarantee quality of service for safety applications. This challenging issue will be addressed in the following chapters.

- **Quality of Service**

Quality of service (QoS) is another big challenge that must be addressed if bearer independence is to become a reality.

Mission-critical railway applications specify strong performance requirements with guaranteed QoS. *Note: Performance requirements of the railway radio communication system could be found in the UNISIG subset-093 document (definition of key performance indicators and how to measure them).*
In the concept of bearer independence, the transport layer has no control on the performance of the underlying bearers. The transport layer cannot influence and tune the radio layers to optimise performance when degradation of the radio link happens. It can only monitor the quality of each bearer by sending and receiving data, checking the quality of the link by comparing received datagrams with transmitted datagrams (i.e. similar to bit-error ratio).

Without any control over the performance of the underlying bearer, must it be viable for bearer independence to guarantee QoS at transport layer without guaranteed QoS at bearer level?

Is bearer independence concept possible without any private and specialised infrastructure to address mission-critical performance requirements?

The concept of bearer independence introduces new principles that need to be assessed deeply to address those challenges:

- ✓ **Broadband data pipes**: current broadband networks provide so much capacity that radio resources will never be exhausted. Broadband networks must be design with more capacity than needed, enabling all users to communicate simultaneously with sufficient voice quality (high definition voice codecs must be used, enabling lots of bits to be sent in the pipe) and low bit error rates (add many bits as possible with best error correction feature must be possible).
- ✓ **Redundancy**: the concept of bearer independence enables the use of redundant bearers, even when users are moving with dynamic and seamless handovers. This could be an answer to guaranteed connectivity and performance when one bearer becomes unavailable or degraded. This principle is also an alternative to avoid harmful interferences, one of the main issues of service degradation in the railway European field.

[13] In this context, *robustness* refers to the ability of a network to continue to deliver necessary services with as little degradation as possible, even when the network is under stress (due for instance to natural or man-made disasters).

- ✓ **Single access point**: the concept enables the use of a single access point for on-board applications. When applications need communication services, the single access point plays the role of arbitration by controlling which flow has the right to communicate, to get priority on and to pre-empt resources for priority users when radio resources are congested. This principle could be an alternative to infrastructure priority and pre-emption feature which are not allowed to be implemented by MNOs to give priority to "gold" users, which is one the principles of Net Neutrality.

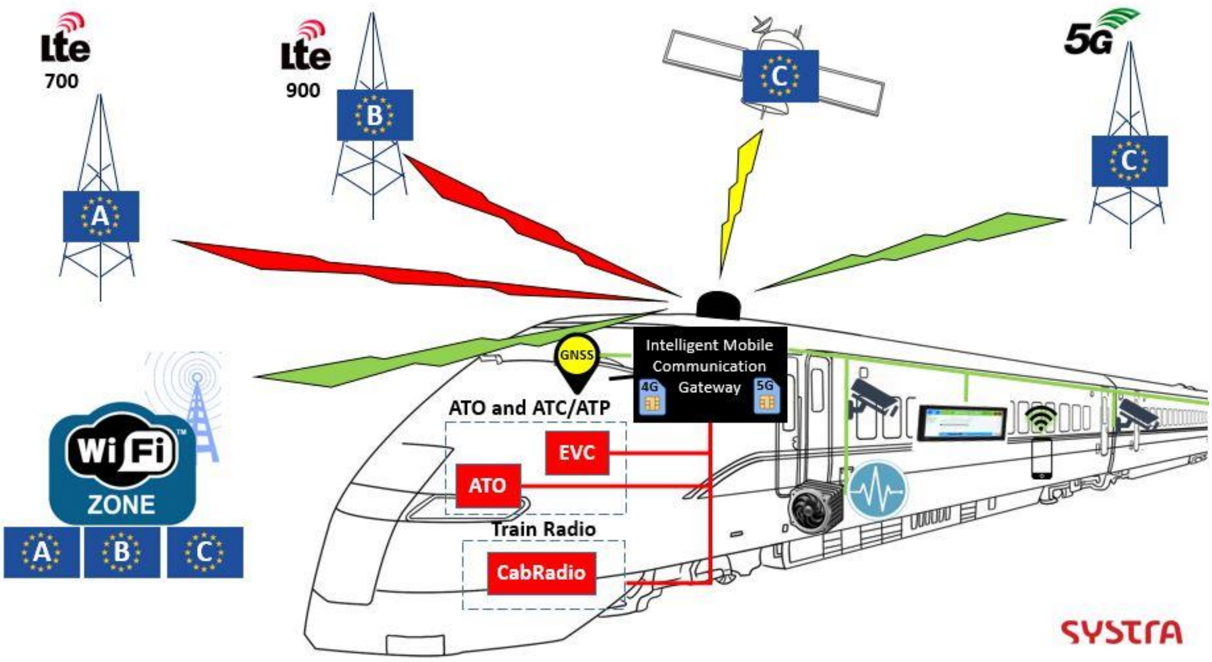


Figure 30. Example of BIC-capable on-board architecture with single-access point

- ✓ **Cognitive system**: the concept of bearer independence provides a cognitive mechanism similar to cognitive radios by means of monitoring radio signal quality of available bearers and switch to the best available bearer suitable to any application with communication needs. The on-board communication system architecture must provide such a cognitive capability as an alternative to improved receivers against interferences.

Finding 18. Current standards for many IP-based candidate bearers are potentially adequate for operational rail communications, once bearer-specific dependencies have been eliminated. Two areas that would nonetheless require intensive attention before incorporating any bearer into operational rail standards are (1) reliability and robustness requirements; and (2) QoS requirements, including end-to-end latency.

4.3.2 Opportunities for Railways

- Sharing communication and location resources (load-sharing, aggregation, guaranteed connectivity…) could bring benefits by reducing time to install, upgrade, maintain, remove on-board equipment. Reduce number of equipment to maintain by sharing key items (communication and location resources) and avoid unnecessary redundancy must be considered as a condition for success. Facilitate installation, maintenance, and evolution of system architecture must be key requirements of the maintainability of the system in the context of BIC.
- Convergent plug-and-play architecture for all on-board railway needs with industrial requirements on lifecycles of railway systems and Information and Communication technologies (digital market). Convergence with other railway users and urban stakeholders by fostering cooperation with CEN/CENELEC ICT standardisation working groups.
- Using standard protocols and internet technologies to reduce CAPEX and OPEX, and generate cost saving.
- Open competition in a setting that encourages innovation and avoid vendor lock-in.
- On-board architecture specified in terms of services to decouple applications from communications (Service-Oriented Architecture).

Modular architecture must also be considered for radio features. With the emerging era of softwarisation, scalability (i.e. replacement or adding a new bearer to on-board system) must be considered for hardware as well as software components. Software portability to target hardware on-board communication devices from a multi-vendor ecosystem must also be considered in the on-board communication system architecture. Software Communications Architecture (SCA) as the one published by the Joint Tactical Networking Center (JTNC), middleware or virtual machines solutions could be key enablers to provide software portability and scalability.

4.4 Potential characteristics of bearer independent architecture and standards

In this section, we summarise characteristics of bearer-independent architecture that have been stated or implied in this chapter and elsewhere in this report.

4.4.1 Principles to which a bearer independent architecture should adhere

For both infrastructure and on-board, application and bearer specifications should be independent of one another.

Applications must be based on IP. This implies that bearers should be packet-based technology supporting the transmission of IP datagrams (with suitable reliability, robustness, and security).

Independence applies to all railway operational applications (critical, performance and business categories) and implies that ETCS, train voice radio, shunting specifications must not depend on any specific bearer.

However, bearer independence communication should continue to ensure interoperability throughout Europe. Interoperability concerns both applications and the legal framework.

The following principles should be considered:

- ✓ Multiple bearers must be suitable for a given application.
- ✓ The need for support of multiple, but limited number of, technologies. Scalability needs to be considered.
- ✓ Flexibility has to be provided when a new bearer is introduced. A new bearer must not necessitate changes in the application framework. The product roadmaps and life cycles of the different communication technologies must also be considered when introducing support of multiple bearers. The coexistence of many generations of multiple technology standards may need to be considered when defining the system architecture.
- ✓ At least one appropriate bearer must be available wherever and whenever an application needs communication services.
- ✓ Specific rail services (functional numbering, location based services…) must be provided. Since bearer-specific implementation is excluded, equivalent functionality is likely to be needed at the Application Layer.

4.4.2 Desirable characteristics of bearer independent systems architecture

The bearer independent architecture should in our judgment be designed with the following desirable characteristics in mind in light of ongoing technological and market evolution (as per the standards and initiatives analysed previously, such as IEC and ITxPT):

- ✓ Interoperable, standard and open, modular and scalable, portable,
- ✓ Easy to maintain, to improve/make evolve (hardware and software),
- ✓ Easy to replace by another type of equipment (hardware and software),
- ✓ Reliable, available.
- ✓ Secure
- ✓ Remotely manageable (S/W upgrade, telematics)
- ✓ Sustainable
- ✓ Cost-effective

4.5 Findings

Several of the findings in this chapter have to do with the relative role of the conservative approach to bearer independence (based on optional 3GPP capabilities) versus the flexible view (which envisions a broader set of bearers, and rejects limiting solutions to bearers that have rail-specific capabilities). Other findings deal with potential or emerging technological developments that may potentially be of interest in implementing bearer independence. The remaining findings deal with implications for the development of standards relevant to bearer independence.

A first findings relates to the capabilities of the Mission-Critical Push-to-Talk (MCPTT) functionality that is an optional function in 3GPP Release 13 standards.

Finding 4. Operational rail communications could potentially take advantage of the Mission-Critical Push-to-Talk (MCPTT) functionality that is an optional function in 3GPP Release 13 standards. It is unlikely, however, that Mobile Network Operators (MNOs) will deploy MCPTT unless they perceive sufficient demand for it from PPDR and/or operational rail. If MNOs do not demand these features, manufacturers will not implement them.

The next few findings address the conservative view versus the flexible view.

Finding 5. Stakeholders tend to gravitate to one of two architectural models of multi-bearer support. The *conservative view* is based on 3GPP standards, and on services similar to those offered by Mobile Network Operators (MNOs). The *flexible view* is based on Over-the-Top (OTT) services using IETF and IEEE standards, and thereby potentially expands the set of bearers to include bearers such as Wi-Fi and satellite.

Finding 6. Full realisation of the flexible view would likely require the definition of new standards and protocols, with careful attention paid to performance and security. The bearers and applications are no longer bound to one another, but they effectively become an ecosystem where functionality and interoperability must be carefully planned for.

Finding 7. Whether the conservative or the flexible view is ultimately followed, revisions to the various European instruments that ensure interoperability of rail communications (notably including the Technical Specifications for Interoperability (TSI)) are likely to be required.

Finding 8. The flexible solution should be preferred in the medium to long term. Only the flexible solution offers full bearer independence. It is the solution that is most attuned to the likely long term evolution of the commercial market, where bearer independence has been taken for granted for many years. Moreover, the flexible solution is best positioned to support non-3GPP bearers such as Wi-Fi or SatCom in the medium or long term. It is the flexible solution that offers the broadest possibility to evolve operational rail communications over time.

Finding 9. Short term implementation of the conservative view can be thought of as a stepping stone on the way to realisation of the flexible view. 3GPP-based solutions become one solution out of many.

Finding 10. With bearer independence, we are seeking to deliver both voice and data operational rail communication services independently of underlying bearer-specific features. Today, it is routine for commercial data services to be fully bearer independent, and for voice services to ride on top of the bearer independent data services (as Voice over IP (VoIP)). This is the most natural approach for bearer independent operational rail communications to take.

The next group of findings relate to potential or emerging technologies that offer promise as regards the implementation of bearer independent operational rail communications.

Finding 11. The IEC TCN communications architecture represents a valuable input as regards the safety of train operations.

Finding 12. The ITxPT initiative provides a full ecosystem to deliver on-board plug-and-play IT systems to avoid vendor lock-in and foster the implementation of a standard IT on-board architecture.

Finding 13. The First Responder Network Authority (FirstNet) that the US is in the process of deploying represents an interesting working example of a single network that provides communication services to both mission-critical safety and other non-mission-critical applications.

Finding 14. Cooperative-ITS (C-ITS) is an Intelligent Transportation initiative that seeks to provide communication services between vehicles, infrastructures and other road users. It incorporates many of the same capabilities as those that are sought for bearer independent operational rail communications, including support for multiple bearers, transparent mobility management, and shared network resources.

Finding 15. Several emerging or developing technologies hold promise for the evolution of operational rail communications by potentially facilitating flexibility and infrastructure sharing. Among those that could be of interest are Open Wireless Architecture (OWA) and especially Software-Defined Radio (SDR), Network Functionality Virtualization (NFV), Software Defined Networks (SDN), and Multi Access Edge Computing (MEC).

Finally, a group of findings consider the standards process, and the limited effectiveness of optional extensions to standards where the market opportunity is small (as is the case for operational rail).

Finding 16. GSM-R has requirements beyond the standardised mandatory GSM capabilities required to support commercial mobile operations. The operational rail market is small, which implies that there is limited demand for equipment that can support GSM-R. This has led to delays in GSM-R standardisation and product availability, and additional cost within a niche market environment. Similar considerations might well apply to any future operational rail solutions that depend on specialised bearer-specific support in the transmission network.

Finding 17. Current standards do not enable the full realisation of bearer independence.

Finding 18. Current standards for many IP-based candidate bearers are potentially adequate for operational rail communications, once bearer-specific dependencies have been eliminated. Two areas that would nonetheless require intensive attention before incorporating any bearer into operational rail standards are (1) reliability and robustness requirements; and (2) QoS requirements, including end-to-end latency.

4.6 Recommendations

This report was prepared on behalf of the European Rail Agency (although it does not necessarily represent their opinion). Consequently, our recommendations are addressed to ERA.

In the standards arena, ERA's mandate is somewhat limited. ERA could in principle ask the Commission to issue mandates to the European Standards Organisations (ESOs), notably to ETSI or (for spectrum) to the CEPT. Through the CCS TSI, can delineate requirements for IMs and RUs, which may motivate these stakeholders to engage in standards activities.

Our sense is, however, that ERA carries substantial moral authority in this space. In the recommendations, when we refer to ERA's "good offices", we mean to say that ERA can be effective in promoting or encouraging actions even in areas where ERA may not have formal authority. In other recommendations, we implicitly rely on ERA's moral authority.

The first group of recommendations that we put forward relate to potential or emerging technologies that may be of interest.

Recommendation 1. The IEC TCN communication architecture may represent a good basis on which to design additional rail safety operations. Collaboration with IEC members should be considered in order to avoid redundant work on train to ground communication systems.

Recommendation 2. Lessons learned from initiatives such as the ITxPT initiative should be considered by the rail sector as a means of overcoming the challenges of implementing SOA models.

Recommendation 3. Lessons learned from initiatives such as the First Responder Network Authority (FirstNet) that the US is in the process of being deploying should be considered by the rail sector as a means of overcoming the challenges of implementing a single network that supports both mission-critical and non-mission-critical services.

Recommendation 4. Lessons learned from initiatives such as the Cooperative-ITS (C-ITS) initiative should be considered by the rail sector as a means of overcoming the challenges of implementing bearer independent mission-critical communications.

Recommendation 5. ERA should consider more detailed study of various network designs that are either being implemented or else are under consideration to determine the degree to which lessons learned are potentially applicable to European operational rail communications. Candidates for further study include the ITxPT initiative, FirstNet in the US, and the Cooperative-ITS (C-ITS) initiative.

Recommendation 6. ERA should use its good offices to promote or encourage interaction between the operational rail communications community and the standards bodies responsible for technologies that are potentially of interest. Technologies where increased engagement may be warranted include the Open Wireless Architecture (OWA) and especially Software-Defined Radio (SDR), Network Functionality Virtualization (NFV), Software Defined Networks (SDN), and Multi-Access Edge Computing (MEC).

The last recommendation is a key finding for the study as a whole. Existing standards efforts are not sufficient in and of themselves to achieve full bearer independence. ERA must exercise leadership in order to promote or encourage the actions that are necessary.

Recommendation 7. In order to ensure that standards are in place to enable the full realisation of bearer independence, ERA should use its good offices to ensure (1) that all relevant functional specifications are updated so as to eliminate dependence on bearer-specific capabilities beyond those embodied in basic transmission standards for most bearers; (2) that a gap analysis is conducted to identify capabilities that would need to be implemented at the Application Layer in order to provide necessary functionality going forward (presumably equivalent to that available under GSM-R today); and (3) that standards are developed that address the gaps identified. Where necessary and appropriate, ERA might ask the Commission to issue mandates to the European Standards Organisations (ESOs).

A last recommendation deals specifically with ETCS.

Recommendation 8. De-coupling of ETCS is called for, both in terms of specifications and of implementation. The introduction of middleware between the Euroradio Safety Layer and the Euroradio Communication Layer should be considered. ERA should consider launching studies as to how best to achieve the de-coupling.

5. GUARANTEED CONNECTIVITY

For the Bearer Independence Communication Concept to work every application needs to be able to send and receive traffic flows at any given time and at any given location with a guaranteed minimum level of service in terms of radio coverage and performance including spectrum, and security. This chapter focusses on this condition for success of the concept and is structured in the following manner:

- Conditions and areas of study
- Setting the scene
- Key challenges (and opportunities, if any)
- Findings and recommendations

Table 14 below presents the scope of the condition.

2	GUARANTEED CONNECTIVITY	Radio coverage	Traffic and QoS	Spectrum
		Security-Availability *(incl. priority and preemption)*		Legal obligations

Table 14. **Scope of Guaranteed Connectivity**

5.1 Conditions and areas of study

This chapter will assess the Guaranteed Connectivity to understand why it is a condition for success of the bearer independent communication concept. Areas of study which are impacted by the Guaranteed Connectivity are outlined in the Table 15 (marked with an "X"):

	Vehicles	Spectrum	Infrastructure	Legal framework	Security aspects
Guaranteed Connectivity	X	X	X	X	X

Table 15. **Areas of study of the Guaranteed Connectivity condition**

5.2 Setting the scene

The aim of Guaranteed Connectivity under BIC is to offer an appropriate bearer for defined application communication. This bearer should be available and reliable wherever and whenever an application needs communication services. The same bearer must be used by all end-users of a single application (different on-board systems) if direct communication is to be considered without the assistance of the infrastructure.

Moreover, if an operational area is covered by more than one bearer for a single application, the concept needs to ensure a guaranteed connectivity between all users of a single application (mobile, fixed users, and all system entities) when using different bearers for each on-board system based on infrastructure transmission (no direct links between on-board systems).

The challenges for BIC is to provide for every application the possibility to send and receive traffic flows at any given time and at any given location with a guaranteed minimum level of service in terms of radio coverage, performance and security.

Challenges that are related to BIC and addressed in this section are:

- Radio coverage issue
- Spectrum issue
- Traffic Management
- Guarantee and Quality of Service
- Availability
- Legal aspect

5.3 Key challenges and opportunities

The key challenges and opportunities in ensuring guaranteed connectivity for applications are varied and include the following:

- Radio coverage – how coverage is provided including network ownership models.
- Spectrum – the implications of frequency allocation on on-board architecture, interference.
- Quality of service - not only in terms of speed, bandwidth, and end-to-end latency, but also in terms of reliability and robustness.
- Security - from an availability of service point of view, including of the use of dedicated networks versus public networks.
- Legal obligations – on network neutrality rules, on operational rail communications, and on passenger communications.
- Availability of additional capacity in areas where there is limited spectrum

5.3.1 Radio coverage

In radio communication, a key factor in designing a radio network is radio coverage requirement. For the rail sector, radio coverage are mainly driven by safety and performance requirements of critical applications (e.g. ETCS and train radio). Radio coverage requirements allow communication services whenever and wherever needed with appropriate levels of service. Designing of a radio network through faulty radio coverage requirements potentially leads to a degraded level of service with increased bit-error-ratio or poor signal quality.

Radio coverage is a key issue for the Bearer Independent Concept in order to offer connectivity in all environments. For train operations, railways required extensive coverage in urban areas such as tunnels and railways stations, and in rural areas along the tracks. Spectrum bandwidth and spectrum bands have a direct impact on the coverage through the number of sites required to ensure sufficient coverage. The higher is the frequency band, the greater the number of radios required to provide the same coverage.

As shown in the previous ERA study on Migration, radio coverage represents the greatest part of CAPEX in a radio network through the number of sites. The concept needs to ensure coverage of rail lines for operational rail requirements, and for passenger services with the most cost effective solutions.

Multi bearer access or a same bearer in different bands can in that way offer extensive radio coverage in particular according to the requested applications requirements (mission critical voice and ETCS, performance and business). Some applications such as voice mission critical require a low throughput but a continuous and reliable coverage with very low latency. On the contrary, business applications require very high throughput but can accept compromises on coverage or reliability. In that sense available bearers are selected according to quality of service requirements and communication profiles, including coverage and availability.

5.3.1.1 Means of obtaining coverage

The means of ensuring coverage are likely to vary depending on (1) whether we are talking about rail operational communications versus rail passenger services, and (2) whether the Member State has chosen to support rail operational communications using a private, dedicated network, a private network shared with other mission-critical applications such as PPDR, or a public commercial network provided by an MNO.

For a dedicated network, whether dedicated exclusively to rail or shared with other mission-critical uses, it is the Member State's responsibility to ensure that the network is deployed. Any funding has to comply with applicable State Aid rules, including the guidance as to how to apply State Aid rules to rail services. Operational rail communications will in many cases qualify as a Service of General Economic Interest (SGEI), in which case many of the rules do not apply.

If a commercial Mobile Network Operator (MNO) is to provide services, particular attention must be paid to State Aid rules. Typically, it will be necessary to ensure that the provider is selected in a fair, objective and transparent way, typically by means of a (reverse) auction, which is in effect a public procurement.

Regarding MNOs as service providers of rail operational communications and passenger services, it should be noted that the European Commission proposed in its action plan for 5G that public services (including railways) should be promoters of 5G connectivity by migrating their operational services from legacy proprietary communication platforms (GSM-R is quoted) to commercial 5G platforms which will provide more secure, resilient and reliable networks. Member States will be the promoters of 5G shared connectivity solutions for the public sector.

The requirement to ensure compliance with State Aid rules applies in principal whether the network is used only for operational rail communications or also for passenger services; however, passenger services raise many additional issues, particularly in as much as the bandwidth requirements are likely to be vastly greater than those for operational rail communications.

If the responsible operator is chosen by means of an auction, then coverage can be assured by means of the auction conditions.

For passenger rail broadband communications and information services, an alternative would be to ensure that commercial MNOs serve train routes with conventional service. This has historically been adequate for typical regional service or considered as fall-back systems, but might not deal well with high speed lines; moreover, passengers increasingly expect the Train Operator Companies (TOC) or MNOs to provide communication services (voice calls and Internet) during on-board journey's experience. There are many technical solutions to provide Broadband communications service to rail passengers including direct to device solutions (3G/4G), Hybrid solutions with Wi-Fi on-board for passengers and MNO or SatCom services gateway with roof-top antennas (with limited voice calls services by providing only VoIP services), on-train 3G/4G small cells… These expectations would tend to require specialised services like on-board gateways that would likely need to be procured by the RU or far less likely by the IM.

In any case, if the Member State wishes to ensure that rail lines are served, the simplest mechanism is to include the requirement as an obligation at the time that spectrum for mobile services including broadband (so-called WAPECS spectrum) is auctioned off. There is ample precedent for Member States imposing coverage conditions so as to ensure that highways and rail lines are covered.

As an example, the French 700 MHz band allocation process included new obligations aimed at improving mobile data availability on everyday trains. These obligations will be complemented by more stringent quality of service requirements for all railway lines (including high-speed lines) and underground lines in order to encourage MNOs to increase the quality of service they provide.[14] The study must examine current and foreseen legal obligations by Member States or at EU level to cover Rail lines to provide internet services and information to passengers. The study must then examine impact on responsibility perimeter and cost for Railway community (Railway Undertakings and Infrastructure Manager) to provide those services to passengers.

Most Member States will be auctioning WAPECS spectrum in the 700 MHz band between now and 2020 (or possibly 2022). Railways and public transport benefit from that target. Since multiple bands might be auctioned at the same time in a given Member State, it might be important to determine requirements for all band auctioned at the same time, and not just the 700 MHz band.

[14] ARCEP (the French National Regulatory Authority (NRA)), Autorité de Régulation des Communications Electroniques et des Postes

Finding 19. Coverage is a fundamental requirement for operational rail communications. Ensuring coverage is a task for policymakers – it is not something that can be left to market mechanisms.

Finding 20. Whether dedicated spectrum is required for operational rail communications depends on whether the Member State has chosen to support rail operational communications using a private, dedicated network, a private network shared with other mission-critical applications such as PPDR, or a public commercial network provided by an MNO.

Finding 21. If the Member State has chosen an approach to operational rail or passenger rail communications where coverage of rail routes by one or more commercial MNOs is needed, this could be achieved by means of coverage obligations in a future spectrum auction (for example, in the coming auctions for 700 MHz spectrum).

Finding 22. For a dedicated network, whether dedicated exclusively to rail or shared with other mission-critical uses, it is the Member State's responsibility to ensure that the network is deployed.

5.3.2 Spectrum

5.3.2.1 Spectrum options

Following the development of the key principles of the BIC concept, we can address the spectrum issues regarding current and future needs to make the BIC concept feasible. There is no additional spectrum designated for railways and currently the 4G standard does not include current spectrum used for GSM-R (876 MHz - 880 MHz for uplink and - 921 MHz - 925 MHz for downlink). The interaction with 3GPP standards is likely to be important particularly where LTE can support railway functional requirements with a sufficient quality of service, high-speed mobility for voice and data service.

This part of the analysis has to be somewhat tentative, since many decisions have yet to be made. Flexibility of on-board architecture (e.g. using Software Defined Radio (SDR)) has obvious merit, since it avoids the need to physically overhaul the train (but probably not the need to test the correctness of the new software). We consider implications of the use of PPDR bands, not only those currently in use but also additional spectrum that might be made available in some Member States (for instance, in the 700 MHz band). If bearer independent equipment is used over commercial mobile networks, then some of the spectrum assignments of the commercial mobile networks must be supported by on-board equipment. Modern mobile handsets automatically switch among many bands, so this requirement does not necessarily constitute a problem; still, the number of bands that can be supported is not unbounded. It is ultimately limited by the antenna design and by the capabilities of the chipset in the mobile device.

In addition to former wide bandwidths (5, 10 or 20 MHz), LTE now integrates smaller bandwidths (3 MHz, 1,4 MHz) particularly for security services, and even smaller with a bandwidth as narrow as 200 kHz to provide connectivity for cellular Internet of Things devices with such technologies as LTE-M or NB-IoT. The smaller the bandwidth, the lower the data rates that can be achieved.

Critical applications such as ETCS and train radio need only low data rates. The requested spectrum bandwidth and the traffic volume will mostly be influenced by the number of users and devices in a single area.

As indicated in question 2 on spectrum conditions in ERA's tender specifications, point raised in (e), a possible deployment strategy considers 1,4 MHz at first and then 3 MHz for railway services. In this situation, geographical separation or guard band should be defined.

During the study, questions related to how things work during a parallel operation scenario are taken into consideration with the help of the frequency study carried out by LS Telcom in the case of GSM-R band use.

The points raised in (b) about possible stringent hardware specifications on the radio terminal side are crucial. Better emission masks compared to the commercial sector can be required and to what extent can better quality / greater selectivity in the receiver ease constraints. Industry can help to answer such questions. By comparison, we know that railways already deal with such situations with protective filters/improved radio modules in the case of coexistence between GSM-R and 3G / 4G systems in the 900 MHz band.

To address question (d) above on extreme spectrum scenarios, consideration on cell borders are required as well as near/far problems. All such issues need to be addressed in border crossing meetings and agreements.

It may be interesting to a certain extent to check the possibility of using wider bands for some new services or under certain circumstances (for example non-critical services offered by MMO networks).

An additional consideration can be made on 5G according to the fact that the European Commission, through the Radio Spectrum Policy Group, would also like to consider a harmonised band below 1 GHz, including particularly the 700 MHz band, in order to enable nationwide and indoor 5G coverage.

To go deeper on this subject, it is important to underline that concerning spectrum needs, availability and management for railway applications from critical to business categories are essential for the BIC concept. Spectrum usage and management have to be more flexible than the ones used in GSM-R to make BIC concept feasible for railways. As spectrum is a scarce and expensive resource many international and European institutions are looking together to optimise spectrum usage for the mobile broadband industry.

Railway spectrum needs required in ETSI TR 103 333 "System reference document (SRDoc); GSM-R networks evolution" are considered as an input data to address spectrum options relevant for BIC.

The following spectrum challenges and options are available now and need to be evaluated if relevant for BIC use cases:

- **Spectrum Access Schemes:** current and foreseen spectrum access schemes need to be analysed and classified into railway categories (valid or not for railway BIC). Coordinators from National Regulatory Authorities (NRA), ECC/CEPT and some research and innovation projects like METIS-II project of the 5G Infrastructure Public Private Partnership (5G PPP) must be interviewed and/or deliverables must be studied to define an exhaustive list of Spectrum Access Schemes:

- **Licensed** (exclusive use, Licensed Shared Access – LSA, …)
- **Unlicensed** (shared access, combined like Licensed Assisted Access – LAA)
- **Network Models**: ownership and control of networks have already been addressed by ERA in the study on the evolution of GSM-R, performed by IDATE/WIK in 2015. This study is an input in the evaluation of network model into railway categories (valid or not for railway BIC).
- **Radio Access Technologies (RAT):** The mobile broadband industry is much more dynamic than the railway one. 4G networks have already been rolled out by mobile network operators across Europe with broadband data available to each of us with a commercial smartphone. These smartphones are backward compatible with 2G and 3G RAT (handovers are possible between different Radio Access Technologies with seamless mobility). 3GPP and non-3GPP current and foreseen standards need to be evaluated into railway categories (valid or not for railway BIC):
  - ✓ LTE-Advanced from 3GPP Release 10 and beyond
  - ✓ LTE-Advanced Pro from 3GPP Release 13 and beyond in line with Public Safety needs (push-to-talk, group communications, Direct Mode, low latency, LTE ecosystem…)
  - ✓ 5G from 3GPP Release 15 and beyond. ETSI TC RT N2GR and 3GPP have already agreed on a Work Item (WI) to introduce Future Railway Mobile Communication System needs in Release 15. This WI must be followed.
  - ✓ Research groups involved in spectrum innovations for the definition of future 5G Mobile Networks. Some 5G PPP research groups introducing cognitive and software-defined radios must be followed. FANTASTIC-5G project aims to define a new air interface considering mission-critical communications and targeting 3GPP Release 14. ERA considers use of cognitive radios for railways as a risk (following discussion with the rail industry on cognitive radio market trends).
- **Frequency Bands:** Frequency bands used by railways, PPDR, PMR/PAMR users around the world, but also bands used by MNO must be considered. Single frequency bands, multiple frequency bands, bandwidth needs, paired vs. unpaired together with Supplementary Downlink (SDL) must be analysed and classified into railway categories (valid or not for railway BIC). Deliverables and papers from ITU World Radio Conferences, ECC-CEPT Frequency working groups, PPDR institutions like Public Safety Communication Europe or the BROADMAP project (Mapping Interoperable EU PPDR Broadband Communication Applications and Technology), BEREC and AGURRE must be studied. FRMCS Spectrum group (FRMCS-SP) has already delivered the bandwidth needs for current mandatory applications (critical applications) and is an input to evaluate frequency bands options. A list for candidate frequency bands could be relevant for on-board equipment.

Spectrum options that are considered relevant for BIC could be put into two main categories:

1. Spectrum harmonisation at a European level
    a. New band
    b. Refarming of GSM-R band
2. No spectrum harmonisation

These categories will be developed with spectrum licensing regimes:

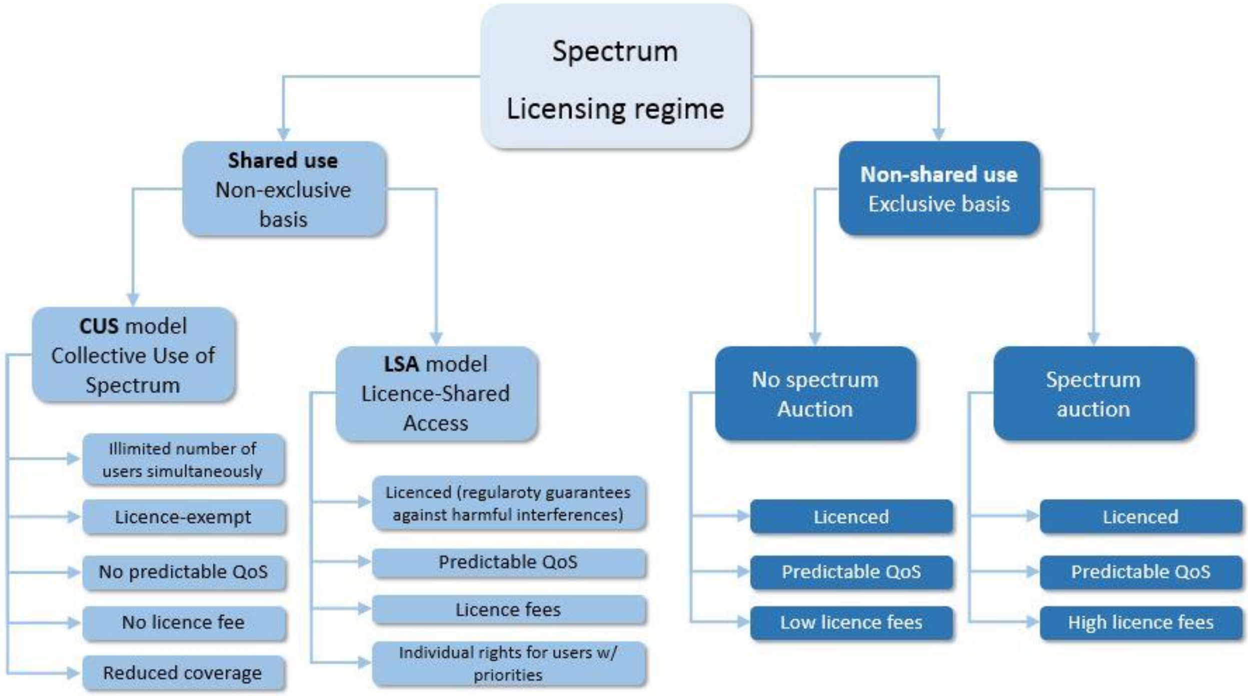


Figure 31. Spectrum licensing

Spectrum options will be assessed by the new Project Team (PT FM#56) dedicated to FRMCS spectrum needs that has been created by ECC WG FM in 2017. The FM#56 work plan has been agreed recently by the group, to be completed before the next WRC in 2019, in order to help to define the CEPT/ECC position on future railway communications (refer to agenda item 1.11).

One of the action of the FM#56 work plan is to evaluate the candidate bands for the implementation of the successor to GSM-R in an ECC report with inputs from other ECC WG such as WG SE.

Finding 23. The spectrum currently used for GSM-R is 876 MHz - 880 MHz for uplink, and 921 MHz - 925 MHz for downlink. The 4G mobile standards do not include these GSM-R bands. No additional spectrum has yet been designated for railways in Europe (to deal with migration to a successor to GSM-R, for example, for Member States that deploy dedicated networks). Many questions are not yet resolved as to how to best address the future evolution of operational rail communications, but efforts to resolve them are already under way by the ECC Frequency Management Working Group.

5.3.2.2 Implications of spectrum options

5.3.2.2.1 On-board architecture

The designation of frequency bands suitable for critical railway applications in Europe must be established to address:

- the limited relative technical complexity of on-board architecture,
- the cost of on-board equipment if multiple modems are needed to cross borders,
- the co-existence studies with other services,
- the early and late adopters migration scenarios,
- Others interoperability issues.

Promoting designation of already standardised spectrum bands and technologies by using commercial off-the-shelf modems could significantly reduce the complexity, the cost and the availability of certified on-board radio equipment by taking advantage of economies of scale.

Promoting synergies with other non-critical railway applications (e.g. energy measurement, telemetry) to address communication needs could reduce the cost of infrastructure and on-board radio equipment, but special care on technical complexity should be taken when designing on-board architecture.

Encouraging railways to take advantage of reconfigurable radio systems could be a catalyst for the adoption of BIC by enabling the on-board radio equipment to operate in a highly heterogeneous and evolving context (e.g. different lifecycles from signalling and telecom industries). It could simplify the migration scenarios for early and late adopters. Late adopters could introduce new spectrum options at a later stage. Introduction of new radio software implies new security requirements and analysis of recent regulations changes in the context of the European Radio Equipment Directive (RED) that should be studied.

The evolution of existing on-board architecture is a pre-condition for success of BIC to address the flexibility of using different spectrum bands and different technologies in a highly heterogeneous and evolving environment.

5.3.2.2.2 Interference

Improved receivers and spectrum emission masks can be standardised if and only if spectrum is harmonised at European level. If spectrum is not harmonised, standardisation of improved receivers and spectrum emission mask for all spectrum options could not be addressed (i.e. too many options).

Finding 24. Spectrum options relevant for BIC provides a patchwork of models from legacy GSM-R model to a fully operated network model. This patchwork could be a major brake of putting into service standardised interference resilient products. Harmonised spectrum for railway applications could provide a framework to standardisation of interference resilient equipment, thus answering reliability figures of the FRMCS.

Other ways of mitigating interference could potentially be introduced with BIC such as potential benefits of duplication and failover principles to manage traffic flows in a smart way, or Reconfigurable Radio Systems (flexible radio concepts like Cognitive Radios, Software-Defined Radios, Licensed Shared Access or Radio Virtual Machine for smartphones) bringing solutions to interference issues by self-adapting to a dynamically changing radio environment.

BIC could avoid interference coordination between the Railways, commercial MNO and the National Regulatory Authority (NRA).

Promoting BIC use (including support of multiple bearers in parallel such as duplication or failover as presented in Section 5.3.3) and Reconfigurable Radio Systems could bring major benefits on managing interferences by self-adapting to a dynamically changing radio environment.

5.3.3 Support of multiple bearers in parallel

The concept of BIC introduces a new way of managing traffic flows from a single application. This new concept enable QoS management at upper layers, independently of the changing radio environment.

As requested by many stakeholders and also expressed by the European Commission in the Commission staff working document on the state of play of the implementation of the ERTMS deployment plan, **one single bearer could handle multiple applications' flows simultaneously**, as expressed below by the European Commission staff working document on the state of play of the implementation of the ERTMS deployment plan:

> "The future ETCS data communication bearer could also **be used by other applications**. It should not be designed in isolation". *Source: EC SWD(2014) 48*.

In addition to that key principle, most of the stakeholders request a new principle to be developed: an application must be able to use one or **several bearers simultaneously**. Different ways of implementing simultaneous bearers depend on application performance objectives.

The main traffic and QoS management models available in telecommunication word are described in following paragraphs.

5.3.3.1 *Load-Balancing and Link Aggregation*

In this use case, an application communication flow is separated between multiple bearers simultaneously.

Load-balancing differs from link aggregation in that load-balancing divides the communication flow between multiple bearers while link aggregation combines multiple bearers to increase throughput.

Load-balancing and link aggregation aims to optimize resource use, increase bandwidth, increase availability and reliability.

An operational use case could be that ATO needs to transfer a high volume of video using simultaneous bearers to transfer the flow with appropriate performance (delay in this case) by increasing throughput.

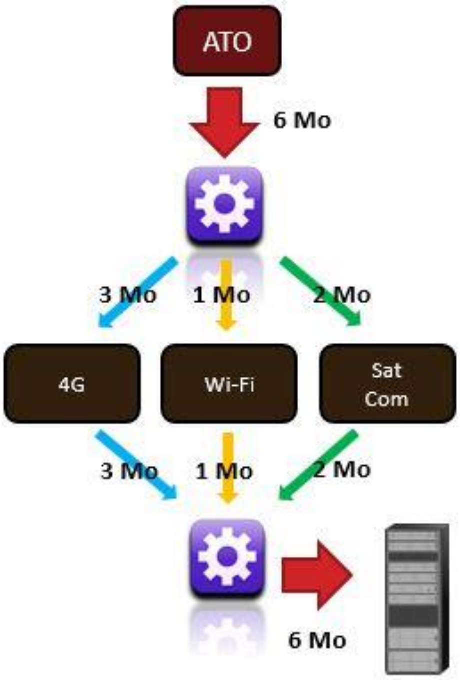


Figure 32. Load-balancing use case

5.3.3.2 *Duplication*

Some stakeholders expressed the need to duplicate data traffic to provide resilient communications against electromagnetic attacks. The duplication use case duplicates or mirrors the same application communication flow through multiple bearers to avoid any type of service interruption (handover or handoff, delayed data packets) or bad quality of service (robustness to electromagnetic attacks).

An operational use case could be that a solution to harmful interferences could be implemented by defining a resilient communication architecture instead of developing static protection standards or coordination/cooperation process and guidelines for the dialogue amongst administrations as well as GSM-R and MNO licensees.

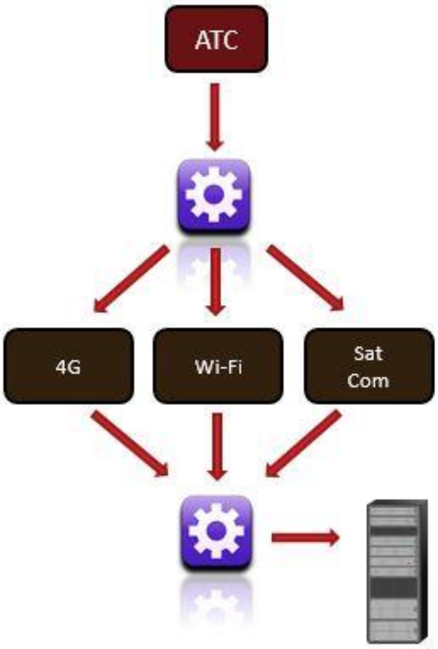


Figure 33. Duplication use case

5.3.3.3 Service Transfer

This use case shows that an application communication could move among multiple connections according to railway or network operators' traffic policies.

Many operational use cases might be considered:

- ✓ A train has stopped at a depot. The train driver initiates a voice call to his business operational centre through a WLAN bearer (VoIP/SIP). The train is automatically sending video recordings (CCTV security videos) to the recording server through WLAN. The WLAN becomes congested due to many file transfers. Therefore, the train radio voice call is automatically moved to a 3G connection transparently to the train driver (as a minimum, no connection loss).

- ✓ A train is moving from country A to country B. Train driver initiates a voice call to his country A dispatcher through a MNO 4G bearer using VoLTE. The train is moving across borders. The 4G bearer is not rolled out in country B but 2G (e.g. GSM-R) bearer is available. The train radio voice call is automatically moved to the 2G connection transparently to the train driver (as a minimum, no connection loss).

- ✓ Railway operators considered 4G bearer as the preferred bearer for ATC. They also considered SatCom as a secondary bearer with degraded level of service (but acceptable). If ATC communication is needed when only SatCom bearer is available, the communication is established through SatCom. When a 4G bearer becomes available, the ATC communication flow is automatically switched to the 4G bearer with minimized service interruption, even if SatCom is still available with sufficient level of service (priority traffic policy).

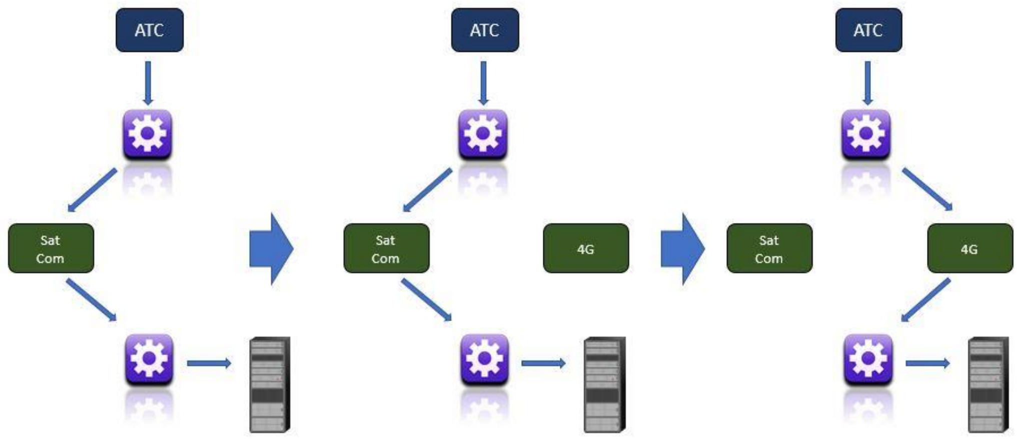


Figure 34. Service transfer use case

5.3.3.4 Failover

In this use case, an application communication flow is automatically switched to a standby bearer upon failure, congestion, or degradation of level of service of the previously active bearer.

Failover aims to increase availability and reliability whilst minimizing service interruption.

An operational use case could be that ATC is using Satellite communication (SatCom) in rural area as an active bearer. In that use case, SatCom is considered as the preferred bearer for ATC. A 4G network is also available but considered as a backup bearer (secondary option). Upon failure or congestion of the active bearer (criteria for failures should be identify among any hardware failures, interferences, degradation of performance to a certain threshold, etc.), the ATC communication flow is switched to the standby bearer which becomes active. The main objective is to provide guaranteed connectivity for mission-critical applications.

The failure or congestion detection could be either:

- ✓ **Corrective**: when a failure or a congestion status (no more resource available) has been detected, the selection is activated.
- ✓ **Predictive**: when the degree of congestion has exceeded a certain threshold with a certain probability of congested bearer in near future, the selection is activated.

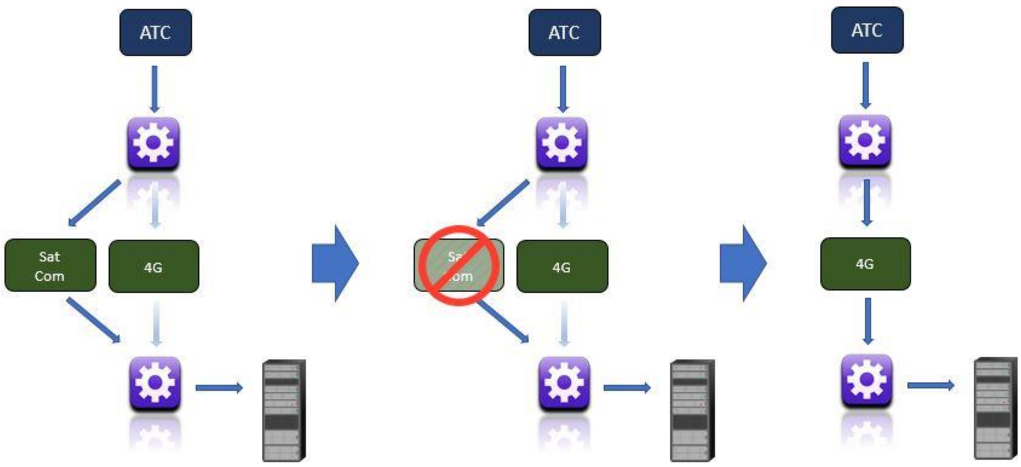


Figure 35. Failover use case

5.3.3.5 *Quality of service under multiple bearers*

Dedicated versus non-dedicated spectrum is the main topic of discussion for the rail sector when dealing with FRMCS. The rail sector is hardly struggling for dedicated spectrum band to avoid harmful interferences from third parties with huge negative impact on train operations. Moreover the rail sector do not want to suffer again from adjacent channel interference from MNOs networks.

But what will happen if the rail sector do not succeed to obtain dedicated spectrum for FRMCS?

Could bearer independence concept be a serious alternative?

The concept of independence coupled with multiple bearers environment must allow applications to be mapped to any bearer or set of bearers with minimum communication requirements at any time.

But, this requires availability of bearers, a certain minimum capacity and quality of service, and sufficient security.

When the quality of service of a bearer based on non-dedicated band is decreasing for any reason, the concept could enable dynamic and automatic selection of a new bearer with sufficient quality of service, if available. The main challenge to consider bearer independence as a serious alternative to dedicated spectrum is to guarantee quality of service requirements. Using non-dedicated spectrum without any process or feature to control the access to the radio resources could not guarantee the performance. If the number of authorised users and devices is known and controlled at any time anywhere, the bearer independence concept could be an alternative. This challenging issue needs to be addressed by industry to confirm the feasibility of such option.

Appropriate sharing and/or Service Level Agreements (SLAs) must be in place.

Finding 25. With the move away from a single, dedicated GSM-R network, there is a need in many scenarios to establish clear Service Level Agreements (SLAs) in order to ensure that the necessary Quality of Service (QoS) is provided. Where multiple bearers operate in parallel, these SLAs might be tricky to implement.

5.3.3.6 Advantages of each model

For each model, we can associate different technical advantages as outlined in the Table 16:

Traffic and QoS Management Model	Increase bandwidth	Optimize resource use	Increase reliability	Increase availability	Increase performance	Minimize service interruption
Load-balancing	X	X	X	X		
Link aggregation	X		X	X		
Duplication			X	X	X	X
Service transfer		X			X	X
Failover			X	X		X

Table 16. **Traffic and QoS Management models**

The choice of traffic and QoS models will have considerable impact on the on-board architecture, performance and the introduction of BIC.

5.3.4 Challenges to guarantee QoS

Guaranteed and predictable QoS for bearers that are not designed with QoS traffic management capabilities such as Wi-Fi are the key challenges to be overcome by industry to make the concept of bearer independence fully open to a multi-bearer architecture.

QoS settings are available on devices such as routers, thus implemented in network elements. Controlling the QoS means settings the routers based on user priority policy such as smart router policy at home: voice is considered as highest priority call service, then video as secondary, best effort follows and then background services. But there is no mechanism to dynamically control and adapt the QoS of the link. An alternative could be to provision sufficient resources by means of a huge data pipe offering more capacity than expected, even during special events. But guaranteed connectivity is a challenging task for these kind of bearers.

Improvement in handling performance must be addressed to overcome existing performance issues of these bearers such as dropped calls, interference and congestion. Due to the fragmented industrial ecosystem in Wi-Fi, efforts and solutions to achieve improvements in quality of service have to be coordinated and standardised to ensure interoperability across the wide variety of smartphones and multi-vendor network elements. It has to be noted that initiatives emerge from IT industry to improve QoS of Wi-Fi networks in an interoperable way. The Wireless Broadband Alliance (collaboration of IT industry) has established a quality of service working group (WG) to define an overall architecture to support QoS implementation and metrics collection and processing in carrier-grade Wi-Fi. One of the objectives of this QoS WG is to provide a priority feature such as LTE QoS Class Identifier mechanism. This WG is also looking at virtualisation, Mobile Edge Computing (MEC), packet data inspection capabilities, and policies to adjust the amount of available resources to different applications or at the user level to manage traffic flows.

Controlling the quality of service of bearers as Wi-Fi is very challenging because these types of bearers are not designed with QoS management features like 3GPP cellular networks are. The Bearer Independence Concept must ensure that QoS management is provisioned for proposed bearers. We can expect that future 5G technology will include high QoS requirements especially for ultra-reliable and low latency communications that are presented as a key market target.

5.3.5 Ensuring continuous availability of transmission capabilities

In this section, we consider security from an availability of service point of view, including requirements for priority and pre-emption. In particular, we consider the justification of the need to use dedicated networks for railways, and the circumstances under which public networks could successfully be used.

In 2015, in the "ERTMS Longer Term Perspective" report, ERA identified Next Generation Communication System as a major contributor for the ERTMS evolution. The expected impact is a potential reduction in cost due to the non-dedicated railway radio communication technology/network model. To reach this target, different network models such as a dedicated railway network, a shared network (e.g. with PPDR), or the use of public commercial MNO networks could be considered. It is thus appropriate to consider whether all of these network models can potentially fulfil railway communication requirements, and if so, under what assumptions.

We note that the Shift2Rail program with IP2 advanced traffic management and control systems TD2.1 adaptable communication for all railways is looking at the possibility of new business model definitions supporting a shift from a "network as an asset" to a "network as a service" model vision. This vision could enable the use of a reliable MNO service to support signalling systems. The reduction of the CAPEX cost and the contribution to a wider use of commercial and low communication networks are in the project scope. This programme has already commenced and publication is expected in the near future.

Another concern is the **increasing availability** of multiple communications bearers. This expectation was identified back in 2014, by the ERA study "Ex-post Evaluation on Operational Requirements of Railway Radio Communication Systems". This report shows that a key requirement for future evolution consideration is to retain security and safety aspects (including REC and short call setup times), prioritisation of calls, and QoS requirements including availability at the same level for GSM-R. The report indicates that GSM-R system performance is positive for rail performance (punctuality, safety, interoperability) and it underlines the importance of **availability** for voice (critical communication) and ETCS data communications service for any future system. In addition to terrestrial networks and Land Mobile Networks, satellite services could also contribute to that reliability target.

In 2014, Analysis Mason in the study "Survey on operational communications" identified several possible network model scenarios and conducted a SWOT analysis on the different models including private networks, commercial networks, networks shared with other mission critical services (e.g. PPDR), MVNO services, or co-operation with an MNO. These scenarios should now be revisited in the light of technological advances.

In the following section, we will try with available information to define new business model scenarios and to analyse and define conditions of use of public radio communications network instead of a dedicated network.

5.3.5.1.1 Dedicated network case

5.3.5.1.1.1 GSM-R situation

Throughout Europe dedicated networks were the network model adopted for GSM-R. This situation is not totally by choice. GSM-R technology is mainly a COTS (commercial off-the-shelf) technology with additional services and software (mainly IN services and specific voice group service). This technical possibility offered the opportunity for GSM networks to fully transport GSM-R services and also allowed GSM-R users to use public mobile networks. **Railway stakeholders benefit from a 4 MHz duplex band in the 900 MHz GSM bandwidth all through Europe (CEPT recommendation). This situation was a success factor of GSM-R. The cost of GSM-R licence varied in each country but globally these costs are rather moderate.** When GSM-R projects were at their inception, Infrastructure Managers could consider different network sharing scenarios. Around the year 2000 when GSM-R equipment first appeared on the market, some Infrastructure Managers issued radio *service* tenders with onerous requirements on coverage, service and performance in particular availability. These tender processes were unsuccessful because GSM operators were not able or willing to offer such services. At the time the operators were developing their own networks with a view to greatly increasing the number of subscribers and hence earning more revenue. They were focused on their own network evolution based on GPRS, EDGE and 3G for packet data introduction and the increase of data bandwidth. At that time, performance of the public networks did not meet the availability targets required of the rail industry. Note that ETCS (requiring low bandwidth and low throughput) still use switched data transmission service even if GPRS is now available. Network operators did not offer sufficient coverage for railways in particular along low density lines (rural) or indoor (stations, depots). To conclude, network operators were not interested in offering specific services for rail (too many and too specific services, too narrow market, too high performance requirements).

We can also note that due to rapid growth and evolution on services requested by the mobile market, GSM-R manufactures were obliged to manage GSM-R software releases separately. This situation created different lifecycles: one short one for GSM and another longer for GSM-R. During this period there was a consolidation in the GSM-R supply industry mainly due to the limited nature of the market.

Despite this climate different agreements were signed between Railway Stakeholders and Public Network Operators in different areas such as:

National roaming agreement: National roaming agreements for GSM-R users in seven countries in Europe. They offer extended coverage or/and fall back in case of GSM-R unavailability service (Belgium, Switzerland, Czech Republic, Germany, France, Italy, Netherlands, Source UIC). It is limited service reduced mainly to some critical communications (point-to-point). Call priority would have been implemented, but is seems not to be the case. We can note that this situation is already a multi bearer scenario with limited services. We can also note that Railway Undertakings have service subscriptions for business (including rolling stock maintenance) communication through public networks and additional terminal equipment.

Site sharing: In some countries, Infrastructure Managers design and construct their sites in such a way as to make feasible the sharing of sites with Mobile Network Operator. With this possibility, the public operator can more economically extend their coverage along the tracks, inside stations or tunnels and allows IM to obtain additional revenue. This possibility exists but not used for all sites because mobile operator either have existing sites in some places or they are not interested in coverage extension or it does not fit with their requirement in terms of site density (different bandwidth, different throughput). However, this possibility is a first step to build a future solution in particular for coverage.

Partnership: To build and operate their GSM-R network, some countries were able to contract with operators or other industries through Build and Operate contract or Public Private Partnership. It is still a private network model but there is convergence and mutualisation on operations and maintenance.

To conclude, a dedicated network is the preferred network model for GSM-R but there are already agreements and mutualisation in place with Mobile Operators. This first step can be enlarged with more convergence in the near future.

Finding 26. The dedicated network is the preferred overall network model for GSM-R, but the alternative arrangements that are already in place demonstrate that other models may have value. The migration to fully bearer independent communications has the potential to facilitate the further evolution of other network operational models.

5.3.5.1.1.2 Benefits and risks of a dedicated network

The future evolution will include independent bearer concept introduction with the separation between application layer and network provider as well as potentially new services introduction with higher throughput. This shift can largely help to build shared scenarios. However, at the same time, railway stakeholders would like to have, as in GSM-R, adapted and high Quality of Service for critical communications (with prioritization) and full coverage throughout the railway network (trackside, stations, shunting areas and depots).

Dedicated networks need to have dedicated spectrum as is the case now with GSM-R. Additionally, to have reasonable cost investment for radio sites, the allocated frequency band should not be too high (optimal bands are sub-1GHz). As a scarce resource, dedicated spectrum is a difficult requirement. For rail, it is particularly difficult because rail occupies only a small part of the landmass on a national basis. Shared licencing on a geographical basis could be considered. Additionally, railways do not use high bandwidth over the communication (traffic) channels except for ETCS data communications but with low throughput, limited to ETCS L2 lines and in degraded mode. Other communication services such as performance or business applications could overload the network. This statement makes it difficult to justify dedicated spectrum for large-areas whilst offering at the same time high levels of coverage as required for performance and business communications.

A reasonable question is to wonder if dedicated radio networks are the only means by which critical communications can be securely provided an affordable price (cost-benefit relationship). In any case, we can note that agreements with MNOs are necessary to fulfil needs for coverage and bandwidth for performance and business communication, as is already the case for GSM-R. In this analysis, we highlight the benefits of having a dedicated network and identifying risks.

In Table 17, we present the possible reasons of using a dedicated network and their impact. We firstly present benefits for end-users and globally for rail operations (i.e. adapted service to support rail traffic).

BENEFITS FOR END-USERS AND RAIL OPERATIONS	IMPACT
Adapted services for end user	Standardization and separation between applications and communication layer should be provided but not only on dedicated networks.
Availability, resilience, and high QoS for critical communications	A dedicated network offers the possibility to build specific architecture and to have high requirements on maintenance to cover such needs. It gives complete control and management of QoS objectives. This solution has a high cost in terms of OPEX.
Extended coverage	A dedicated network gives the full possibility to add sites where needed. This possibility has a cost in terms of investment and OPEX and can be limited by frequency reuse scheme and interference increase. In low density areas, a reuse of GSM-R sites will be welcomed.
Guarantee in terms of capacity and call priority	Compared to public network use, a dedicated network will offer a guarantee on capacity according the spectrum bandwidth of that network. Rail critical communications use very low throughput compared to today’s use of public networks with increasing high bandwidth data demand.
Security	Bearer independent concept will create new security issues on both the network and the application parts. Railway stakeholders will have to manage and control security items.
Reactivity on service support and end-user management	As a service support, railways should keep the possibility to have an easy, flexible and scalable end-user management and eventually adapt the service to sustain the traffic management.

Table 17. **Benefits for end-users and rail operations of a dedicated network**

We now present the possible opportunities and advantages to have a dedicated network for Infrastructure Managers. If well exploited, these opportunities can counterbalance in part the potential extra cost of a dedicated network. Table 18 highlights the issues.

POSSIBLE OPPORTUNITIES OR ADVANTAGES	IMPACT
CAPEX management	IM invested already in sites buildings. The reuse of these sites buildings can limit the new investment in particularly if the new technology benefits from similar budget link and frequency bands (sub-1 GHz). Simulation must be conducted.
Possibility to share sites	IM can continue to propose site sharing and to have potential additional revenues. This advantage could also benefit from mitigating interferences.
Possibility to share network with similar users such as PPDR	This choice give the possibility also to share network (fully or partially) with another professional network such as PPDR. Only, if technology manages priority and capacity, agreement can be found. It can be same or slightly different frequency bands.
Avoid difficulty to contract with Mobile Operator (SLA, penalty, insurance, …)	As already shown, a dedicated network avoids creating complex contractual situation. In terms of safety, risk transfer from rail to other partners is difficult to contract. There is a risk not to agree on the appropriate contract (long negotiations …).
Kept independence, on network management and OPEX	In this case, IM is independent and can manage and operate easily the network according its own need. During service introduction, it can help to shift and to support changes.
Migration and Interoperability management	In a first approach, migration and interoperability seem to be simpler in that case. It can avoid fragmentation that will be damaging for rail sector.

Table 18. **Opportunities and advantages for IM of dedicated network**

After benefits on service and advantages for IMs, we present a list of preliminary conditions, remaining risks and possible limitations that should be considered and managed for dedicated network scenarios. Due to a number of uncertainties, some of them can be seen as a barrier to having a dedicated network such as spectrum allocation. Table 19 outlines the issues.

PRELIMINARY CONDITIONS, RISKS AND LIMITATIONS	IMPACT
Spectrum availability and efficiency	A pre-requisite to have a dedicated network is to have dedicated spectrum. As a scarce resource, spectrum usage should demonstrate a good efficiency depending on candidate technologies. High density and urban areas are the most critical areas from this point of view. The possibility to have a rail spectrum allocation is limited to critical communications which are not directly concurrent with MNO customers. The possibility to benefit from a larger bandwidth can be associated with sharing with others users.
CAPEX Funding for the Infrastructure	Another pre-requisite is to have funding to pay the network renewal. The amount of CAPEX is also depending of spectrum attribution. Attribution in a high frequency band will result in additional investment in terms of number of sites. **Dedicated spectrum bandwidth allocation may also increase the CAPEX due to potential auctions or license cost (potentially different prices than GSM-R).**
Only one network/bearer – no fall back or extended coverage	A dedicated network can also limit the possibility to have contract with MNOs to provide coverage and services (different services, different frequency bands) except if terminal equipment manage that case.
Availability of equipment/ niche market –infrastructure part	As for GSM-R technology, creating dedicated networks will separate rail or professional equipment evolution from public technology evolution. It will create a niche market with fewer competitors. This situation can also slow down innovation for rail services. However, this situation could improve partially if PPDR and rail share some technologies (potentially with other verticals industries such as utilities).
Long time to deploy a full new network	A dedicated network deployment will be a long process. This situation will increase migration path.
Limit the possibility to manage evolution	A dedicated network offers stability but on the one hand it can slow down evolution compared to public mobile network. On the other hand, the future application oriented network architecture will provide high development possibilities. We can forecast that in the future, younger (digital native) end-users will request more evolution even for critical communications.
Terminal equipment: time to market and high cost	A dedicated network on a dedicated spectrum led to the creation of a captive market with specific terminals. This risk can decrease with transverse technological evolutions such as SDR.
Skilled people and new competence for application development and for network management	Due to evolution, new skilled people and new competences will be required. These competences will be in public operator side. Some convergence should be studied at least on that item in case of dedicated network.

Table 19. **Preliminary conditions and risks analysis of dedicated network**

As conclusion, whilst the dedicated network model is still relevant for railways, this scenario imposes conditions and is not without risk.

As is already the case with the legacy network, and will be the case with the potential new technologies possibilities, agreements with others operators are inevitable and even more favourable.

Additionally; due to technological evolution, the possibilities for MNOs to complete or even fully ensure the rail telecoms services is potentially increasing however it also creates considerable complexity from a technical point of view and even more on the contractual side.

Finding 27. The introduction of business and operational models other than dedicated GSM-R networks offers opportunities for rail operations, but it potentially also leads to considerably more technical and contractual complexity.

5.3.5.1.2 Use of public networks

In this section, we will consider under which circumstances public networks could be used to cover rail requirements.

In 2014, SCF published an interesting study untitled "Is Commercial Cellular Suitable for Mission Critical Broadband" on the use of commercial mobile networks and equipment for Mission Critical communication. This study presented different network options at the time for PPDR and LTE 4G shift from dedicated network to commercial MNO and hybrid networks. This report includes other sectors in addition to PPDR such as utilities and ITS with road and rail.
The SCF report gives five conditions to be fulfilled to use LTE public mobile communications for PPDR:

1. **Contractual and legal aspects** to obtain adequate service and contract (SLA, long-term relationship…). Under Public Safety, MNO social responsibility can be requested, and even new regulation regarding MNO must be enforced by each Member State's national agency.
2. **Increased availability** more than 99% (target 99.999%)
3. **Extended coverage** to a reasonable cost
4. **Provide this service to others sectors** (transport and utilities)
5. Still **offer different possibilities to EU countries** that will choose the model and the timing.

At this stage, we can highlight major differences between PPDR and rail situation even if both have comparable situations with 2G dedicated networks and a need to shift. Firstly, PPDR needs to shift more quickly than rail because of the need of broadband data (video transmission) compared to rail that still primarily needs resilient voice and data, without broadband data for critical applications (note: ATO could change that need). Secondly, PPDR and rail have two different experiences: PPDR with TETRA and others standards have almost no contact and experience with public mobile operators compared to GSM-R operators. Additionally, the rail sector has experience and requirements on roaming (national and international) as well as interoperability. On the other hand, PPDR can better rely on Member States support with obligation and new regulations, and possibly spectrum due to the highly important political concern on Public Safety.

The SCF study reported few examples of use of commercial MNO for Mission critical communications. The most interesting for our study is UK program ESMCP (Emergency Services Mobile Communication

Programme) to replace TETRA technology by LTE. This project, now called Emergency Services Network, will use 4G public network for emergency service communications. The UK National Audit Office report published an audit in September 2016 highlight a number of risks as well as ways to mitigate them. The study also proposes recommendations on how to introduce the project (for information the service will be launched mid-2017). An additional study was conducted by Kable to check if this project is the most advanced in the world. It seems that it is the case. This project is interesting to follow in the near future in order to check the feasibility and to evaluate difficulties. A link to the report is included below:

(https://www.nao.org.uk/report/upgrading-emergency-service-communications-the-emergency-services-network/

As a first approach, the question of public network use can be further subdivided:

- **Service requirement**: Will they provide the required level of network availability, resilience, quality of service, security and coverage?
- **Cost and contractual aspect:** Can commercial operators be trusted to provide reliable services under fixed-price contracts over long periods?

In Table 20, we evaluate the technical conditions to offer a service:

SERVICE REQUIREMENT	HOW TO ACHIEVE IT WITH PUBLIC NETWORKS
Adapted services for end user	Standardization and separation between applications and lower layers.
Availability, resilience, quality of service	Availability increase in MNO due to infrastructure including transmission and O&M equipment improvement. MNO have also large teams and spares for maintenance and operations. Additionally, revenue decrease on the public market will push operators to search for new markets such as professional users. It will also be an opportunity to increase availability and robustness for other business as urban transport, IoT or automotive. The market maturity can be an advantage. MNO operations should insure the target performance (e.g. set up time for emergency call).
Extended coverage	Ensuring trackside coverage is still challenging even if it is easier to cover lines for cab-mounted equipment rather hand-portables in trains. Railway lines can often be in coverage blackspots in rural areas. Mainly populated areas are covered. Up to now the coverage inside train is not complete. Additionally, the high speed of trains make the continuous coverage difficult (guaranteed connectivity with seamless mobility). In the future, we can hope a better service for rail operations if coverage for passengers increases. However, it will not be sufficient. Additional, site installation should be done unless satellites can cover that need. The reuse of GSM-R sites can then also be considered under a specific agreement. Tunnels or cuttings coverage should also be carefully considered. In urban areas, a sharing of equipment with urban transport will enlarge the coverage. Rail requirements are more coverage-oriented than high bandwidths for critical communications, then frequency should be considered as sub-1 GHz.
Guaranty in terms of capacity and call priority	Capacity and call priorities are very sensible questions for critical communications. Standards and manufacturers will have to offer such functionalities and operators will have to put into service and take the engagement to operate them. Due to narrowband requirements, it is quite easy to allocate capacity of rail critical communications. The situation is much more difficult for PPDR and video requirements. Operators should accept to guarantee such services that create differences between users with different classes of services.

Security	MNO have ensured security with all up to date technology. They employ dedicated and skilled security people. They are a target for cyber-security attacks but they have means to protect their networks. A possibility for rail is to have agreements with different operators in order to provide redundant services.
Reactivity on service support and end user management	The future architecture with application layer will provide different means of subscription management and service provision. Standardisation and manufacturers should develop suitable functionalities and specific functions for rail sector.

Table 20. **Service requirement for rail**

In the following section, we will compare operator interests and associated risks for the rail sector in order to evaluate the feasibility in terms of contractual aspects.

MNO have commercial interests. They need to optimize return on investment and to have OPEX optimization in order to maximize revenue. During negotiation of new contracts, they cannot accept risk transfer outside of their focus (example from telecom to rail operations) or accept clauses that may compromise the future agreement for the company. They can be interested in having long-term contracts with stable customers in order to ensure stable revenue. Table 21 highlights the issues.

RISK/OPPORTUNITY FOR RAIL	MITIGATION TECHNIQUES
Long negotiation	Reduce as much as possible specific requirements
Higher expense than expected	Reduce as much as possible specific requirements
No or too few extended coverage	Provide solutions with exiting GSM-R sites if the frequency band is compatible.
Prohibitive costs in case of modifications	Do not add or limit specific requirements during the contract in order to avoid being captive customers.
Possible service degradation with impact on rail operation	SLA obligations and penalties. IM should have performance measurements. Legal obligations will be welcomed but difficult to obtain.
End of service	Option 1: Long term service agreement; Exit clause penalty Option 2: Agreement between an IM and more than one MNO
Complex terminal equipment (time to market, cost,)	Terminals will be in all scenarios a challenging issue. Future evolutions with application layer separation will help to have off-the-shelf equipment like commercial smartphones. Rolling stock mounted equipment will still be challenging.
Additional service coming from public market (opportunity)	MNO may propose additional services to rail during the contract. It is of particular interest for performance or business communications.
Shorten migration duration (opportunity)	Limitation of the impact of migration from GSM-R toward successor because the site coverage will partly be already done. On-board equipment should be ready and deployed.
Decrease the interoperability for the Single European Railway Area	With the introduction of different scenarios, a risk of non-coordination introduction and fragmentation exist. This risk can degrade interoperability. Some specific actions should be studied and measures to be taken to avoid that situation.

Table 21. **Risks and opportunities for rail with public network usage**

5.3.6 Legal obligations

- ✓ In this chapter, we will aim to answer to the following questions: Have Member States imposed obligations on Infrastructure Managers (IMs) and Railway Undertakings (RUs) to offer broadband services to rail passengers, or are they likely to do so in the future?
- ✓ How do the network neutrality rules enacted in 2015 interact with rail requirements? Do rail passenger communications raise different issues than rail operational communications?

5.3.6.1 Obligation to provide service to rail passengers

There is at present no explicit obligation at European level to ensure that broadband services and information services are available to passengers on-board. Considering broadband services to passengers in stations, the European Commission proposed a new legislative measure in September 2016 called **Wifi4EU** to increase free Wi-Fi access points to any European citizens and visitors, which are in spaces where public services are provided. Among the main socio-economic drivers considered as public services are train stations, referring to communication COM(2016)589 "proposal for a regulation of the European Parliament and of the Council amending regulations (EU) N° 1316/2013 and (EU) N° 283/2014 as regards the promotion of Internet connectivity in local communities".

The European Commission also proposed a non-legislative measure "**5G for Europe: An Action Plan**", which foresees among other things a joint work with Member States and Industry stakeholders to encourage the adoption of national 5G deployment roadmaps across all EU member States. Complementary objectives to the Digital Agenda for Europe (with 2010 connectivity objectives valid up to 2020) have been identified to build on and boost existing network investments up to and beyond 2025. One of the 2025 strategic objective is **high performance 5G connectivity** procured by uninterrupted 5G coverage on all urban areas and all major terrestrial transport paths (including railways in line with the definition of Trans-European Transport Networks). 5G connectivity on railways will address rail passengers' broadband services needs on-board.

As expressed above, obligations exist at Member State level, and it is likely that these obligations will become more common over time.

Imposition of a right for passengers to have wireless Wi-Fi access would be challenging because passenger Wi-Fi would have major implications for the amount of bandwidth required to the train. This is the main reason why passenger broadband communications have generally been treated as distinct from operational rail communications. If there were to be any integration of the two, then prioritisation must favour operational rail communications – otherwise, there would be risk that the operational service would not achieve sufficient bandwidth or QoS for safe and proper train operation.

5.3.6.2 Network neutrality

National Regulatory Authorities (NRA) claim that Internet, fixed and mobile networks interconnect to form a global network "infrastructure of freedom". This global network interconnect users and contents/applications. National regulators ensure that this global network is developing as a common property with strong requirements in terms of accessibility, universality, performance, neutrality, trust and confidence.

On 25 November 2015, the European Union enacted new binding rules for network neutrality under Regulation 2015/2120.[15] The Board of European Regulators of Electronic Communications (BEREC) subsequently developed guidelines to National Regulatory Authorities (NRAs) as to how the Regulation should be interpreted and implemented.

This regulation states users must have access to Internet on an open basis. This European regulation covers only neutrality of access networks to internet, not end-users' devices such as smartphones and mobile operating systems with android and iOS hegemonies. This regulation focus on Communication Service Providers and not on other providers such as media services such as OTT players.

These guidelines warrant careful consideration in the context of rail communications, but the implications are somewhat different for operational rail communications than for passenger communications.

A key issue that, had the Regulation been applicable, it might have prevented the kind of prioritisation that rail communications unquestionably requires. Happily, prioritisation of operational rail communications and passenger communications appear to be permissible in general.

5.3.6.2.1 Network neutrality and operational rail communications

It is fairly clear that Regulation 2015/2120 does not apply to operational rail communications because operational rail communications do not provide access to the Internet, and do not serve the general public. They do not constitute a PECP.

This is also in keeping with the spirit of Recital 13 of the Regulation, which amplifies on the three exceptions to the limitations on traffic management. The limitations on traffic management themselves are specified in Art. 3(3), which states that network operators "shall not block, slow down, alter, restrict, interfere with, degrade or discriminate between specific content, applications or services, or specific categories thereof, except as necessary, and only for as long as necessary, in order to … " accomplish various obviously necessary activities. Recital 13 specifically notes that "situations may arise in which providers of internet access services are subject to Union legislative acts, or national

[15] European Union Regulation (EU) 2015/2120 of the European Parliament and of the Council of 25 November 2015 laying down measures concerning open internet access and amending Directive 2002/22/EC on universal service and users' rights relating to electronic communications networks and services and Regulation (EU) No 531/2012 on roaming on public mobile communications networks within the Union, 2015 O.J. (L 310) 1 [hereinafter Regulation 2015/2120].

legislation that complies with Union law (for example, related to the lawfulness of content, applications or services, *or to public safety* [emphasis added]), …"

Even if the Regulation were applicable in principle, however, it would appear that operational rail communications would fall well within the bounds of so-called *specialised services*. Per Article 5(5) of the Regulation, "Providers of electronic communications to the public, including providers of internet access services, and providers of content, applications and services must be free to offer services other than internet access services which are optimised for specific content, applications or services, or a combination thereof, where the optimisation is necessary in order to meet requirements of the content, applications or services for a specific level of quality."

Paragraph 101 of the Guidelines makes clear that specialised services

- ✓ are services other than IAS services;
- ✓ are optimised for specific content, applications or services, or a combination thereof; and
- ✓ the optimisation is objectively necessary in order to meet requirements for a specific level of quality.

All three appear to be clearly met in the case of operational rail communications.

If an MNO were providing the operational rail communications service using the same network that is used to serve normal commercial end-users, it would probably be necessary to demonstrate that the operational rail communications service is "not to the detriment of the availability or general quality of the IAS for end-users."[16] If the network is properly designed, this should not be a problem.

Finding 28. If a commercial MNO were to support operational rail communications, network neutrality rules (Regulation 2015/2120) are inapplicable because operational rail communications do not provide access to the Internet, and do not serve the general public. Even if they were applicable, operational rail communications would clearly represent a *specialised service*. Network neutrality does not appear to pose an impediment to the use of public mobile networks for operational rail.

5.3.6.2.2 Network neutrality and passenger broadband and information services

The BEREC Guidelines appear to exclude rail passenger communications from the scope of Regulation 2015/2120. Notably, they state: "The term 'provider of electronic communications to the public' (PECP) comprises both 'public communications networks' and 'electronic communications services' (ECS), which are defined in Article 2 of the Framework Directive. Conversely, the definition of PECP does not cover providers of electronic communication services or communication networks that are not publicly available, which are therefore out of scope of this Regulation. … Electronic communication

[16] BEREC Guidelines (2016), Paragraph 102.

services or networks that are offered only to a predetermined group of end-users could be considered to be not publicly available. ... The following examples could be considered as services or networks not being made publicly available, subject to a case-by-case assessment by NRAs taking into account national practices:

- ✓ access to the internet provided by cafés and restaurants;
- ✓ internal corporate networks.

In other words, Wi-Fi provided by cafés and restaurants is outside of the scope of the Regulation because the services are available only to customers of the café or restaurant, not to the public at large; moreover, the BEREC Guidelines go on to make clear that if the services were offered to anyone who wants it, it would then become subject to the Regulation.

This very substantial "carve out" from the scope of the Regulation appears to be directly and fully applicable to rail passenger communications, as long as they are offered only to passengers. It probably also covers closely related activities, such as people in the train station.

If, however, an IM or RU were to attempt to use the same network to provide services to the general public – for example, to residential consumers in cities served by rail – then the carve out would appear to be inapplicable.

It is always possible that individual NRAs might interpret these provisions in different ways, but this appears to be the most natural reading of the Guidelines.

Finding 29. Network neutrality (Regulation 2015/2120) does not appear to be applicable to rail passenger communications, as long as the services are offered only to passengers. To the extent that they are offered to the public at large (in train stations, for example), then the network neutrality rules might well be applicable.

5.3.7 Opportunities

The concept of bearer independence introduces a new way of implementing redundancy. Redundancy is not seen only as a duplication of devices or local transmission links but provide capabilities to duplicate bearers. This duplication should be understood as potential answers to main radio issues such as:

- Saturation of networks (especially the radio access network). This issue is tackle with the priority and pre-emption function implemented in private networks (not provided by public networks). The BIC concept provides an alternative by switching from saturated network to under loaded one.
- Jamming (i.e. interferences) from external/internal radio sources. This issue is quite hard to tackle, even when dedicated frequency band is used. Railway communities are well aware of harmful interferences and the impact on train operations and safety of passengers. Dedicated spectrum, robust receivers, jammer detectors, are solutions to detect and protect the railway communication system against interferences. But the BIC concept provides potential alternative: while on-board system constantly monitors the

quality of the link (active bearer) and when the quality of active bearer is considered as degraded, the system could switch from the jammed bearer to an interference-free bearer. This concept could be considered if multiple bearers are available at the same time and at the same location with appropriate QoS. Degraded QoS must be considered by Railways to provide reliability figures. Better network planning in unlicensed bands such as Wi-Fi must also be considered mainly in indoor environment (transportation hubs or stations) with multiple APs to avoid network to interfere with itself.

- **Limited dedicated spectrum** (also called the "extreme spectrum scenario"). Back to the Border crossing use case identified in §3.2.3, capacity issues or degradation of the service have been identified at border areas and in regions with limited availability of frequencies such as big stations, in the study on co-existence of GSM-R and other radio technologies in the current railway radio spectrum, performed in the context of evolution of the railway radio. The study outlined that the full ER/R-GSM bands might not be available, as coordination with GSM-R networks in neighbouring countries is required. This constraint might lead to capacity issues or degradation of service. Same kind of issues should have to be tackle considering next generation bearers for neighbouring countries using R-GSM dedicated band only (4 MHz GSM-R band). Update of bi- or multilateral preferential frequency agreements for border areas between neighbouring countries could not overcome those issues. But the concept of BIC provides flexibility with the following alternative: when the intended dedicated network has limited resources or degraded level of service, failover to standby bearer such as SatCom, public networks or even neighbouring dedicated networks with appropriate QoS should occur, thanks to the bearer independence. Degraded QoS must be considered by Railways to provide reliability figures.

Finding 30. Making the most of opportunities introducing bearer independence provides flexible solutions and alternatives to complex radio issues such as saturation of networks, interferences or extreme spectrum scenario.

5.4 Findings

The challenge for the BIC in terms of guaranteed connectivity is to provide for every application the possibility to send and receive traffic flows at any given time and at any given location with a guaranteed minimum level of service in terms of radio coverage, performance and security. Findings and recommendations are outlined below in the different areas to guarantee connectivity.

Finding 19. Coverage is a fundamental requirement for operational rail communications. Ensuring coverage is a task for policymakers – it is not something that can be left to market mechanisms.

The network ownership and operational model interacts strongly with how the provision of coverage is most appropriately achieved.

Finding 20. Whether dedicated spectrum is required for operational rail communications depends on whether the Member State has chosen to support rail operational communications using a private, dedicated network, a private network shared with other mission-critical applications such as PPDR, or a public commercial network provided by an MNO.

Finding 21. If the Member State has chosen an approach to operational rail or passenger rail communications where coverage of rail routes by one or more commercial MNOs is needed, this could be achieved by means of coverage obligations in a future spectrum auction (for example, in the coming auctions for 700 MHz spectrum).

Finding 22. For a dedicated network, whether dedicated exclusively to rail or shared with other mission-critical uses, it is the Member State’s responsibility to ensure that the network is deployed.

Finding 23. The spectrum currently used for GSM-R is 876 MHz - 880 MHz for uplink, and 921 MHz - 925 MHz for downlink. The 4G mobile standards do not include these GSM-R bands. No additional spectrum has yet been designated for railways in Europe (to deal with migration to a successor to GSM-R, for example, for Member States that deploy dedicated networks). Many questions are not yet resolved as to how to best address the future evolution of operational rail communications, but efforts to resolve them are already under way by the ECC Frequency Management Working Group.

Finding 24. Spectrum options relevant for BIC provides a patchwork of models from legacy GSM-R model to a fully operated network model. This patchwork could be a major brake of putting into service standardised interference resilient products. Harmonised spectrum for railway applications could provide a framework to standardisation of interference resilient equipment, thus answering reliability figures of the FRMCS.

Coverage is only meaningful if it is provided with a suitable Quality of Service (QoS), not only in terms of speed, bandwidth, and end-to-end latency, but also in terms of reliability and robustness.

Finding 25. With the move away from a single, dedicated GSM-R network, there is a need in many scenarios to establish clear Service Level Agreements (SLAs) in order to ensure that the necessary Quality of Service (QoS) is provided. Where multiple bearers operate in parallel, these SLAs might be tricky to implement.

Again, different operational and business models have different implications.

Finding 26. The dedicated network is the preferred overall network model for GSM-R, but the alternative arrangements that are already in place demonstrate that other models may have value. The migration to fully bearer independent communications has the potential to facilitate the further evolution of other network operational models.

Finding 27. The introduction of business and operational models other than dedicated GSM-R networks offers opportunities for rail operations, but it potentially also leads to considerably more technical and contractual complexity.

Our remaining findings relate to the applicability of the network neutrality rules introduced in 2015 to operational rail communications, to passenger communications and to the extreme spectrum scenario.

Finding 28. If a commercial MNO were to support operational rail communications, network neutrality rules (Regulation 2015/2120) are inapplicable because operational rail communications do not provide access to the Internet, and do not serve the general public. Even if they were applicable, operational rail communications would clearly represent a *specialised service*. Network neutrality does not appear to pose an impediment to the use of public mobile networks for operational rail.

Finding 29. Network neutrality (Regulation 2015/2120) does not appear to be applicable to rail passenger communications, as long as the services are offered only to passengers. To the extent that they are offered to the public at large (in train stations, for example), then the network neutrality rules might well be applicable.

Finding 30. Making the most of opportunities introducing bearer independence provides flexible solutions and alternatives to complex radio issues such as saturation of networks, interferences or extreme spectrum scenario.

5.5 Recommendations

No specific recommendations flow from the many findings in this chapter.

6. MOBILITY MANAGEMENT

For the Bearer Independence Communication Concept to work functional calls need to be allowed considering stationary and high-mobility scenarios in a bearer-agnostic approach referring likely to a multi-bearer environment. Service continuity must be guaranteed in every scenario for any authorised users and devices, while ensuring end-to-end integrity and confidentiality of traffic flows. This chapter focusses on this condition for success of the concept and is structured in the following manner:

- Conditions and areas of study
- Setting the scene
- Key challenges (and opportunities, if any)
- Findings and recommendations

The Table 22 presents the scope of the condition.

3	MOBILITY MANAGEMENT	Subscriber authorisation	Subscriber location
		Addressing	
		Seamless mobility (incl. interworking with GSM-R, vertical handover and roaming)	
		Security (incl. authentication, integrity and confidentiality)	

Table 22. **Scope of Mobility Management**

6.1 Conditions and areas of study

This chapter will assess the Mobility Management to understand why it is a condition for success of the bearer independent communication concept. Areas of study which are impacted by the Mobility Management are outlined in the Table 23 (marked with an “X”):

	Vehicles	Spectrum	Infrastructure	Legal framework	Security aspects
Mobility Management	X		X	X	X

Table 23. **Areas of study of the Mobility Management condition**

6.2 Setting the scene

The aim of Mobility Management is to track where the subscribers are, allowing mobile communication services to be delivered to them. In the context of BIC, there is not a single network with its set of subscribers but multiple networks with their own administration of subscribers and own subscription profiles. Each underlying network has its own addressing scheme, its own routing management including mobility, its own security protocols to cover authentication of authorised subscribers, integrity and confidentiality of communications. The challenges for BIC is to address all of these independent mobility and call management mechanisms as a common overlay network system to locate subscribers whatever the network they are registered to. Challenges that are related to BIC and address in this section study are:

- Subscriber authorisation
- Subscriber location in a multi-bearer environment (static and dynamic localization)
- Addressing subscribers to provide communication services

Different requirements are:

1. Subscriber authorisation
2. Subscriber location
3. Addressing
4. Seamless Mobility
5. Security

6.3 Key challenges and opportunities

Authorised subscribers need to be allowed to register to any type of authorised bearer. Railway and non-railway users, and all kinds of data devices such as CCTV cameras must be considered when providing communications for railway services.

Automation needs to be considered to lay down all communications infrastructure, to set up access points or to register to authorised networks by authorised users, independently of applications that are not aware of where the communication pipe has been established. The communication system architecture must provide a mean to give access to authorised networks by authorised users by means of database, for instance. Authentication must be provided as a fast and secure process.

Authentication of railway users (a.k.a. railway subscribers to mobile communication services) need to be guaranteed independently of underlying bearers, even when moving from one access network to another or between different access technologies. Unauthorized users must be rejected by underlying bearers, whatever bearer technologies such as cellular with SIM cards or Wi-Fi login and password authentication processes.

Security considerations must be based on the network plane to be secured:

- **User plane**: applications must be free to choose appropriate end-to-end security protocols based on their security requirements.
- **Control plane**: the concept must consider how security of control planes could be managed in a bearer independent environment. This challenging issue needs to be taken into consideration.

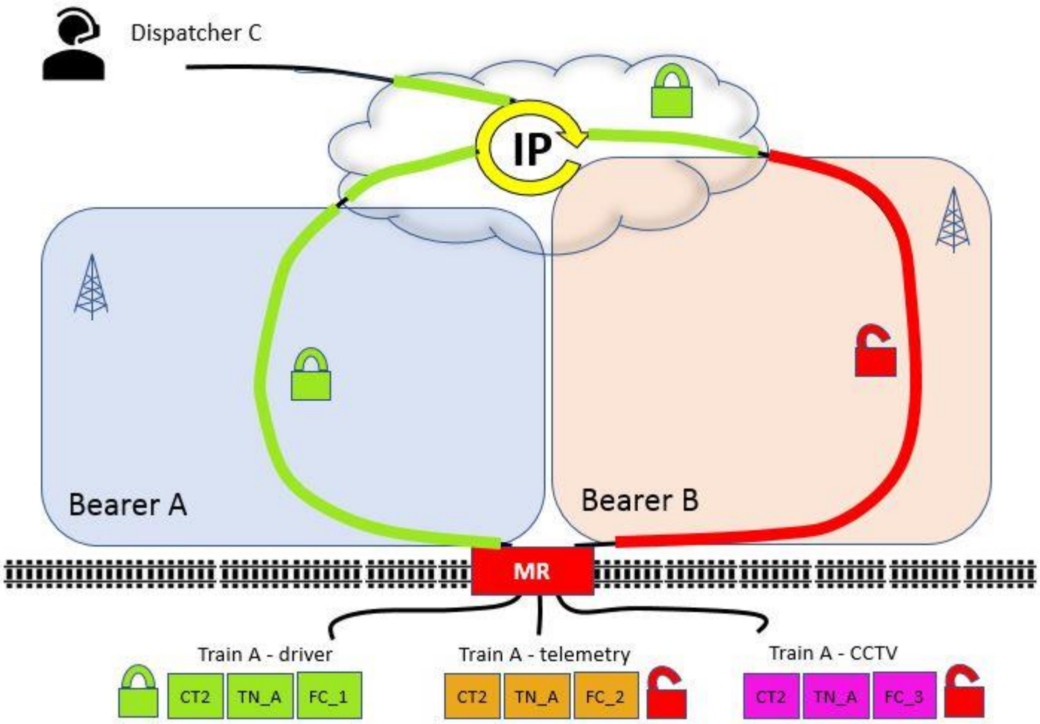


Figure 36. Security requirements for bearer independent communications

The ownership of subscribers' data could be an issue. All data produced from bearers must remain the property of railway users.

6.3.1 Subscriber location and addressing

6.3.1.1 Mobility of on-board communication device

The mobility objective of the concept of bearer independence is that mobility must be transparent to applications, without any communication interruptions (i.e. seamless) when moving. One of the main challenge introduced by the seamless mobility conditions is that the on-board communication device acquires a new address when it is moving from one access network to another or between different access technologies. The on-board communication device is not reachable with its previous address anymore. It implies that all current communication services are stopped and should be restarted by applications or users themselves. The routing of data packets or datagrams is location-dependent (i.e. dependent of its point of attachment) and is not transparent when one entity of an established call is moving.

Mobility Management in the context of BIC must address these constraints and allow the on-board communication device to be always reachable at the same address whatever the access network it uses. It allows the on-board communication device to move transparently for the applications and the users, without the need to reset all the current connections each time it moves to another access network. Mobility Management must allow for **location-independent routing** of data packets or datagrams. Mobility Management needs to be designed to support seamless and continuous connectivity for the on-board communication device.

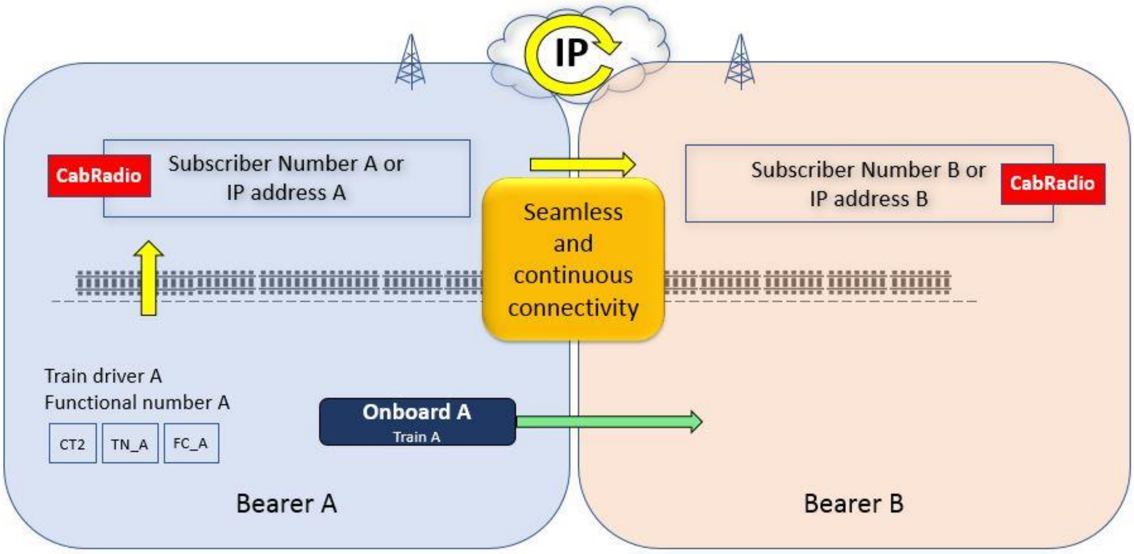


Figure 37. Mobility of on-board communication device

6.3.1.2 Mobility of on-board local Mobile Network

While the previous condition of Mobility Management focused on on-board communication device addressing challenge, an additional challenge is to make mobility transparent to applications when an on-board communication device shares multiple access technologies and multiple applications. Multiple functional entities could be connected to a single on-board communication device through a Mobile Network such as an access network deployed in a train such as the TCN.
Note: benefits of having a single on-board device to deliver communication services are considered later in this study.
Mobility Management must be considered for one whole network, and not only one on-board communication device. Mobility Management must ensure session continuity for all the application entities in the Mobile Network, even as the on-board communication device changes its point of attachment. Mobility Management must also provide connectivity and reachability for all application entities in the Mobile Network as it moves. The Mobility Management needs to support both mobile application entities that do not support mobility in the Mobile Network. The only device that needs to have mobility functionalities when the whole mobile network moves must be the one that connects the Mobile Network to the bearers, i.e. the on-board communication device.

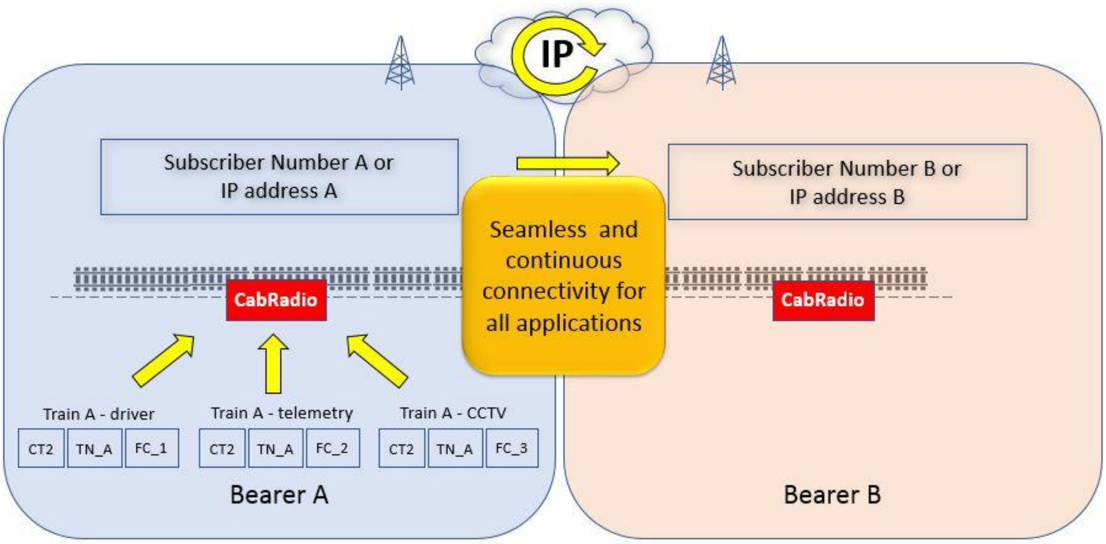


Figure 38. Mobility of on-board mobile networks

Mobility Management must also consider mobility using simultaneous bearers with dynamic flow control for different application entities with a single on-board communication device.

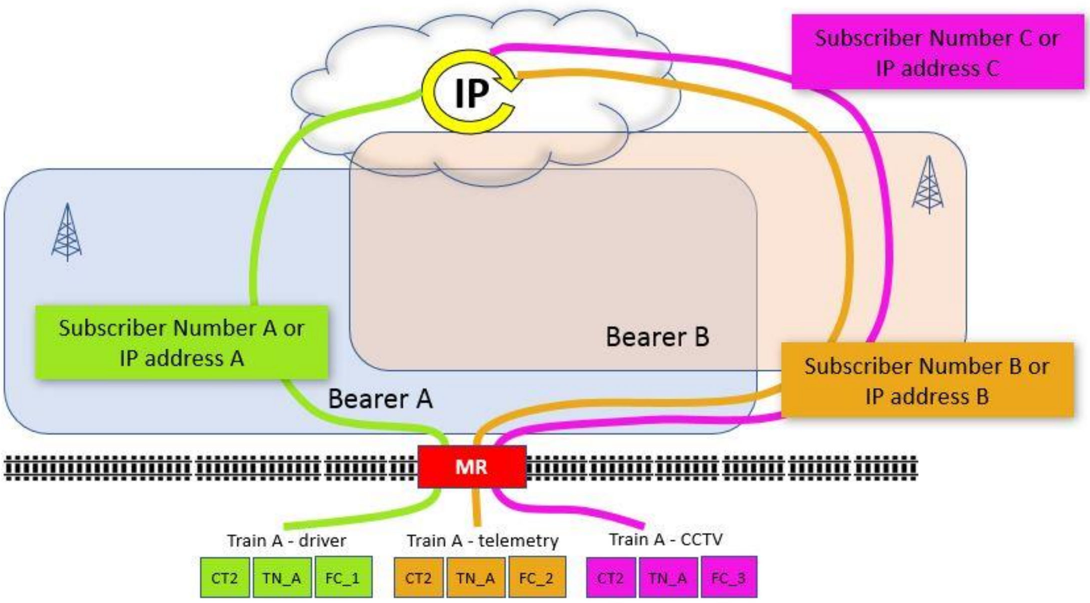


Figure 39. Mobility using simultaneous bearers

6.3.1.3 Functional addressing

An address is the location identifier for a specific entity (unicast) or a group of entities (multicast) in networks of transport stratum. The addressing mechanism is a set of actions to define the address structure, to specify the entities to be addressed, and to clarify the allocation method.

The address structure and entities to be addressed have already been defined by railway sector.

IEC and UIC have defined two different addressing schemes for railway users with similarities on railway staff functions, but UIC does not address functions of devices such as CCTV.

UIC first defines the EIRENE numbering plan to be used by GSM-R networks. EIRENE numbering plan purposes are the same as IEC: train controllers and other railway staff want to call a train by its running number rather than by the subscriber number or IP address. This is because the traction unit of a certain regular service may change from day to day, whereas the running number is uniquely identified, at least within a single railway domain. On the other hand, maintenance staff in depots will only know a traction unit by its engine number and will prefer to communicate (e.g. remote diagnostics) to a device within the traction unit by this number. In each of these situations, it is necessary to be able to call a device on the train without knowing its subscriber number or IP address.

EIRENE is already defining a numbering plan providing a range of number types to meet railway addressing requirements. For instance, a certain Functional Number identifies the driver of a certain train rather than the subscriber number or IP address of the cab radio installed in the locomotive. If the locomotive is changed during the journey, the Functional Number based on the Train Running Number will stay the same. Railway users must therefore be able to originate and receive calls using Functional Numbers, independently of underlying bearer.

IEC is also defining an address structure and entities. IEC 61375-2-6 standard defines an addressing scheme. For addressing a train, train identification is based on train mission number (called *train journey ID*) quite similar to the functional identify used in EIRENE functional addressing.

Any function, application or users must be uniquely identified by labels. These labels form a FQDN based on TCN-URI scheme defined in IEC 61375-2-3. As an example, a train driver in train journey ES9558 is addressed by the following TCN-URI label:

driver@cabCtrl.leadVeh.leadCst.anyCtrTl.ES9558

A common addressing structure and list of entities for all kind of railway applications must be considered to address the complete picture of voice and data applications to be supported by the next generation communication system.

What is missing as a condition for success of addressing mechanism is the number translation or allocation method. The number translation is the mapping of the functional number to the underlying bearers addressing schemes such as MSISDN or IP addresses. A functional number over bearer A must be able to setup a call to another functional number over bearer B, the called number could be on-board and/or on ground entity as shown in Figure 40.

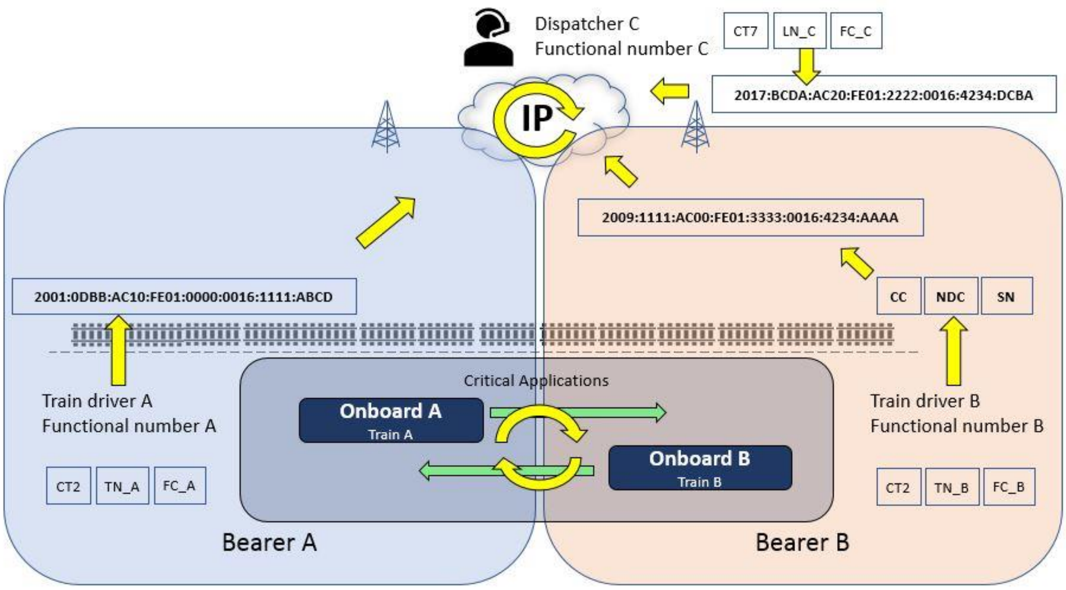


Figure 40. Number translation

Regarding the IEC standard, a number translation is possible from TCN-URI labels to local train IP/DNS zone. Addressing trains in an interoperable DNS area is not described. A global and unambiguous mapping of functional identity to DNS scope is needed for interoperability.

Number translation is missing and needs to be addressed in a multi-bearer environment.

IP address handling should be a solution but need investigations. The on-board must acquire an IP address for communication and addressing information of the DNS. This process depends on bearers. This address may be assigned by the CSP or DHCP, depending on implemented solutions.

In sum, a common addressing structure and list of entities for all kind of railway applications needs to be considered to address the complete picture of voice and data applications to be supported by the bearer independence concept. A new addressing scheme compliant to EIRENE functional addressing is required to be studied. Complimentary standardisation of EIRENE numbering plan could be considered.

Number translation is missing, and must be addressed in a multi-bearer environment. A technical solution for implementing functional addressing over a multi-bearer environment but bearer independent (e.g. it cannot function as GSM-R functional addressing does, based as it is on the 3GPP Follow Me functionality) is needed. Such a solution should also consider linkages with MSISDN numbers, IP addresses, and other bearer specific addressing schemes.

Finding 31. Addressing and routing using rail-specific identities has not yet been specified in a manner consistent with bearer independence. Number translation is missing.

Recommendation 9. ERA should use its good offices to ensure that a bearer independent solution is found that addresses the need for addressing (including number translation) and routing using rail-specific identities.

6.3.2 Seamless Mobility

A main requirement for bearer independence is to define how, who and when to select one appropriate bearer for a single application communication whilst not degrading the level of service.

Using the literal definition of bearer independent communication, applications are not aware of which bearer(s) is/are used when communication services are applied. Applications could use different bearers, related to location, time, mobility, signal quality, etc. and even simultaneous bearers **without impacting the level of service** requested by the applications. Transition between bearers (inter-system handover or vertical handover) or the use of simultaneous bearers must not impact the requested level of service regardless of physical location, time, and speed as shown in Figure 41.

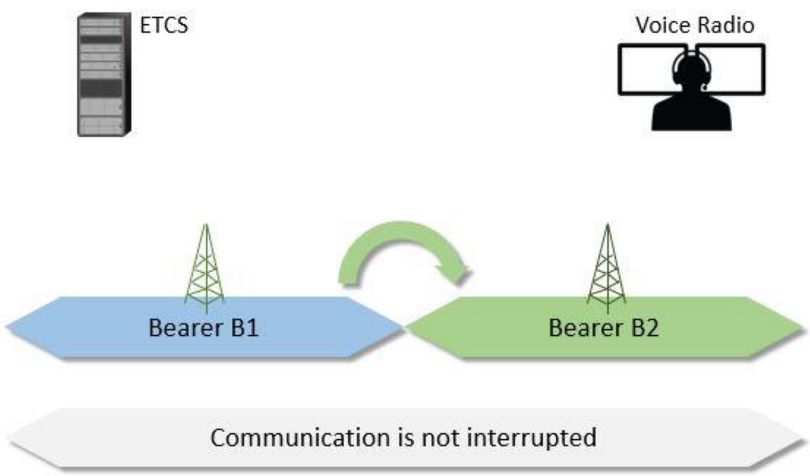


Figure 41. Seamless mobility requirement

Based on the questionnaire, the following principles could be considered:

- ✓ End users need not be aware of transitions/simultaneous bearers and must not experience discontinuity
- ✓ Voice call continuity and data/video connection continuity need to be considered for users' experience when moving, even at high speed, during handovers (between different

technology, different bands, different access schemes and duplex modes) and roaming, indoor/outdoor and at borders. The achievement of a continuous IP communication experience is required.

- ✓ Service interruption must be minimised during transitions (applications requirements must be achieved at any time, any place, any speed) with no connection loss (including transparent functions to the end-users/applications like network registration, mobility management and addressing schemes translations, security management, …).
- ✓ Continuous end-to-end security is to be provided without impacting performance
- ✓ The technical solutions must be standardised

Here again, stakeholders expressed two different views on the support of seamless mobility:

- ✓ **Flexible**: literal definition of bearer independent communication concept and principles
- ✓ **Conservative**: transition between bearers needs be avoided, particularly if not considered in standardized 3GPP framework. The effort to standardize, the complexity of the technical solution, and economical considerations must be taken into account when establishing requirements for the bearer independent communication concept.

The following questions are emerging on seamless mobility:

- ✓ How to implement the transition?
- ✓ Which entity will oversee the transition?
- ✓ When to start the transition?

We can progress further on seamless mobility concept by decoupling it into two steps (time sequence):

- ✓ **Bearer discovery**: how to detect available bearers at a location and time without assistance of applications. Flexibility must be considered when adding a new bearer.
- ✓ **Bearer selection**: evaluate the bearer performance and requested application level of service, engage mapping process from application to appropriate bearer(s) (one-to-one or one-to-many) without assistance of applications.

6.3.2.1 Bearer discovery requirement

There are many options to define the bearer discovery principle, among them:

- ✓ On-board only discovery – static: Hard-coded or predefined list of (preferred) bearers with geolocation data for all countries and all applications or manually requested by application or end-users (e.g. border-crossing use case)

- ✓ On-board only discovery – dynamic: On-board dynamic detection and continuous supervision of available bearers (scanning frequency bands, collect signal levels, SNR, interferences)

- ✓ Network-assisted discovery: Access to a database with predefined list of bearers with geolocation data. An active bearer connexion is needed in that case (at first connexion for example). Databases should be updated dynamically.

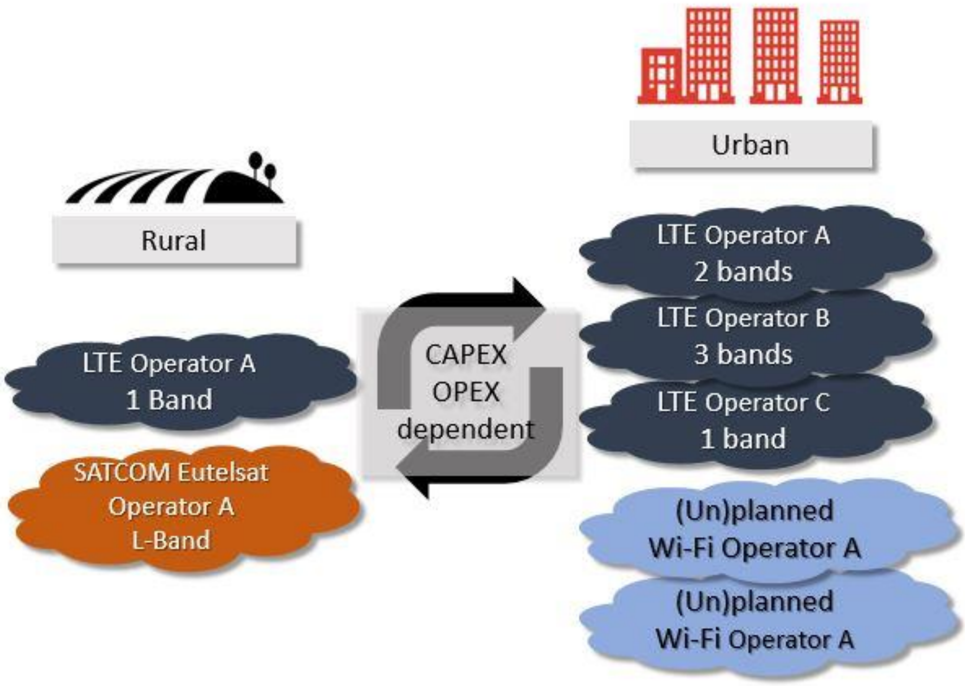


Figure 42. Bearer discovery requirement

6.3.2.2 Bearer selection requirement

Many options must also be considered to evaluate bearer performance:
- ✓ On-board only evaluation (static or dynamic evaluation)
- ✓ Network-assisted evaluation

Then a mapping process from application to appropriate bearer has to be engaged by defining criteria and algorithm to select the bearer according:
- ✓ Performance or Quality of Service
- ✓ Signal quality
- ✓ Capacity or bandwidth
- ✓ Availability
- ✓ Reliability
- ✓ End-to-end delay
- ✓ Location and time
- ✓ Security
- ✓ Traffic policies and pricing/cost

✓ Railway rules

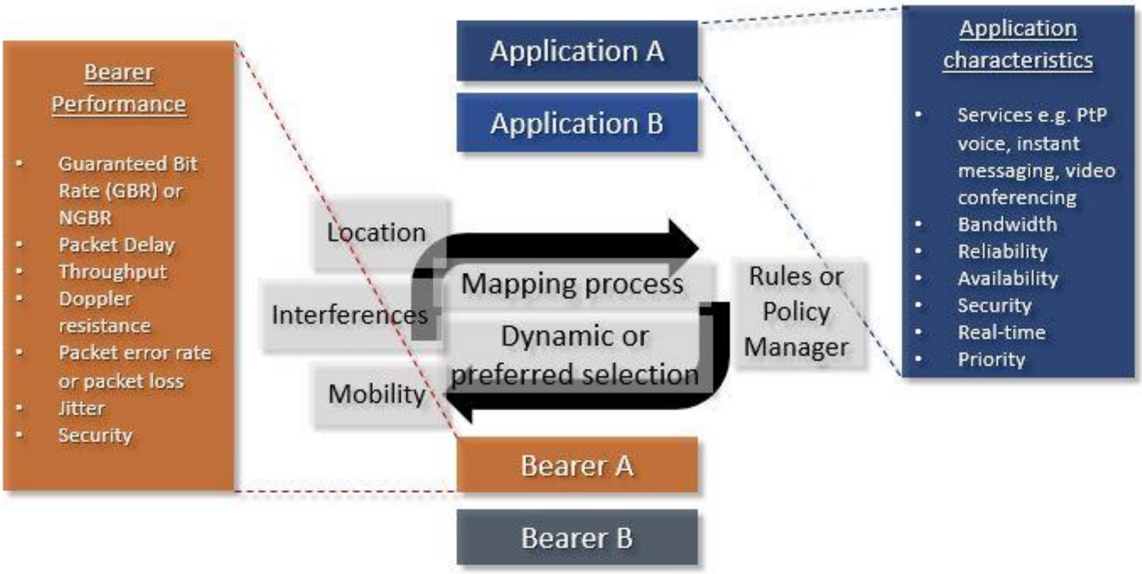


Figure 43. Mapping process chart

Many criteria (or combination of criteria) could be used to define a **smart policy-management**, to precisely define when to select the appropriate bearer suitable to a given application at a given time and physical location:

- Radio conditions (signal strength and signal quality monitoring), electromagnetic attacks or interference and jamming.
- Traffic policies (e.g. load sharing, congestion or failures, bandwidth capacity needs, offloading).
- Railway rules (e.g. list of preferred or dedicated bearer for a given application) while moving within European railway networks
- Location-based (e.g. balise and trackside signals/markers or virtual balise or GNSS-location rural / dense areas / main lines / shunting yards / depot / stations)

Additionally, the entity in charge of the transition could be:

- On-board entity, or
- Infrastructure entity

However, it needs to be independent of applications. It could be network-assisted if the on-board entity is the "brain".

Multiple IP flows using multiple IP addresses must be possible. Multipath TCP (MPTCP) could be a candidate. IMS SIP / Multipath RTP could be another one.

Core network with periodic measurement reports from on-board equipment could also be considered.

Finding 32. The bearers available to on-board equipment will continually be in flux as the train moves. Full bearer independence makes this hand-off problem considerably more complex than it is today under GSM-R. The choice of bearer(s) might perhaps best be address by coordination between on-board equipment and infrastructure. This is not a solved problem.

Recommendation 10. ERA should ensure that technical solutions are found to identifying the correct bearer(s) as the train moves. A study might be appropriate as a first step.

6.3.3 Security

This section is focused on security challenges that need to be addressed in this study to achieve the bearer independent communication concept for European railways.

We address the security conditions to support bearer independence with the following items:

- Justification of the need to use dedicated networks, or under which circumstances could public networks be used;
- Considerations related to security to support bearer independence for the applications and networks used (such as user management, securisation of the communication link, etc.).

Before addressing justifications and considerations on security aspects, we firstly need to define what is security, what are the risks and threats, and which aspects of security are relevant for BIC.

6.3.3.1 Security: definition, risks, and threats

Security could be defined as the **protection measures of assets or systems** against human mistakes, natural disasters, technical failures or malicious attacks including terrorist attacks.

Security measures to protect assets or systems could be classified into following categories:

- Technical measures (including installation of detection, access control, protection and prevention means such as CCTV) ;
- Organisational measures (including procedures for alerts and crisis management) ;
- Control and verification measures ;
- Communication ;
- Awareness raising and training ;
- Security of Networks and Information Systems (NIS) better known as cybersecurity.

6.3.3.2 Security: assets, objectives, and legal obligations

Security was defined in the previous section as the protection measures of assets against attacks or failures. In the context of BIC, which **assets** or **systems** are relevant to security?

Wireless and wireline communication systems are based on three main components:

- **Hardware** equipment (including modems, RF transceivers, SIM cards, antennas, network elements, transmission links, database…). These equipment are physically located in the infrastructure domain (railway or third-party data centres – could be cloud –, sites along the track, railway stations, depots, shunting yards, etc.) or in the vehicle domain (predominantly trains).
- **Software** components (including communication layers, mobile and fixed Operating Systems, transversal layers such as security, and applications) hosted by hardware equipment;
- **Data** exchanged between peers (voice and video are considered as data in this context), data recorded for post-incident analysis such as train radios or CCTV, user subscriptions.

In the context of BIC, hardware equipment, software components and data are part of the communication systems and need to be considered as assets to be protected.

Now that assets have been identified in the context of BIC and before defining protection measures, we next need to define the **security objectives** by addressing the **level of protection** we want to achieve. The level of protection is relevant to the security objectives and requirements of a single application. Each application with communication needs has different security objectives and requirements. And each component (hardware, software or data) engage into the communication chain need protection measures relevant to that objective and level of protection.

Individuals could simply imagine that signalling systems need a high level of protection while passenger information systems (PIS) need lower protection. But railway stakeholders and hackers or terrorists could have different views: a PIS could be hacked, displaying wrong information to the passengers on-board when a train has stopped. In reaction to this incorrect information, passengers could get out and walk on the railway tracks while this area is still in operation with trains running. Potential fatalities or injuries have to be taken onto account to define relevant level of protection.

Member States, Railway Undertakings and Infrastructure Managers are the entities responsible to define the level of protection relevant to railway applications. But are there any legal obligations at European or Member State levels on security requirements and protection measures?

One of the major goals of the European Union is to reduce the vulnerabilities of critical infrastructure and to increase their resilience. The European Programme for Critical Infrastructure Protection (EPCIP) sets the overall framework for activities aimed at improving the protection of critical infrastructure in Europe. A key pillar of this programme is the 2008/114/EC Directive on identification and designation of European Critical Infrastructures. The Directive has a sectoral scope, applying only to the energy and transport sectors (including rail transport but excluding electronic communications).

Critical Infrastructure Protection (CIP) is about ensuring that services vital to the society continue to function. A **European Critical Infrastructure** (ECI) is defined in this context as an *asset, system or part thereof located in Member States which is essential for the maintenance of vital societal functions, health, safety, security, economic or social well-being of people, and the disruption or destruction of* *which would have a significant impact in a Member State as a result of the failure to maintain those functions*. Each Member States must identify and designate ECI (including critical infrastructure assets of ECI) in priority sectors of Energy and **Transport**.

In France for example, before the translation of this Directive into the French regulatory framework, a list of ECI had been identified in 2006. This list is a classified document so the name of entities considered as part of ECI are not known, but **Transport** (including Rail) **and Electronic Communications** (including MNOs) sectors have been considered.

The European Programme for Critical Infrastructure Protection (EPCIP) concentrates on energy and transport sectors and should be reviewed with a view to assessing the need to include other sectors within its scope such as information and communication technology (ICT) sector. Regarding ICT sector, the **EU Cybersecurity strategy** from DG CONNECT identifies actions that will further contribute to the cyber resilience and security infrastructures covered by EPCIP. DG CONNECT collaborates with security agencies, cybersecurity bodies and experts such as the European Union Agency for Network and Information Security (ENISA). ERA should collaborate with appropriate EU cyber-security organisations (e.g. ETSI CYBER, ENISA...) and adopt the EU Cybersecurity strategy from DG CONNECT.

6.3.3.3 Implications of using dedicated or public networks

Before considering the implications of using dedicated or public networks on security aspects, we are addressing the definition of **dedicated versus public networks**. In the context of BIC, a relevant definition for public network could be "*Electronic Communications infrastructures to provide mobile voice and/or data services to the Public in public or private domains (including Railways)*". A study prepared for DG CONNECT from SCF Associates on the use of commercial mobile networks and equipment for "mission-critical" high-speed broadband communications in specific sectors refers to commercial instead of public in the same spirit. Then a dedicated network should delivered services to professional users without access to the public.

In this context, commercial Mobile Network Operators (MNO) are identified as public networks, even if they already offer data access to businesses. However, commercial MNO are considered as "best-effort" commercial service without priority and pre-emption capabilities to priority users. Wi-Fi hotspots in railway stations and trains are also considered as public networks by delivering access to internet for passengers.

6.3.3.4 Implications of BIC for applications and networks

In the context of BIC, and without knowing the protection measures of underlying bearers, could security be managed independently from bearers? Solutions must be developed at application level such as ETCS today or at network and transport layers such as IP security protocols or at Operating Systems levels or at transversal layers such as security plane in Intelligent Transport System (ITS) station architecture. But some threat categories could not be addressed without protection measures on the bearer side. Availability is one of them.

We can note that the security concept must also ensure that URS **communication attributes are sufficient** to characterize an application and map it to an appropriate bearer. The mapping process has been detailed previously in this report. It is important to underline that some applications have specific needs on security (authentication of users, ciphering and/or integrity of messages). An additional point is that these **security attributes** are missing in the current URS and must be considered in the following revision. Railway security requirements for critical, performance and business applications are missing and must be established by the railway community.

Security could not be addressed without protection measures on the bearer side (vehicles and infrastructure) such as providing availability requirements essential for mission-critical operations.

The linkage to mobility management is that continuous end-to-end security must be provided without impacting performance when traffic is moving from one bearer to the other.

Finding 33. Mobility management has implications for security that are not yet well defined.

Recommendation 11. ERA should ensure that a security architecture for bearer independent operational rail communications is developed. A security risk assessment based on major threat use cases, vulnerability of each assets, and potential impact is needed. The results could be reflected in a future revision of the UIC User Requirements Specification (URS).

6.4 Characteristics to be sought in solutions for mobility management

How, who, and when to start the transition are open questions today for railways, to be answered by industry and standardisation bodies if seamless mobility is kept as a principle of bearer independent communication concept.

When trying to find answers to these open questions in the near future, we have to keep in mind the following:

- ✓ "User needs, use of the expertise/experience gained but also an open-minded approach (look at experiences in other sectors) are key points of attention." Source: EC SWD(2014)48.
- ✓ "The R&D projects and cooperation with other sectors are critical and should not duplicate efforts." Source: EC SWD(2014)48.

For information, other vertical markets such as automotive with the development of ITS have started standardised initiatives to promote a multi-vector architecture with seamless mobility (vertical handovers are possible between ITS-G5 and LTE based on congestion criteria). These initiatives need to be taken into account to consider potential synergies and cooperation in standardisation process to promote an open standard and open market.

Desirable or required characteristics of a solution include:

- Authentication of railway users (a.k.a. railway subscribers to mobile communication services) must be guaranteed independently of underlying bearers, even when moving from one access network to another or between different access technologies. Railway and non-railway users, and all kinds of data devices such as CCTV cameras must be considered in authenticating entities for Railway communication services.

- Applications must be free to choose appropriate end-to-end security protocols based on their security requirements.
- Mobility Management must be allowed for location-independent routing of data packets or datagrams.
- Mobility Management must be designed to support seamless and continuous connectivity for the on-board communication device(s).
- Mobility Management must make mobility transparent to applications when on-board communication device shares multiple access technologies and multiple applications.
- Mobility Management must also consider mobility using simultaneous bearers with dynamic flow control for different application entities with a single on-board communication device.

6.5 Findings

Mobility management in a bearer independent environment poses challenges beyond those that are already addressed by GSM-R. These are visible in terms of (1) addressing and routing, including number translations; (2) selection of the most appropriate bearer or combination of bearers as the train moves from one bearer to another; and (3) security across hand-offs.

Finding 31. Addressing and routing using rail-specific identities has not yet been specified in a manner consistent with bearer independence. Number translation is missing.

Finding 32. The bearers available to on-board equipment will continually be in flux as the train moves. Full bearer independence makes this hand-off problem considerably more complex than it is today under GSM-R. The choice of bearer(s) might perhaps best be address by coordination between on-board equipment and infrastructure. This is not a solved problem.

Finding 33. Mobility management has implications for security that are not yet well defined.

6.6 Recommendations

If bearer independence is to be achieved, each of the gaps identified must somehow be addressed.

Recommendation 9. ERA should use its good offices to ensure that a bearer independent solution is found that addresses the need for addressing (including number translation) and routing using rail-specific identities.

Recommendation 10. ERA should ensure that technical solutions are found to identifying the correct bearer(s) as the train moves. A study might be appropriate as a first step.

Recommendation 11. ERA should ensure that a security architecture for bearer independent operational rail communications is developed. A security risk assessment based on major threat use cases, vulnerability of each assets, and potential impact is needed. The results could be reflected in a future revision of the UIC User Requirements Specification (URS).

7. ECOSYSTEM DEVELOPMENT

For the Bearer Independence Communication Concept to work, an ecosystem needs to be developed. This is because making applications independent from bearers introduces new hardware and software components and likely new stakeholders (i.e. new entrants within the traditional telecom rail sector) from standards organisations to industry players. The development of a collaborative framework including these new stakeholders together with the traditional telecom rail sector must be considered with special attention during the complete product lifecycle to be delivered to early and late adopters while ensuring interoperability. This chapter focusses on this condition for success of the concept and is structured in the following manner:

- Conditions and areas of study
- Setting the scene
- Key challenges (and opportunities, if any)
- Findings and recommendations

The Table 24 presents the scope of the condition.

<table>
<tr><td rowspan="3">4</td><td rowspan="3">ECOSYSTEM DEVELOPMENT</td><td colspan="2">Stakeholders</td><td colspan="2">Products & Components</td></tr>
<tr><td>Traditional rail sector</td><td>New entrants</td><td>New radio</td><td>Application ecosystems</td></tr>
<tr><td colspan="4">Lifecycle & product availability</td></tr>
</table>

Table 24. **Scope of Ecosystem Development**

7.1 Conditions and areas of study

This chapter will assess the ecosystem development to understand why it is a condition for success of the bearer independent communication concept. Areas of study which are impacted by the ecosystem development are outlined in Table 25 (marked with an "X"):

	Vehicles	Spectrum	Infrastructure	Legal framework	Security aspects
Ecosystem development	X	X	X	X	X

Table 25. **Areas of study of the Ecosystem development condition**

7.2 Setting the scene

7.2.1 Application ecosystem

In a fully bearer independent world, applications and services will be independent of any specific bearer's features. This potentially offers a huge degree of flexibility.

Historically, operational rail solutions have tended to be highly integrated. Equipment for operational rail communications and the software running on it have been tightly coupled, and have been acquired as an integrated package.

Finding 34. The same de-coupling of transport from application that provides bearer independence could also potentially enable rail operational software by third party providers that are independent of the firms that provide the transmission equipment. In some cases, applications that have general commercial application might be used, with or without rail-specific enhancements, to meet operational rail communication needs.

Whether the provision of operational rail applications by third parties is possible depends on many prerequisites being fulfilled.

- **Operating system:** The operating system for the equipment must offer documented interfaces that enable third parties to offer applications.
- **Communications Application Programming Interfaces (APIs):** Interfaces to the communications software would need to be provided in a bearer-independent manner.
- **Competitive constraints:** The provider of the equipment must not impose needless barriers to the incorporation of approved third party software.
- **Certification and approval:** To the extent that safety of property and human lives depends on rail operational software, it cannot be deployed without rigorous testing and certification.
- **Legal and regulatory requirements:** Legal and regulatory requirements would need to be considered.

Finding 35. If third parties are to be able to supply operational rail applications (especially in on-board systems), attention must be paid to ensure (1) open operating system platforms with well documented interfaces, (2) open well documented communications Application Programming Interfaces (APIs), (3) competitive constraints are not allowed to impede entry of new players, (4) the certification and approval process needs to carefully consider how to enable this kind of innovation without sacrificing safety, and (5) legal and regulatory requirements need to be fully thought through.

Our preliminary assessment is that a third party application ecosystem could be viable, but the details require careful consideration.

As regards the **operating system**, it might well be appropriate for on-board equipment to use a widely deployed operating system such as Google Android or Apple IoS. If so, the rules for providers of third party applications are well documented and well understood. Proprietary operating systems could also be considered for trackside and on-board, but third party applications would be possible only if APIs for third party integrators are open and well documented.

As regards the **communications interfaces**, similar considerations apply. Standardised interfaces exist (for example, Berkeley sockets). Access to rail-specific functionality, for example to identify nearby trains, might need to be accommodated.

As far as **competitive impediments** imposed by platform providers, *these can be governed by contract with the IM or RU* – there is no need for regulation.

Certification and approval pose serious challenges. The objective of the de-coupling of applications would best be achieved if software can be tested without requiring re-certification of the transmission equipment, or (worse) the entire train; however, the degree to which this is feasible requires careful consideration.

As far as **legal and regulatory requirements**, it is clear that the European Regulatory Framework for Electronic Communications (RFEC) has little or no relevance to *operational* rail communications. The RFEC is generally concerned with Electronic Communication Services (ECS) that are offered to the public; operational rail communications are however generally available only to IM and RU staff, not to the general public, and are therefore not generally subject to the RFEC. Moreover, this is appropriate in our view – the issues that the RFEC seeks to control do not apply, or do not apply in the same way, as they apply to services offered to consumers. Consumer protection, consumer privacy, and market power issues manifest very differently for operational rail communications. Further, to the extent that controls are needed, they can be imposed through the contracting process with the IMs and RUs. Harmonisation at European level of the obligations to be imposed under contract by IMs and RUs, however, may be in order.

Recommendation 12. ERA's support for bearer independence should be undertaken in such a way as to make possible the development and deployment of third party operational rail applications.

Recommendation 13. ERA should consult with stakeholders, and launch studies if appropriate, to determine how best to ensure that operational rail (on-board) equipment is based on open and well documented operating systems and communication APIs so as to enable deployment of independently developed operational rail applications.

Recommendation 14. ERA should consult with stakeholders, and launch studies if appropriate, to determine whether actions at European level would be needed to ensure through standards and through IM and RU procurement policies that unnecessary barriers are not erected to market entry of third party operational rail applications.

Recommendation 15. ERA should consider carefully, consulting with stakeholders and launching studies if appropriate, how to evolve the certification and approvals process so as to support bearer independence in general and the introduction of third party applications in particular.

The following sections in this chapter explain how functional requirements can be implemented by communication and location software applications and services independently of the underlying bearer.

7.2.1.1 Over-the-Top (OTT) communications applications

Modern communication methods such as Skype are now reflecting the way people and businesses communicate today. The use of smartphones through what is called Over-The-Top (OTT) communications applications is ubiquitous in our modern age. Individual consumers and businesses use these OTT services through mobile apps every day and everywhere due to the IP technology transition and Internet access democratisation. OTT services are useful for communication needs but also for viewing media content or, in the transportation sector, to provide alternative transport services. BEREC defines OTT as “content, a service or an application that is provided to the end-user over the open internet” (open internet here means that IP private networks are excluded). OTT are internet-based services provided by third parties, independent of the underlying IP-based bearer and Internet service provider. OTT communication services include voice services, data services (e.g. instant messaging or emails as SMS and MMS substitutes) and video (e.g. media streaming - broadcast, video conferencing – multicast). OTT services operate over IP-compatible public or private networks, between users or devices on different bearers.

Capabilities that are closely integrated with the network in GSM-R, and that would continue to be closely integrated with the network if the optional LTE MCPTT capabilities are used for operational rail (see also Chapter 4.2.1.3.1), could in principle be provided over-the-top instead. This evolution is already visible in the Private Mobile Radio (PMR) environment. As already expressed in chapter 4.3 we stress that railway group communication needs voice service and in particular PTT as well as reliable emergency group calls for train operation. PTT is primarily required to ensure clarity of communication by forcing users to request an uplink in order to talk thereby ensuring radio discipline - only one person speaks at a time and there is no background noise caused by other participants in the call.

PMR businesses such as utilities are using OTT communication applications enabling Push-to-Talk group calls. Businesses experience secure group-communications that enables Push-to-Talk (PTT) and real-time location and presence information between team members, all from their smartphone, tablet or wearable device. OTT communication applications for PMR businesses have been designed to replicate key features of PMR radio networks including:

- Group or Individual Call
- Emergency call
- Caller ID
- Encryption
- Late Entry calls

- Priority and Pre-emption
- and many other features

By using existing commercial broadband networks, they can extend their PTT communications from a local system to the nationwide coverage footprint of the commercial carrier, Wi-Fi, SatCom or other data networks.

The PPDR sector has long used PTT (Push-to-talk) as a way of maintaining discipline during critical situations. It is also already involved in the new era of OTT communication applications. PTT solutions let smartphone users securely communicate with a simple press of a button. In addition to enabling groups of smartphone users to easily communicate with one another, a PTT bridge is provided with the land mobile radios police use today, enabling teams to communicate using push-to-talk **across networks and devices**.

PTT functionality has long been considered to be essential for rail communications (and for PPDR) as a means of governing who speaks at a given instant on a group call. The experience with PMR suggests that OTT applications could fulfil the same needs; however, this can only be the case if the OTT service, in conjunction with the underlying bearers, delivers suitable reliability, robustness, and Quality of Service. If we assume that reliability and robustness are need to provide availability, then the three main characteristics needed for an OTT mission-critical voice service with PTT capabilities can be expressed in terms of **availability**, **latency** and **voice quality**.

A conventional approach to fulfil the **availability** requirement is to use redundancy in legacy mission-critical communications systems such as GSM-R or TETRA. Commercial bearers are more prone to failure than mission-critical communication systems (and therefore should not be deployed alone) as the level of redundancy is lower. But the concept of bearer independence enables redundancy using at least two communication systems that are unable to be subject to a *shared fate* where the same failure disables both or all (see Section 5.3.3). Redundancy provides a means of achieving the necessary level of reliability and robustness at an affordable cost.

Latency is a more challenging issue. In legacy PMR systems, the time between pressing the PTT button and when the call is established is less than a second in GSM-R, even less in TETRA (around 200 milliseconds). Controlling that timing is crucial to fulfil the latency requirement. The concept of bearer independence needs to ensure that latency requirements are fulfilled by using appropriate bearer. Appropriate bearers must be delivered when and where PTT services have to be provided.

Voice quality must be guaranteed at all times, including when the PTT feature is needed. Voice quality cannot be degraded while selecting or switching to the appropriate bearer. Existing PMR PTT voice solutions do not necessarily fulfil these requirements. Many existing PMR OTT solutions provide non-mission critical PTT features. Careful product and system design is likely to be needed in order to deliver mission-critical OTT PTT capabilities that meet the needs of operational rail.

OTT could be used over non-mission critical bearers to expand the mission-critical coverage, making the PTT feature available anytime and anywhere as long as IP connectivity is provided.

The concept of bearer independence must provide a means of enabling non-mission critical and mission critical railway users using PTT features across infrastructure and vehicles (i.e. different bearers).

7.2.1.2 The alternatives of traditional network operators to OTT competitors

The public telecoms operator (telco) industry is actively involved in standardised alternatives to OTT, enabling users to communicate through Wi-Fi, called Wi-Fi calling. Wi-Fi calling is a feature already implemented and commercialised in the US telco market. AT&T, Sprint, Verizon, and T-Mobile have made Wi-Fi calling services available to their clients. Wi-Fi calling provides capabilities to use public Wi-Fi hotspots with a smartphone as a priority bearer to make a call without the use of specific apps such as Viber, Skype, WhatsApp. The call service of the smartphone is used by simply typing the called number. Then the infrastructure, not the smartphone, chooses the best available bearer.

Wi-Fi calling provides voice and video calls.

Wi-Fi calling depends on MNO's implementation choices. Devices (smartphones) need also be compliant with Wi-Fi calling. Deployment and performance requirements are changing: built out initially for coverage, then for density and dealing with congestion. It now turns to mobility. Deployment provides sufficient access point (AP) density and coverage to continue calls as end users move through the area such as transportation hubs or stations.

Wi-Fi calling could not be considered to be a bearer independent solution because it is based on 3GPP features without portability on other kind of bearers. But Wi-Fi calling provides opportunities to switch from bearers automatically as an integrated calling service. It is in line with the bearer flexibility terminology used in the UIC FRMCS program, but not with the goal of full bearer independence (the flexible view) that we have identified as the desired goal in the medium to long term.

Finding 36. *Wi-Fi calling* depends on 3GPP features. It is thus consistent with what we have referred to as the conservative view, but not with full bearer independence (i.e. the flexible view).

IT industry predicts that 50% of all IP traffic will be Wi-Fi by 2021 (source: CISCO). It also predicts that VoWi-Fi will carry 53% of IP voice traffic by 2020, similar to what happened between cellular and Wi-Fi in data offload transition, due to lower cost-per-bit. Improvement in handling of performance must be addressed to overcome existing performance issues such as dropped calls, interferences and congestion. Then Wi-Fi could be considered as candidate bearer to business-critical applications for instance. Here is a short focus on International Wi-Fi trends:

- Wi-Fi is becoming available for passengers in regional, national and international high-speed trains in Europe for free or not.
- Free Wi-Fi to users in developing countries is brought by GAFA starting with India's transportation hubs or stations, working with Indian Railways and RailTel.
- Wi-Fi is an important element of the MNOs' strategy related to spectrum bands and auctions. Some are deploying portable Wi-Fi routers connected to their LTE network as Wi-Fi front end to avoid users to purchase smartphones supporting their specific frequency bands.
- Wi-Fi services such as virtual stations are deployed in 14 Italian stations by Italian State Railway Group on its project called "Wi-Life Station". The virtual station provides information such as maps and guides, the ability to interact with end users via context aware services such as local

event promotions. User behaviour data could also be accessed by stakeholders such as public safety alerts due to unusual crowds.

7.2.1.3 Location services

Location services are also mainly use in combination with communication applications to provide customised services to end users (a.k.a. location-based services). Location services are accessible through APIs, which allow developers to manage geolocation-based services according to the needs of their application. Location technologies such as GNSS (GPS, Galileo, Glonass, etc.), Bluetooth Low Energy, Wi-Fi, LPWAN, UWB, beacons, etc., or a combination of those location technologies could be made accessible through a single API with accuracy as input parameter. Location technologies could provide accurate measurements appropriate to railway applications: less than 1 meter accuracy must be provided for mission-critical applications to be able to distinguish parallel and adjacent tracks, even when trains are running or stopped in closed environments such as tunnels.

7.2.2 New radios: software and hardware

The BIC concept introduces additional key components: new radios (and thus implicitly new players).

Several techniques to improve radio terminal performance are now being available to ensure efficient communications across the chaotic radio spectrum (i.e. a non-interference-free environment, even across licensed bands). Among them are:

- **Software defined radio (SDR)**: A radio in which the operating parameters including but not limited to frequency band, modulation type, data rates, output power limitations and frequency hopping schemes can be set or altered dynamically by software.
- **Reconfigurable radio system (RRS)**: Radios whose hardware configuration and software can be changed through software.
- **Cognitive radio (CR)**: A radio or system that senses and is aware of its operational environment and can dynamically, autonomously, and intelligently adjust its radio operating parameters. CR has the ability of learning, understanding and adapting so that it can access the spectrum more effectively and dynamically adapt to channel conditions. The concept of bearer independence provides a similar cognitive mechanism by means of monitoring radio signal quality of available bearers and switch to the best available bearer suitable to any application. The on-board communication system architecture could provide such a cognitive capability as an alternative to improved receivers against interferences.

A lot of the radio signal processing is already possible through digital processing. Digitalisation means that "softwarisation" of legacy hardware signal processing should be introduced. But digitalisation of RF signals still has limitations including at least antennas and analogue/digital converters. Efficient spectrum emission masks limit adjacent channel interference allowing channels to operate closer together, improving spectral efficiency at the cost of implementation difficulty in hardware components. Meeting these strict limits is a significant challenge for implementing new radios. Implementation difficulty would lead to additional costs and delays in product availability.

SDR is becoming increasingly popular among all type of users, with primarily with the military. SDR software and hardware are available at very low prices could make feasible the introduction of the concept in professional and business-critical radio solutions, even for railways. Therefore, we recommend efficient spectrum emission mask limits and prevention of blocking as well as intermodulation by pushing, for instance, the limits to the total interfering power that any receiver can handle. A further study on this specific subject can check the feasibility of being digitally processed through fully integrated software-defined radio transceivers. Liaising with ETSI TC RRS could be a first step to define the methodology.

As the concept of Bearer Independency Communications is to decouple applications from bearers, and to define an open and scalable system architecture, new industry players should be willing to bring innovative solutions in a collaborative framework lead by railways for railways.

This collaborative framework is termed an **ecosystem**.

Finding 37. The shift to bearer independence implies the need for re-thinking of the ecosystem of rail operation transmission systems and rail operational applications. Both must be active in the market if rail operational communications are to be successful, and to evolve over time to benefit from technological and market evolution.

7.2.3 Why is developing such an ecosystem vital for railways?

Such a collaboration allows solutions and products to be integrated together, enabling interchangeability, portability and interoperability of standardised components. Collaboration and cooperation is vital in maintaining a healthy ecosystem. Within a strong ecosystem, the generation of innovative ideas becomes targeted and projects advance in a smoother fashion. It could also accelerate the development of the system by reducing complexity. Vendor lock-in should also be avoided through this collaboration framework.

In order to fully realise the potential benefits of the BIC concept, it will be necessary to promote and influence the development of this new ecosystem. Doing so likely requires the sector to:

- address skills shortages
- guarantee interoperability of solutions
- cost-efficiency, by reducing CAPEX and OPEX of legacy GSM-R solutions
- ensure fair and healthy competition
- promote standardised solutions that avoid vendor lock-in
- accelerate availability of products for early adopters of the new generation radio system supporting the BIC concept

The development of such ecosystem will bring together traditional stakeholders of the rail sector with likely new entrants. Collaboration frameworks needs to be built around stakeholders such as:

- The European Rail industry
- European agencies
- Member state governments and national regulators
- Traditional railway standard bodies (IEC, ISO)

- Legacy network operators
- Standardisation bodies such as ETSI, 3GPP, the IETF and the IEEE
- Railway users' communities
- The signalling industry
- The traditional railway operational communications industry
- New tech firms to develop mobile apps, web services and APIs.

New service providers are likely to be most interested in providing on-board solutions or cloud-based services. If third party applications are to be possible, on-board communication devices will need to have sufficient internal memory and processing power to allow new functionalities and applications to be added without degrading overall performance. Some functionalities may not be anticipated in the beginning, so the system needs to be scalable. A collaborative framework could avoid development of solutions in silos, thereby enabling convergent solutions.

Working with communities outside the traditional railway telecom industry ecosystem could offer solutions to some of the skills shortages such as developers of mobile apps and Web services, or security experts. New collaborations could accelerate the development of standardised apps to match the strong planning requirements of railway early adopters for next generation railway communication system.

Finding 38. Making it possible for third parties to provide applications potentially addresses a number of long-standing operational rail needs, including skill shortages for application developers and security experts.

The European Parliament has approved allowing OTT service subscribers to access their subscriptions in the EU, waiting next step which is the approval by the EU Council of Ministers. This draft law is part of the Digital Single Market (DSM) strategy to bring Europe closer together by lowering the cross-border barriers. Reducing the cost of communications is a central pillar of the DSM strategy. Combination of the end of roaming charges and the cross-border portability of OTT services could bring benefits to EU Railways by developing performance and business services with best-effort QoS needs over public mobile networks using OTT.

We recommend the rail sector to not consider OTT and IT industry players as a threat but rather as an opportunity for railway users to foster innovation and development of solutions to support the bearer independent concept. We recommend the rail community to be opened to other private industry sectors such as IT and OTT.

If 3GPP WG SA1 FS_FRMCS work item were to fail to deliver 3GPP features to fulfil railway functional requirements, an alternative will be needed. Fully bearer independent PTT applications might provide the answer, and third party PTT apps might possibly be the most effective way to ensure availability of the necessary applications. The current work plan is to identify gaps in 3GPP release 14 and include normative work to be done in release 15 to make FRMCS a success. This work item focussed on the development of 3GPP features to cover railway functional requirements without any bearer independent vision. But OTT is to be considered as a viable alternative if the rail sector supports the bearer independent concept. Proof of Concept (PoC) are methodologies to trial innovative solutions should be fostered by the rail sector to understand the capabilities of OTT to cover functional needs whilst guaranteeing performance and security.

Finding 39. If 3GPP standardisation efforts were to fail to deliver the 3GPP features needed to fulfil railway functional requirements, an alternative will be needed. Fully bearer independent PTT applications could provide the answer, and third party PTT apps might possibly be the most effective way to ensure availability of the necessary applications.

We would like to highlight to the railway community involved in initiatives such as struggling for dedicated and harmonised spectrum or fighting MNOs to avoid harmful interference that new radios are also to be considered as alternative candidates. Is it possible to imagine the future of railway communications without any dedicated and European harmonised spectrum for mission-critical applications? New radios could be an answer to a multi-band environment in European countries or to non-dedicated spectrum for rail (e.g. licensed from MNOs, unlicensed from public networks or shared with PMR/PPDR).

7.3 Key challenges and opportunities

The collaborative framework must include all the steps of the BIC components development lifecycle, from the concept to product availability, through design, development, lab and in-situ testing, and certification prior to integration.

7.3.1 Development ecosystem around OTT

The pace of development of new operational rail applications has been slow to date. Opening up the process potentially offers new opportunities. Some of the approaches that have been tried are most appropriate for consumer applications, but others (such as the Airbus approach that we describe shortly) are potentially applicable to the operational rail environment.

Innovation contests could offer the opportunity for transport authorities and industry players to invite developers to trial OTT applications and services through a competition within the framework of a Proof of Concept (PoC) methodology. PoC approach should make the rail sector more confident in OTT capabilities to demonstrate its feasibility.

In Washington DC, one of the first cities to open its public sector data, an innovation contest called "Apps for Democracy" was held in 2015. This generated 47 web and mobile apps **in a month**, tackling a range of social and service issues.

In the public safety sector, some of the traditional telcos players have already launched application developer programs to invite developers to produce OTT mission-critical apps for their brand-new android-based smartphones.

We would like to highlight one of them, the SmarTWISP programme, from Airbus about their new hybrid TETRA/4G public safety device. This programme has reach a level of maturity by creating an application ecosystem for hybrid devices in the public safety and critical communications sector. This programme could help the railways to understand how PPDR industry is preparing the emerging era of smartphones and apps suitable for mission-critical applications and how to develop an ecosystem around that fulfils the railway requirements while ensuring interoperability of the components.

The SmarTWISP programme proposes four levels of membership, the basic level providing free of charge membership. Developers must be qualified as professional software developers, and approved by the Airbus programme's committee. Once developers have been accepted into the programme, they can:

1. Produce mission-critical app(s) on the Airbus platform, free of charge, with access to guidelines, tools and Application Programming Interfaces (API)
2. Get licensed (with a limited, non-exclusive, non-sub-licensable and non-transferable license) and start testing the app
3. Receive Airbus **certification**
4. If the developer's app helps boost Airbus sales, developers will become partner of their reward scheme.

The programme gradually implements a professional process including quality checks and certification process to select and sell the most demanding, useful and secure applications for android users in the public safety sector. Lessons learnt are not yet available because of the early stage of the programme. But railways should take special attention to lessons learnt, especially on the development challenges of the ecosystem.

Security and legal requirements must also be considered such as, but not limited to:

- Proof of compliance of the platform and applications to the European regulations, considering that applications can change over time
- Proof of the integrity of applications
- Proof of the identity of the developers of applications
- Built-in support for security updates (e.g. Windows periodic security updates to keep your favourite laptop work securely with lessons-learnt from vulnerabilities)
- Prevention of code theft
- Over-the-air secure delivery and installation of applications
- Intellectual property rights

7.3.2 Development ecosystem around new radios

ETSI TC RRS provides a framework for introducing **Radio Apps**, i.e. applications which extend or modify existing radio features and define solutions for technical, certification and security needs. The benefits of Radio Apps are multiple such as introducing new radio features to meet optimum configuration, or the replacement of entire radio access technologies (i.e. a complete bearer).

ETSI RRS framework will provide radio software components being available through a secure platform, the Radio Apps market or Radio Apps store. Only software components which have been previously tested and validated, included in the Declaration of Conformity (made available by the Radio Application providers) will be made visible on the Radio Apps market.

Figure 44. Illustration of possible Radio Apps

New actors such as Radio Application providers need to be introduced in the rail ecosystem. But considering only commercial-off-the-shelf Radio Access Technology to be supported by the bearer independence concept will greatly facilitate the introduction of software reconfiguration.

We would like to highlight to the railway community that collaboration with ETSI TC RRS to provide COTS RAT software components should foster the introduction of RRS in the rail domain. The main condition is that railway specific services are not implemented in the RAT, avoiding specific standardisation process, radio development, increasing cost and delays.

7.3.3 Collaborative framework to ensure interoperability

Collaborative industry initiatives such as the ETSI Plug tests provide an ideal opportunity for vendors to test their products to ensure interoperability of ETSI standards-compliant products and services. The goal of the ETSI Plug tests is to validate the interoperability of a variety of different solutions on the market using different scenarios and test cases.

For instance, ETSI Mission Critical Push To Talk (MCPTT) Plug tests will be based on 3GPP, ETSI and IETF standards, and are designed for:

- UE vendors
- EPS vendors
- MCPTT server system vendors
- SIP/IMS Core vendors
- Control Room vendors
- MCPTT test solution vendors

The objective of the ETSI MCPTT Plug tests is to trial independently and jointly all components of the MCPTT communication chain such as:

- SIP Registration

- Authentication
- Affiliation
- Group Call
- Floor Control

For many manufacturers, the MCPTT Plug tests supported by the European Commission represent an important step in understanding the level of interoperability of their implementations and as a means of validating their understanding of the standards.

In evolving to fully bearer independent solutions, and especially to the extent that operational rail application development is opened up to third parties that have not traditionally been part of the operational rail environment, plug tests similar to those used for MCPTT may play an important role in promoting broad interoperability.

Plug tests are not, however, a substitute for the certification process.

7.4 Findings

The migration to bearer independent technology opens many doors, but also introduces new issues into the operational rail environment.

Finding 34. The same de-coupling of transport from application that provides bearer independence could also potentially enable rail operational software by third party providers that are independent of the firms that provide the transmission equipment. In some cases, applications that have general commercial application might be used, with or without rail-specific enhancements, to meet operational rail communication needs.

Finding 35. If third parties are to be able to supply operational rail applications (especially in on-board systems), attention must be paid to ensure (1) open operating system platforms with well documented interfaces, (2) open well documented communications Application Programming Interfaces (APIs), (3) competitive constraints are not allowed to impede entry of new players, (4) the certification and approval process needs to carefully consider how to enable this kind of innovation without sacrificing safety, and (5) legal and regulatory requirements need to be fully thought through.

Finding 36. *Wi-Fi calling* depends on 3GPP features. It is thus consistent with what we have referred to as the conservative view, but not with full bearer independence (i.e. the flexible view).

Finding 37. The shift to bearer independence implies the need for re-thinking of the ecosystem of rail operation transmission systems and rail operational applications. Both must be active in the market if rail operational communications are to be successful, and to evolve over time to benefit from technological and market evolution.

Finding 38. Making it possible for third parties to provide applications potentially addresses a number of long-standing operational rail needs, including skill shortages for application developers and security experts.

Finding 39. If 3GPP standardisation efforts were to fail to deliver the 3GPP features needed to fulfil railway functional requirements, an alternative will be needed. Fully bearer independent PTT applications could provide the answer, and third party PTT apps might possibly be the most effective way to ensure availability of the necessary applications.

7.5 Recommendations

We suggest that the migration to bearer independent technology provides an opportunity for a comprehensive shift in the manner in which operational rail applications are produced. Opening up the system so as to enable third parties (some of whom may not have historically been suppliers to the operational rail community) potentially opens the door to greater and faster innovation.

Recommendation 12. ERA's support for bearer independence should be undertaken in such a way as to make possible the development and deployment of third party operational rail applications.

Recommendation 13. ERA should consult with stakeholders, and launch studies if appropriate, to determine how best to ensure that operational rail (on-board) equipment is based on open and well documented operating systems and communication APIs so as to enable deployment of independently developed operational rail applications.

Recommendation 14. ERA should consult with stakeholders, and launch studies if appropriate, to determine whether actions at European level would be needed to ensure through standards and through IM and RU procurement policies that unnecessary barriers are not erected to market entry of third party operational rail applications.

Recommendation 15. ERA should consider carefully, consulting with stakeholders and launching studies if appropriate, how to evolve the certification and approvals process so as to support bearer independence in general and the introduction of third party applications in particular.

8. DEPLOYMENT PLAN

For the Bearer Independence Communication Concept to work, every national migration plan from GSM-R to bearer independent communication system need to be considered in a heterogeneous radio access environment. European deployment plan must address this specificity within a coordinated or non-coordinated approach while ensuring interoperability of international trains across Europe. This chapter focusses on this condition for success of the concept and is structured in the following manner:

- Conditions and areas of study
- Setting the scene
- Key challenges (and opportunities, if any)
- Findings and recommendations

The Table 26 presents the scope of the condition.

5	DEPLOYMENT PLAN	European coordination		Legal aspects
		Vehicle/ RU	Infrastructure/ IM	

Table 26. Scope of Deployment Plan

8.1 Conditions and areas of study

The following chapter will assess the national and European migration strategies to roll-out bearer independent communication systems in a coordinated or non-coordinated approach. Areas of study which are impacted by the deployment plan(s) are outlined in Table 27 (marked with an "X"):

	Vehicles	Spectrum	Infrastructure	Legal framework	Security aspects
Deployment plan	X	X	X	X	

Table 27. Areas of study of the Deployment Plan condition

8.2 Setting the scene

Before assessing a coordinated versus a non-coordinated approach to deploy new bearer(s) for Infrastructure Managers (IMs) and Railway Undertakings (RUs), assumptions to define migration scenarios are being called into question due to the bearer independence concept.

The migration scenarios have been defined in ERA study on migration of railway radio communication system from GSM-R to other solutions in 2016.

These migration scenarios have been established taken as an assumption that GSM-R will be replaced with a **single radio system**. In the migration study, the new radio system is called Next Generation (NG) and is defined as a new generation technology of radio. (Note that this view is at odds with what we have termed the *flexible view*, where operational rail communications can be supported over various bearers, including bearers such as Wi-Fi that provide no rail-specific support.)

Two main scenarios are then described based on the infrastructure deployment strategy, either single network or dual network:

- A **single network strategy** is called the "big bang" scenario: only one bearer is available at a time on ground infrastructure, GSM-R or NG.
- A **dual network strategy** which is more progressive: both bearers are available on ground infrastructure, GSM-R and NG, enabling a smooth migration of vehicles.

Another criterion is used in the definition of migration scenario, which is the delay to migrate to NG. This criteria is used to define sub-scenarios depending on the time to migrate infrastructure and on-board.

The introduction of Bearer Independence Concept is questioning the assumptions taken as basis to define migration scenarios. The concept introduces the idea of decoupling applications from bearers. The new radio system is not a single radio system across Europe but could be a set of multiple bearers, nationally or widespread across European countries. Moreover, Member States, Infrastructure Managers and Railway Undertakings should consider using different bearers for different applications, in different areas or for parallel operations depending on communication services requirements.

The list of candidate bearers is not yet defined by the rail sector but a defined and finite list of bearers should likely be allowed based on the previous requirements. Candidate bearers will likely be cellular systems such as 3GPP networks, Low-Power Wide-Area networks (LPWAN) and IoT networks, or LMR networks, Satellite or even Wi-Fi and Li-Fi spots.

The candidate bearers and the approach to defining a list of candidate bearer are well defined in Chapter 5, which deals with the need for guaranteed connectivity.

8.2.1 Impact on the migration scenarios of IMs

As an example to understand the bearer independence concept, an IM of one country could consider using a broadband data network such as private LTE-Advanced Pro network with stringent performance to deliver communication services to ETCS and other mission-critical data applications. On the other hand, he could consider using a narrow-band PMR network for voice-related applications.

Another example could be to use one Communication Service Provider (CSP) in urban areas (commercial networks already deployed for non-professional consumers) and one other CSP in rural areas such as satellite provider where commercial MNOs do not provide full radio coverage along the tracks due to a non-viable business model coupled with no legal obligations to provide internet connectivity to passengers.

Other alternatives are possible such as active and backup systems available on certain locations to improve reliability and availability. These examples are all and well defined in the previous operational use cases paragraph.

From an IM perspective, the next generation radio is not a single radio system in all railway areas but a set of radio systems. For each railway area, one or more eligible bearers could be made available for each application. ETCS and voice train radio are considered as two different applications. Moreover, one or more eligible bearers could be made available for two consecutive areas such as different operational areas with different performance or coverage requirements. With the introduction of the Bearer Independence Concept, an IM need not limit itself to a dual or single network scenario, but could instead deploy a set of bearers for each railway section such as:

- Application A:
  - Railway section x = active bearer Bi and potential backup bearer Bj
- Application B:
  - Railway section y = active bearer Bk and potential backup bearer Bl

The concept behind the single or dual network scenario (which is that GSM-R services would be in operation for a short or for long period of time) is however still valid.

8.2.2 Impact on the migration scenarios of RUs

Instead of implementing a mono- or dual-mode Cab Radio and EDORs, a new on-board system should be emphasized based on a service-oriented architecture for instance. The on-board system should be equipped with an appropriate set of bearers to ensure interoperability for train operations across European countries as well as regional trains when moving from operational areas supporting different or multiple bearers.

But **time and cost** are the key drivers to be considered by RUs. Depending on the migration scenario chosen by IMs and independent of the Bearer Independence Concept, the benefits and disadvantages of migration scenarios that are outlined in the migration study are still valid. Moreover, the cost of on-board communication device(s) in a multi-bearer environment must be considered. The cost could however be drastically reduced if the on-board communication device is the single point of communication for all applications.

8.3 Challenges and opportunities

The concept of bearer independence provides great flexibility for railway stakeholders to choose the best bearer to meet their needs while ensuring interoperability of mission-critical applications across borders. But this flexibility introduces new challenges. Giving the choice to deploy an appropriate but not unique communication infrastructure in each Member State does not provide a common view of an overlay network such as GSM-R does. In contrast, it provides a vision of a patchwork of communication infrastructure, which is outlined in the following pictures:

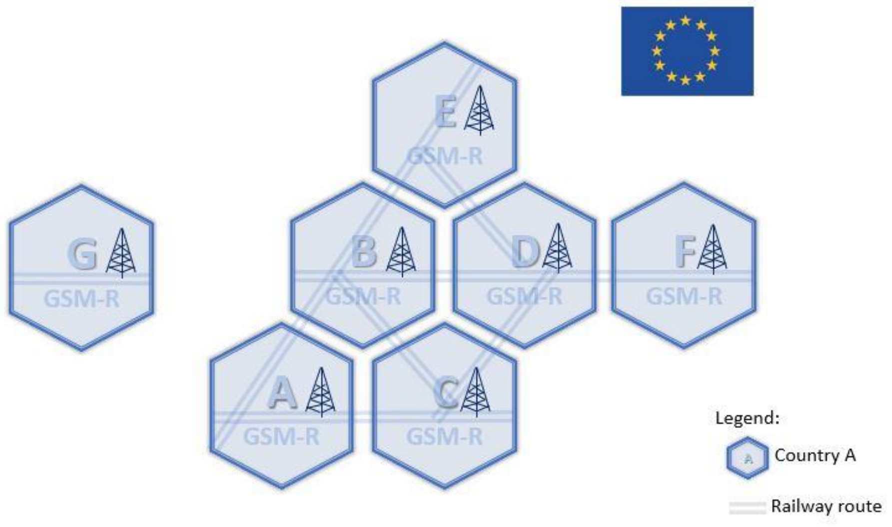


Figure 45. Before BIC – GSM-R European overlay network

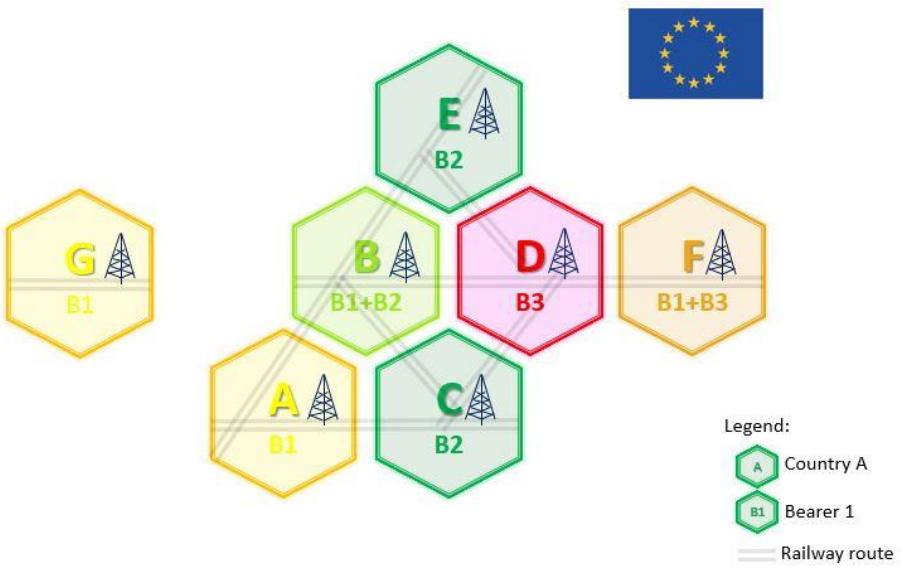


Figure 46. With BIC – patchwork of communication radio systems

We attempt to articulate key challenges which may be able to overcome more easily through a **coordinated approach** between railway stakeholders. Let's get a picture of challenges to arise for railway sector in a non-coordinated approach.

8.3.1 Key challenges for IMs

Assume for the sake of argument that the GSM-R band is the only spectrum band available for mission-critical applications. Under this assumption, migration plans need to consider only the single network approach.

One of the key challenges to be tackled by IMs concerns border crossing issues related to spectrum. Radio engineers know that radio broadband technologies have much more impact on adjacent bands than narrow band systems. As 4G technologies are broadband radio systems, the impact of migrating 4G adjacent to 2G bands causes more interference than 2G technologies do. A non-coordinated approach at borders between two neighbouring countries could lead to harmful interference to the neighbours while early IM migrates to NG. A European coordination should help to tackle this challenging spectrum issue to maintain interoperability, protect investments already made in GSM-R and ETCS, and ensure service continuity beyond national borders.

Single- or dual-network migration scenarios are driven by cost efficiency. The main objective for IMs in their respective deployment plan is to operate and maintain GSM-R for the shortest period of time. Operate and maintain GSM-R while NG is commissioned require IMs to maintain operational support, network management systems and teams for both radio systems.

The main condition to stop operating and maintaining GSM-R is that all trains running on sections where GSM-R is deployed are equipped with NG-compliant on-board units. If a single train is not equipped to support NG, GSM-R cannot be decommissioned.

To speed up the deployment plan and to enable decommissioning of GSM-R, European, national or IM rules might oblige RUs to migrate to NG by a predetermined and reasonable deadline (if and only if CCS TSI allows the use of NG). A coordinated approach may be necessary, since RUs otherwise have little incentive to migrate.

Funding the migration is a separate but complex issue that was touched on in the ERA study on migration of railway radio communication system from GSM-R to other solutions in 2016. It is outside the scope of the current study.

Recommendation 16. Migration plans to new bearers may need coordination at a European level, and must be harmonised with updates to the CCS TSI. Consider establishing a requirement at European, national or IM level for RUs to support NG (the Next Generation successor to GSM-R) by a predetermined and reasonable deadline, since RUs otherwise have little incentive to migrate.

8.3.2 Key challenges for RUs

In a non-coordinated approach, RU's must anticipate the migration to NG before IMs decide to migrate infrastructures. They must upgrade all traction units in advance. They would not likely be able to take advantage of already scheduled maintenance cycles of traction units including Cab Radios and EDORs. Moreover, the installation of multi-mode radio units must be foreseen by RUs while considering the exhaustive list of bearers, even if bearers are not deployed on the ground. Note that new software radio like SDR might help to solve this problem. Particularly, if new spectrum bands must be supported (assuming the hardware has the necessary capabilities) to a greater degree than was the case with GSM-R technology.

The financial impact for RUs will need to be considered based on the defined and finite list of bearers (including the spectrum bands in which they operate), especially for mission-critical applications. A coordinated approach for national and international train services should help to efficiently control the financial impact for RUs by providing a smoother and phased deployment plan.

Some tools could help to coordinate efficiently. One of them has been identified as a key enabler of a coordinated approach which is the register of infrastructure (also known as **RINF**).

The format of the RINF gives an exhaustive view to RUs of national sections where analogue and GSM-R infrastructures are already deployed or planned. RUs could thus have a clear picture of radio systems deployed along the railway routes where they deliver national and international train services.

The RINF tool could be updated with additional data to describe a set of bearers already deployed or planned for any railway section.

Recommendation 17. Consider expanding the register of infrastructure (RINF) tool and database to depict the routes where each of the bearers permitted under a future TSI is deployed, or is planned to be deployed.

8.3.3 **Additional challenges**

8.3.3.1 Network models

One additional key criterion to influence deployment strategy is the network model. In legacy radio systems, the Railway IMs are owner of the infrastructure and spectrum bandwidth. IMs are in charge of providing communications services to railway stakeholders by means of owning and operating the radio mobile infrastructure. But other models are existing in parallel such as Public Private Partnership (PPP) or using commercial Mobile Networks, or a private and shared infrastructure (e.g. PPDR) or site sharing. A new disruptive infrastructure and ownership model should be foreseen, and the rail sector should think Communications "**as a Service**". Commercial or private Communication Service Providers (CSPs) deliver a service to their customers with agreements/contracts on communication services, performance and security requirements to be met. Service Level Agreements (SLA) must be foreseen between IMs/RUs and CSPs.

This "as a Service" model could be considered in both dual- and single network migration scenarios.

But new stakeholders such as CSPs provide additional complexity in the process of the deployment plan.

8.3.3.2 Spectrum

Spectrum needs to be address as a key criterion to influence migration scenarios. Note that according decision on frequency, on-board equipment will have to potentially support various frequencies (different antenna, sharp filtering…).

Lessons learnt from the previous European migration from analogue radio system to digital radio system (i.e. GSM-R) did not bring to light issues on spectrum. Because the previous deployment plan provided the way to migrate from analogue to digital radio systems without any common or adjacent frequency bands.

When radio systems were analogue, UIC provided technical regulations for international analogue train-to-ground radio systems in 440-470 MHz frequency bands (referring to UIC leaflet 751-3). The previous signalling system was not a European harmonised system across Europe and many proprietary solutions was deployed with or without any radio communication needs.

Then GSM-R was introduced to provide a mean of communication for train-to ground voice radio and ERTMS signalling system across Europe to ensure interoperability. GSM-R was standardised on a dedicated frequency band for rail, using 4 MHz duplex band:

- 876-880 MHz for uplink transmission
- 921-925 MHz for downlink transmission

The GSM-R band was identified, harmonised at European level and made available by Member States to IM's to provide railway communication services.

Back to the migration, the analogue and digital bands were not adjacent, providing an easy way for migration without the need to establish a strategic frequency plan to avoid harmful interferences between radio systems.

It will not be the same story for the introduction of the future radio system and the migration plan.

Assuming that the GSM-R band is the only available frequency band for both GSM-R and the future digital communication system for at least mission-critical data such as ERTMS and train-to-ground voice radio, migration scenarios have to be re-defined.

The key benefit identified in the migration study for railway stakeholders could not be enjoyed such as a smooth migration for RUs. RUs will have to speed up their migration plan, bringing additional cost.

As identified in the migration study, the scenario based on a single network on ground (referred to scenario 1c in the migration study) is the most cost effective scenario for both IMs and RUs.

8.3.3.3 Radio softwarisation

Radio softwarisation emerging concept (refer to ETSI TC RRS for more details) could bring benefits by means of ease of migration. Radio Apps, already introduced in the ecosystem development paragraph, in the ETSI software reconfiguration framework allow replacement of entire RATs (Radio Access Technology) in case of sufficient computational resources on the device.

A smooth infrastructure migration could be considered if on-board communication equipment provides sufficient memory and computational resources to download Radio Apps of newly deployed infrastructure.

As an example, while country D has already migrated from GSM-R to newly deployed bearer 3 (B3), country E is still using GSM-R technology on ground. International trains need to comply with B3 and GSM-R to cross the borders. On-board communication devices must be ready to migrate to future infrastructures even though infrastructure RAT is not already known by means of Radio Apps download.

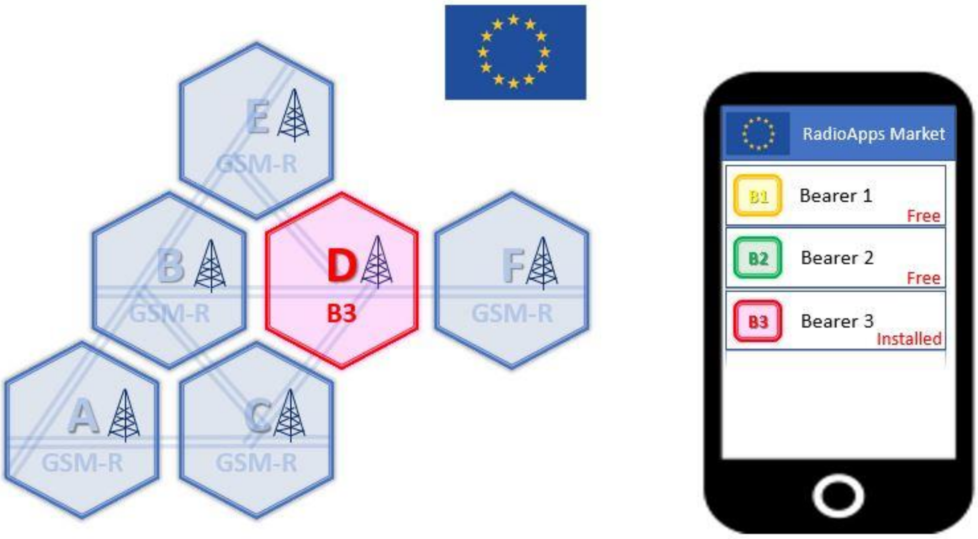


Figure 47. On-board device ready to cross borders with B3 and GSM-R

When the new infrastructure has been deployed and commissioned (bearer 2 – B2), on-board device must download the newly deployed bearer B2 via the Radio Apps market to ensure interoperability when crossing the borders from country D to country E.

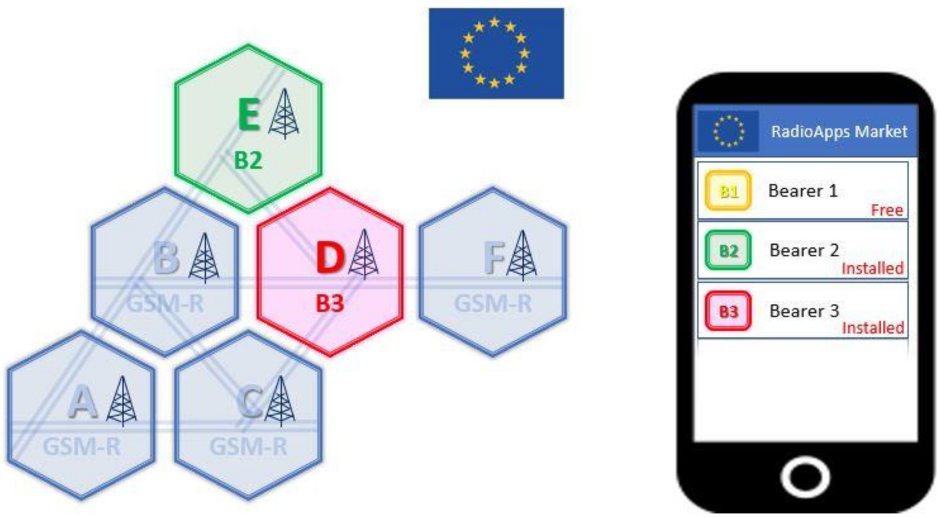


Figure 48. On-board device ready to cross borders with B3 and B1

With the emerging concept of softwarisation even of radio processing, regulation challenges have to be overcome with the certification process to install software components impacting mandatory requirements or radio characteristics. Radio equipment (hardware and software) must also be compliant with the future Radio Equipment Directive (RED) including articles on software reconfiguration.

Over-the-air security delivery and installation of software components must also be addressed.

Recommendation 18. ERA should initiate a detailed study to explore a range of potential practical, legal and regulatory impediments to the future migration to bearers other than GSM-R. Potential impediments include (1) the possible need for re-certification of the train; (2) legal and regulatory barriers; and (3) security concerns with over-the-air update of operational rail software.

8.3.4 Legal aspects

The impact of bearer independent communication concept on legal framework (Interoperability directive, Technical Specification of Interoperability, interoperability Control-Command & Signalling sub-systems, Interoperability Constituents) must be further analysed but out-of-scope of this study. In particular, if there is no more reference to any bearer in the specifications of ETCS, do we need a list of (limited) appropriate bearers to support ETCS on the TEN-T network or must it be left to Members States to choose if interoperability is not impacted due to appropriate implementation of the concept? What will be the impact of bearer independence on CCS TSI on-board and trackside sub-systems? Same question for Interoperability Constituents (current ICs are GSM-R voice cab radio, GSM-R EDOR, SIM cards) and conformity assessment process? Interoperability constituents must be redefined for the new system depending on the solutions provided to support the bearer independence.

The new candidate bearers should likely not be directly referenced in the CCS TSI; however, the CCS TSI must clearly define the minimum mandatory functional requirements of the communication system by means of communication services, performance, and security requirements to ensure interoperability. Candidate bearers must comply with these functional requirements in order to be considered to be eligible. This list of eligible bearers must be made available to IMs and RUs as a **defined and finite list of bearers**. But the concept of TSI compliant radio will be no more valid. What could be the process of conformity assessment of the radio components? This is a key question to be addressed by ERA if the concept is supported by the rail sector.

Whatever decision is chosen to update the TSI and the conformity assessment, new legal obligations will have direct impact on national deployment plans. A European coordination is an essential condition to ensure interoperability of trains across Europe.

8.4 Findings

No new findings were identified in this chapter. The recommendations are dependent on findings from previous chapters.

8.5 Recommendations

European coordination should help to tackle the challenging spectrum issues to maintain interoperability, protect investments already made in GSM-R and ETCS, and ensure service continuity beyond national borders particularly in this extreme spectrum scenarios where not the full R-GSM band is available.

Recommendation 16. Migration plans to new bearers may need coordination at a European level, and must be harmonised with updates to the CCS TSI. Consider establishing a requirement at European, national or IM level for RUs to support NG (the Next Generation successor to GSM-R) by a predetermined and reasonable deadline, since RUs otherwise have little incentive to migrate.

Recommendation 17. Consider expanding the register of infrastructure (RINF) tool and database to depict the routes where each of the bearers permitted under a future TSI is deployed, or is planned to be deployed.

Recommendation 18. ERA should initiate a detailed study to explore a range of potential practical, legal and regulatory impediments to the future migration to bearers other than GSM-R. Potential impediments include (1) the possible need for re-certification of the train; (2) legal and regulatory barriers; and (3) security concerns with over-the-air update of operational rail software.

9. OPERATIONAL MANAGEMENT

For the Bearer Independence Communication Concept to work, network operations and maintenance services together with vehicle maintenance need to be provisioned in a multi-bearer environment.

This chapter focusses on this condition for success of the concept and is structured in the following manner:

- Conditions and areas of study
- Network management
  - Setting the scene
  - Key challenges (and opportunities, if any)
  - Findings and recommendations
- Vehicle maintenance
  - Setting the scene
  - Key challenges (and opportunities, if any)
  - Findings and recommendations

The Table 28 presents the scope of the condition.

6	**OPERATIONAL MANAGEMENT**	Network Management	On-board communication devices maintainability

Table 28. **Scope of Operational Management**

9.1 Conditions and areas of study

The following chapters will assess the network management and vehicle maintenance challenges to be overcome by the rail sector to support the BIC concept. Areas of study which are impacted by network management and the vehicles maintenance are outlined in Table 29:

	Vehicles	Spectrum	Infrastructure	Legal framework	Security aspects
Operational management	X		X		

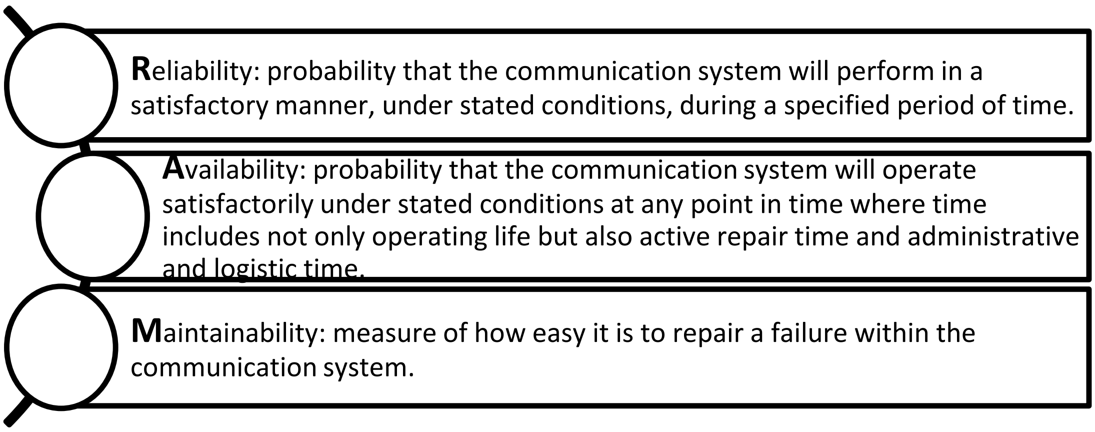
Table 29. Areas of study of the Operational Management Condition

9.2 Network Management

9.2.1 Setting the scene

When a railway communication system has been commissioned such as GSM-R in main European countries today, the infrastructure needs to be monitored 24 hours a day, 7 days a week to comply with Reliability, Availability, and Maintainability (RAM) requirements of any given railway application supported by the communication system.

The definitions of the RAM requirements are outlined in Figure 49 below:



Source: ITU

Figure 49. RAM

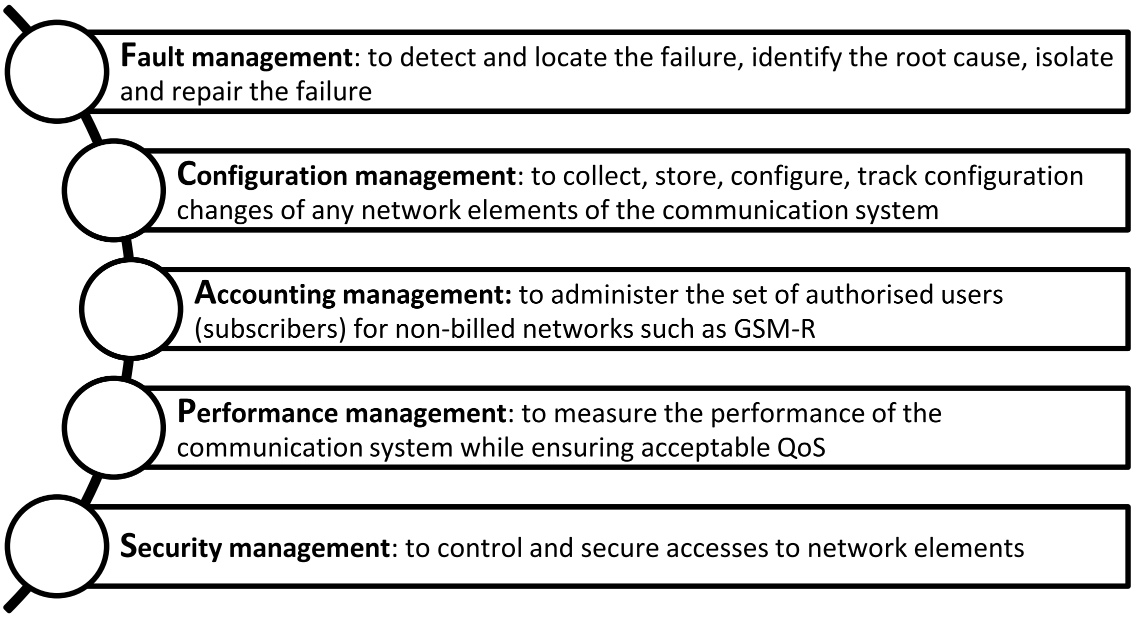
To comply with these RAM requirements, network operators must use network management architecture and models to define appropriate network management activities such as operations and maintenance service provisions, organisation and processes, repair and operational readiness, subscriber management, performance management and exchanges with railway operations to deal with planned works and real-time failure management.

Network Management architectures are often broken down into four component models (classification referenced in ETSI network management architectures based on "Web-based Management of IP Networks and Systems". J-P Martin-Flatin, Wiley):

1) A data model (e.g. SMI, CIM) i.e. the way in which information is represented such as object-oriented for instance.

2) A communication model (e.g. SNMP, CMIP, HTTP, FTP, CORBA) i.e. a list of protocols.
3) An organisational model e.g. centralised, distributed, and the way in which agents and managers communicate to each other.
4) A functional model (e.g. the FCAPS functions or eTOM) which are almost universally accepted as models.

The ITU-T has categorized network management into five management functional areas (refer to ITU-T Rec. M.3400). The five FCAPS management functional areas identified to date are outlined in Figure 50:



Source: ITU

Figure 50. FCAPS

Performance is essential for Railways to ensure delivery of mission-critical applications. End-to-end performance of voice and data services are the main points of interest for railway users. That is why network operators need to ensure that performance requirements are met 24 hours a day, 7 days a week. If not, they must ensure to railway users that the system will be restored in a pre-defined and guaranteed delay.

Network Management activities are often located in a Network Operations Center (NOC), managed by the Infrastructure Manager (IM) or outsourced by third parties such as commercial MNO’s network management team. When the NOC is outsourced, a service level agreement (SLA) is signed between the IM and the Network manager to ensure that RAM requirements are met.

The team in charge of network management activities must:

- Monitor in real-time all network elements of sub-networks
- Maintain the sub-networks

- Manage the subscription
- Manage the performance (i.e. report to the IM key performance indicators)
- Contact with railway operations (often organised as a one-stop-shop)

The network management activities of a traditional GSM-R infrastructure as seen as a set of sub-networks such as the access network, the core network, the transmission network and the test lab network, are outlined in Figure 51:

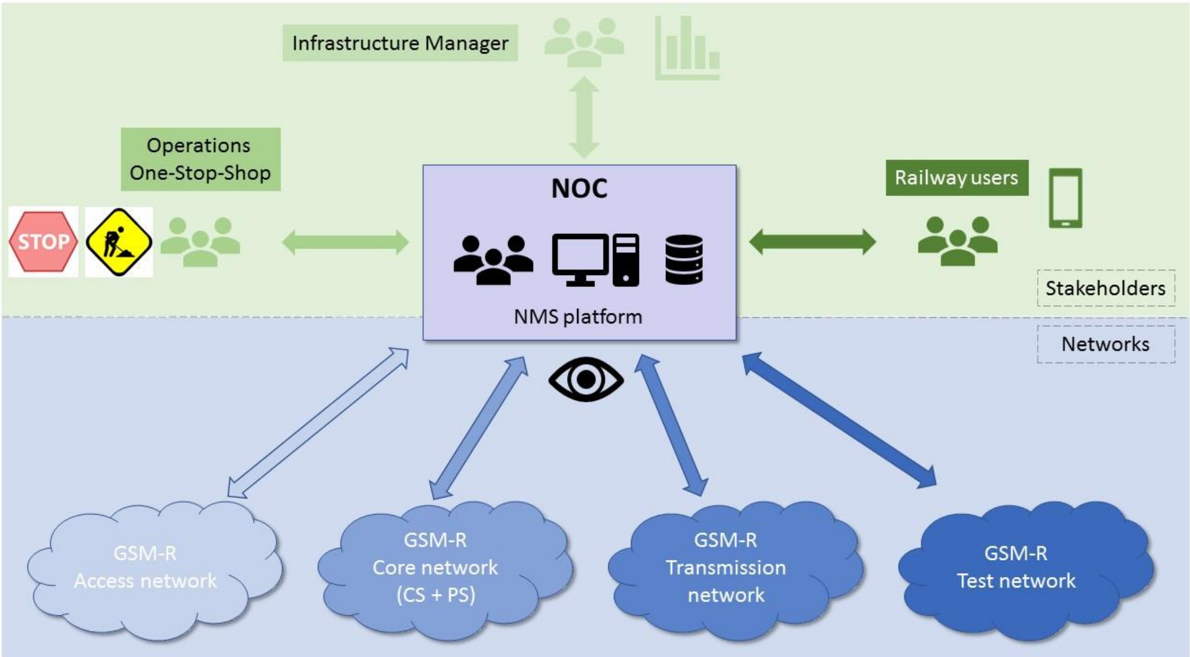


Figure 51. Network management activities

9.2.2 Key challenges and opportunities

But what are the implications of bearer independent communication concept on network management?

The BIC concept is based on heterogeneous networks environment, where network equipment are coming from different industries (Telecom, Information Technology - IT, Satellite) using different technologies, and managed by different network operators or Communication Service Providers (CSPs).

These different networking environments are managed by different network management platforms connected to network equipment that operate independently in silos. These network operators are using different:

- Data models.
- Communication models. IT are mainly using standardised protocols (RFC standards) such as SNMP, FTP, or HTTP while telcos are mostly using proprietary solutions provided by vendors

(e.g. monitoring platforms OMC-R/OMC-S) and specialized providers of network monitoring solutions (not open standards and open platforms).
- Organisational models. Different networking resources are also needed (roles, high-level of expertise and understanding of various technology platforms).
- Functional models.

The key challenge of network management to make BIC feasible is **end-to end management**: how do we successfully manage heterogeneous networks end-to-end? How do we avoid mission-critical service disruptions to railway users, detect and locate the failure quickly, identify the root cause as soon as possible and remediate the problem effectively (restore failure)?

Real-time information on network elements status is required from Network Operators/CSPs within their scope of responsibility.

But how do network operators be inclined to give access to key performance indicators?

How to reduce OPEX while the number of network operators will increase while complimentary developments will be needed to provide an integrated network management system?

All of these challenges need to be addressed to provide end-to-end network management and make the concept feasible.

Innovative technologies in network management could be a real opportunity for the rail sector to provide solutions to heterogeneous network management. At the centre of the network management transformation are three key technologies in Telecom and IT industry: software-defined networking (SDN), Network Functions Virtualization (NFV), and cloud. Traditional monolithic telecom infrastructure is being replaced by software elements that run on commercial off-the-shelf hardware—aided by virtualization technologies and cloud-based deployment and delivery models. SDN is driving automation and real-time programmability for the network infrastructure. Together, these three technology initiatives are transforming the CSP infrastructure into a highly programmable entity that has the potential to be personalized in real time and on a massive scale.

9.2.3 Desired characteristics of bearer independent network management

The key challenge of network management to make BIC feasible is the **end-to end management**: how do we successfully manage heterogeneous networks end-to-end? How do we avoid mission-critical service disruptions to railway users, detect and locate the failure quickly, identify the root cause as soon as possible and remediate the problem effectively (restore failure)?

End-to-end management must fulfil the requirements outlined below:
- Standardised protocols to manage faults and performance from heterogeneous networks
- Improve visibility across the heterogeneous networks to accelerate root cause identification, analysis, and diagnosis.
- Ensure reliability by decreasing Mean-Time-Between-Failure (MTBF) and Mean-Time-To-Failure (MTTF).
- Ensure maintainability by decreasing Mean-Time-to-Repair (MTTR) and Maximum-Time-to-Recovery.
- Ensure availability by reducing down-time (combination of MTBF and MTTR) and maximize SLA. Support quick failure recovery.

- Maximise bandwidth usage across the network (e.g. avoid non-optimised protocols such as SNMP producing unnecessary heavy traffic and overloading the network).

An integrated, scalable, and cost-efficient end-to-end network management solution with previously listed minimum requirements is key enabler to the success of network management in the concept of BIC.

Finding 40. End-to end management is a key enabler for the successful realisation of the bearer independence concept.

9.3 On-board equipment maintenance

9.3.1 Setting the scene

9.3.1.1 Maintainability

The maintenance of the vehicle-mounted equipment will be focused on maintainability of on-board communication devices throughout the rest of this study.

As a first step, maintainability has to be defined to better understand challenges and opportunities in the context of BIC concept. The EN 50126 standard series define maintainability as "the probability that a given active maintenance action, for an item under given conditions of use can be carried out within a stated time interval when the maintenance is performed under stated conditions and using stated procedures and resources."

The ERTMS users group and UIC actively collaborated by editing ERTMS/ETCS RAMS requirements specification (reference 31). The chapter 2 of these requirements had a main focus on RAM requirements to the overall ERTMS/ETCS system, including the on-board equipment and the radio.

ERTMS maintainability targets have been addressed through a set of qualitative maintainability requirements. The objectives of those requirements were to address the design to facilitate preventive and corrective maintenance on ERTMS/ETCS devices and software modules.

ERTMS maintainability targets and associated key requirements are of particular interest for this study with special attention on economic criteria focusing on radio modules (to be seen as similar to bearer modules).

Among those maintainability requirements, those are of particular interest for our study on bearer independence concept are outlined below:

- Hardware requirements
  - Accessibility of the ERTMS/ETCS devices
  - Dismounting of the ERTMS/ETCS devices
  - Standardised and interchangeable elements lowering diversification
- Software requirements
  - Analysability of detecting failures and causes
  - Changeability when modifications are needed

Those ERTMS maintainability requirements must be met when designing the new on-board architecture introduced by the bearer independence concept.

9.3.1.2 On-board communication devices

After reviewing the basic principles of on-board equipment maintainability, we would like to address the equipment to be maintained, which are the on-board communication devices.

On-board GSM-R radio terminals are typically called in Europe Cab Radios and EDORs, which are the TSI compliant radios in the legal railway interoperability framework.

Cab Radios are radios for train-to-ground voice and non-mission critical data applications.

EDORs are data radios for ETCS applications.

Cab Radios and EDORs have typical modular construction. Their typical hardware architectures are using the same hardware modules for their communication services, providing standardisation and interchangeability to meet requirements of ERTMS/ETCS maintainability targets. These hardware modules are GSM-R modems (also called GSM-R modules or transceivers) provided by telecommunication industry suppliers which are independent devices from EDOR and Cab Radios devices. This architecture provides plug-and-play maintenance operations to provide highest flexibility for in line unit replacement.

Cab Radios and EDORs could typically use up to three GSM-R modems, as redundant devices, to meet reliability and availability requirements. When a traction unit need to be equipped with ETCS and train radio, EDORs and Cab Radios are installed. Assuming than two GSM-R modems are integrated in EDOR and three GSM-R modems are integrated in Cab Radio, a total of five modems are installed in one train cabin for communication services. The duplication of GSM-R modems for same purpose introduces a *de facto* duplication of maintenance operations. This multiplicity of modems increase the total time of predictive and corrective operations to be performed by maintenance staff. This excessive time increase the total cost of maintenance operations.

Moreover, SIM (Subscriber Identity Module) cards are hardware devices integrated in GSM-R modems provided by IMs. SIM cards are needed to access the service of a particular GSM-R network (i.e. establish and receive calls). Public emergency calls are the only communication service available without any SIM cards installed in the modems. The SIM won't work with the subscriptions of other networks. If the modem want to select a new MNO network, the SIM has to be changed unless roaming agreements have been signed.

SIM cards could be easily removed from GSM-R modems but not so easily when the modem is integrated in the Cab Radios or EDORs. The number of SIM cards is dependent of the number of GSM-R modems. In addition, if a new technology is introduced, a new SIM card is needed. Then a manual maintenance operation must be planned to switch the SIMs with physical access to the device.

9.3.2 Key challenges and opportunities

The Bearer Independency Concept must not introduce too many hardware elements with additional maintenance cost due to human interventions either with manual remote operations (e.g. network management team) or manual operations (traction unit maintenance staff) when tractions units stand at maintenance depots.

We would like to highlight maintenance cost with the following GSM-R recent use case: interference issues in Europe and impact on the railway sector, especially for RUs.

Interference issues between GSM-R and MNO networks are major handicaps to the right operations of ERTMS/ETCS. Railway sector worked together with national frequency regulators and MNOs since a while to define, build and run processes, standards and solutions to mitigate harmful interferences.

The technical standardised solution was a new *improved* receiver specification to make the GSM-R modems more robust from external jammers. Without the introduction of new radios such as software-defined radios (SDR), *improved* radios need a hardware upgrade (i.e. adding radio filters) to be compliant to the revised specification. As we already mentioned about the multiplicity of GSM-R modules in Cab Radios and EDORs, the cost to update a train fleet for a single RU depends on the volume of trains to be upgraded and the number of modems to be interchanged. Hardware changes and standing vehicles at depots outside of periodic maintenance cycles are too costly, representing an order of magnitude of up to tens of millions of euros for some of the biggest RUs in terms of trains' fleet.

One of the main challenge with the introduction of bearer independency concept will be to avoid multiple transmission hardware devices for same communication purposes. Evolution of specification on radio layers should not impact significantly the cost of maintenance operations for RUs.

We would like to sum up high-level conditions for success on vehicles maintenance with the introduction of bearer independency concept:

- Minimise the duration of human maintenance operations during periodic maintenance cycles
- Allow remote and secure maintenance operations outside periodic maintenance cycles without the need of standing vehicles at maintenance depots
- Reduce OPEX

Automation, Softwarization and **Integrated features** could be key solutions to overcome those challenges.

Automation could provide solutions to remote diagnosis, over-the-air secure updates, and optimised maintenance processes.

Softwarization with the emerging technological concept of new radios such as software-defined radios could be an opportunity to overcome these challenges by providing a way to upgrade radio features over-the-air without the need of standing vehicles at depots for maintenance purposes.

Integrated features such as embedded SIM (a.k.a. eSIM) which is a new kind of SIM provide ease of maintainability for former removable UICC. eSIM provides the following opportunities for the rail sector to improve on-board device maintainability without swapping the SIM out when changes are needed:

- SIM profiles should be easily downloaded over-the-air.
- Average life span of traditional SIM cards must be expanded.
- New technologies must be easily introduced.
- Ease of migration by remotely provisioning new subscriptions and supporting multiple subscriptions without adding technical complexity and roaming agreements to interconnect cellular networks across Europe.

Note that SIM cards are necessary for some bearer access in particular 3GPP and MNO technologies but not relevant for all access. For example, Wi-Fi access does not require a SIM card.

Additional maintenance solutions should be considered to reduce OPEX but are without the scope of the bearer independency concept such as preventive or predictive maintenance. Predictive maintenance anticipates critical technical failures before vehicle immobilisation, to reduce the number of technical failures during service. The optimisation of maintenance activities must be considered to reduce operation costs, improve service performance and quality perception. It also improves safety and drivers' confidence in the vehicle. Improvement of maintenance processes (which also impacts on the overall reliability of the service) needs also to be considered with focus on life cycle cost including investment cost, maintenance cost and operating costs.

9.3.3 Desired characteristics of vehicle maintenance

We would like to sum up high-level conditions for success on vehicle maintenance with the introduction of Bearer Independence Concept:

- Minimise the duration of human maintenance operations during periodic maintenance cycles
- Allow remote and secure maintenance operations outside periodic maintenance cycles without the need of standing vehicles at maintenance depots
- Reduce OPEX

are key enablers to the success of vehicle maintainability in the concept of BIC.

ERTMS/ETCS maintainability requirements must be met when designing the new on-board architecture introduced by the bearer independence concept.

The bearer independence concept must not introduce too many hardware elements with additional maintenance cost due to human interventions either with manual remote operations (e.g. network management team) or manual operations (traction unit maintenance staff) when tractions units stand at maintenance depots.

One of the main challenges with the introduction of bearer independence concept will be to avoid multiple transmission hardware devices for same communication purposes. Evolution of specifications on radio layers should not impact significantly the cost of maintenance operations for RUs.

Finding 41. Key goals in terms of vehicle maintenance are (1) to minimise the duration of human maintenance operations during periodic maintenance cycles; (2) to allow remote and secure maintenance operations outside periodic maintenance cycles without the need of standing vehicles at maintenance depots; and (3) to reduce OPEX. These are also the goals today under GSM-R. The introduction of bearer independence must not interfere without attainment of these goals.

9.4 Findings

End-to-end network management, together with cost efficient maintenance of on-board equipment, will continue to be important. The implementation of bearer independence must not negatively impact the attainment of these goals.

Finding 40. End-to end management is a key enabler for the successful realisation of the bearer independence concept.

Finding 41. Key goals in terms of vehicle maintenance are (1) to minimise the duration of human maintenance operations during periodic maintenance cycles; (2) to allow remote and secure maintenance operations outside periodic maintenance cycles without the need of standing vehicles at maintenance depots; and (3) to reduce OPEX. These are also the goals today under GSM-R. The introduction of bearer independence must not interfere without attainment of these goals.

9.5 Recommendations

No specific recommendations were identified in this chapter.

10. SUMMARY OF FINDINGS AND RECOMMENDATIONS

10.1 Introduction

This chapter is structured in the following manner:

- Final definition of Bearer Independent Communication
- Summary of the findings from each of the chapters relating to conditions (Chapter 3 to 9)
- Summary of key findings
- List of recommendations

10.2 Final definition of Bearer Independent Communication

Bearer Independent Communications (BIC) are communications between two or more users and/or applications over a single access network or multiple heterogeneous access networks with no dependence on the availability of any bearer-specific features. Applications communications could in principle be supported over any IP-based bearer, whether commercial or private, without assuming that the bearer provides any capabilities beyond data transmission using the Internet Protocol (IP). Service continuity is required in both stationary and (high-)mobility scenarios with the transparent use of one or more bearers.

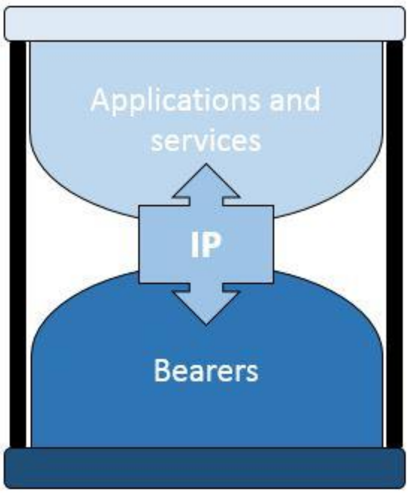


Figure 52. Bearer Independence Communication Concept

10.3 Findings

The findings address a range of issues including the goals and methodology of the study; the different visions of bearer independence, and their implications; standards and technology; network ownership and operational models; the management of mobility; the development of a bearer independent operational rail ecosystem addressing both transmission systems and operational rail applications; deployment plans; and operational management.

A numbered List of Findings appears at the beginning of this document, following the List of Figures and the List of Tables. For each finding, the List of Findings indicates the page on which the finding is initially derived.

For clarity of exposition, we present the findings in the most logical sequence, which is in many instances a different sequence than that in which they appear in the text (thus causing the Finding numbers to be out of sequence).

In terms of goals and methodology:

- Finding 1. Bearer independence can be introduced among new bearers, but full and comprehensive bearer independence is unlikely to be achieved until GSM-R has been decommissioned.
- Finding 2. The principal aims of introducing the Bearer Independent Communication Concept are (1) to allow flexibility in the implementation of new and diverse track-to-train radio services; (2) to facilitate the migration from one transmission technology to another; (3) to facilitate the maintenance of equipment; (4) to provide flexibility for the introduction, update, modification of, and maintenance of applications; (5) to provide flexibility for the introduction, update, modification and maintenance of the communications bearer; (6) to potentially provide better fall back or additional coverage offered by different networks and technologies; and (7) to provide flexibility in network capacity.
- Finding 3. In order to analyse conditions for success of the Bearer Independence Concept, it is helpful to categorise the conditions as relating mainly to (1) independence of the application layer and the transport; (2) guaranteed connectivity; (3) management of mobility; (4) ecosystem development; (5) the deployment plan; and (6) operational management.

Our findings as regards different visions of bearer independence and their relative desirability and sequencing:

- Finding 5. Stakeholders tend to gravitate to one of two architectural models of multi-bearer support. The *conservative view* is based on 3GPP standards, and on services similar to those offered by Mobile Network Operators (MNOs). The *flexible view* is based on Over-the-Top (OTT) services using IETF and IEEE standards, and thereby potentially expands the set of bearers to include bearers such as Wi-Fi and satellite.
- Finding 8. The flexible solution should be preferred in the medium to long term. Only the flexible solution offers full bearer independence. It is the solution that is most attuned to the likely long term evolution of the commercial market, where bearer independence has been taken for granted for many years. Moreover, the flexible solution is best positioned to support non-3GPP bearers such as Wi-Fi or SatCom in the medium or long term. It is the flexible solution that offers the broadest possibility to evolve operational rail communications over time.
- Finding 9. Short term implementation of the conservative view can be thought of as a stepping stone on the way to realisation of the flexible view. 3GPP-based solutions become one solution out of many.

Specific to the conservative view:

- Finding 4. Operational rail communications could potentially take advantage of the Mission-Critical Push-to-Talk (MCPTT) functionality that is an optional function in 3GPP Release 13 standards. It is unlikely, however, that Mobile Network Operators (MNOs) will deploy MCPTT unless they perceive sufficient demand for it from PPDR and/or operational rail. If MNOs do not demand these features, manufacturers will not implement them.
- Finding 36. *Wi-Fi calling* depends on 3GPP features. It is thus consistent with what we have referred to as the conservative view, but not with full bearer independence (i.e. the flexible view).

Specific to the flexible view:

- Finding 6. Full realisation of the flexible view would likely require the definition of new standards and protocols, with careful attention paid to performance and security. The bearers and applications are no longer bound to one another, but they effectively become an ecosystem where functionality and interoperability must be carefully planned for.
- Finding 7. Whether the conservative or the flexible view is ultimately followed, revisions to the various European instruments that ensure interoperability of rail communications (notably including the Technical Specifications for Interoperability (TSI)) are likely to be required.
- Finding 10. With bearer independence, we are seeking to deliver both voice and data operational rail communication services independently of underlying bearer-specific features. Today, it is routine for commercial data services to be fully bearer independent, and for voice services to ride on top of the bearer independent data services (as Voice over IP (VoIP)). This is the most natural approach for bearer independent operational rail communications to take.

As far as standards and technology in general:

- Finding 17. Current standards do not enable the full realisation of bearer independence.
- Finding 16. GSM-R has requirements beyond the standardised mandatory GSM capabilities required to support commercial mobile operations. The operational rail market is small, which implies that there is limited demand for equipment that can support GSM-R. This has led to delays in GSM-R standardisation and product availability, and additional cost within a niche market environment. Similar considerations might well apply to any future operational rail solutions that depend on specialised bearer-specific support in the transmission network.
- Finding 18. Current standards for many IP-based candidate bearers are potentially adequate for operational rail communications, once bearer-specific dependencies have been eliminated. Two areas that would nonetheless require intensive attention before incorporating any bearer into operational rail standards are (1) reliability and robustness requirements; and (2) QoS requirements, including end-to-end latency.

As regards potential or emerging technologies and standards that may be of interest in implementing bearer independence:

- Finding 15. Several emerging or developing technologies hold promise for the evolution of operational rail communications by potentially facilitating flexibility and infrastructure sharing. Among those that could be of interest are Open Wireless Architecture (OWA) and especially Software-Defined Radio (SDR), Network Functionality Virtualization (NFV), Software Defined Networks (SDN), and Multi Access Edge Computing (MEC).
- Finding 11. The IEC TCN communications architecture represents a valuable input as regards the safety of train operations.
- Finding 12. The ITxPT initiative provides a full ecosystem to deliver on-board plug-and-play IT systems to avoid vendor lock-in and foster the implementation of a standard IT on-board architecture.
- Finding 13. The First Responder Network Authority (FirstNet) that the US is in the process of deploying represents an interesting working example of a single network that provides communication services to both mission-critical safety and other non-mission-critical applications.
- Finding 14. Cooperative-ITS (C-ITS) is an Intelligent Transportation initiative that seeks to provide communication services between vehicles, infrastructures and other road users. It incorporates many of the same capabilities as those that are sought for bearer independent operational rail communications, including support for multiple bearers, transparent mobility management, and shared network resources.

As regards network ownership and operational models, and their implications:

- Finding 24. Spectrum options relevant for BIC provides a patchwork of models from legacy GSM-R model to a fully operated network model. This patchwork could be a major brake of putting into service standardised interference resilient products. Harmonised spectrum for railway applications could provide a framework to standardisation of interference resilient equipment, thus answering reliability figures of the FRMCS.
- Finding 26. The dedicated network is the preferred overall network model for GSM-R, but the alternative arrangements that are already in place demonstrate that other models may have value. The migration to fully bearer independent communications has the potential to facilitate the further evolution of other network operational models.
- Finding 27. The introduction of business and operational models other than dedicated GSM-R networks offers opportunities for rail operations, but it potentially also leads to considerably more technical and contractual complexity.
- Finding 25. With the move away from a single, dedicated GSM-R network, there is a need in many scenarios to establish clear Service Level Agreements (SLAs) in order to ensure that the necessary Quality of Service (QoS) is provided. Where multiple bearers operate in parallel, these SLAs might be tricky to implement.

As regards spectrum needs in order to achieve coverage in a bearer independent environment:

- Finding 19. Coverage is a fundamental requirement for operational rail communications. Ensuring coverage is a task for policymakers – it is not something that can be left to market mechanisms.

- Finding 23. The spectrum currently used for GSM-R is 876 MHz - 880 MHz for uplink, and 921 MHz - 925 MHz for downlink. The 4G mobile standards do not include these GSM-R bands. No additional spectrum has yet been designated for railways in Europe (to deal with migration to a successor to GSM-R, for example, for Member States that deploy dedicated networks). Many questions are not yet resolved as to how to best address the future evolution of operational rail communications, but efforts to resolve them are already under way by the ECC Frequency Management Working Group.
- Finding 20. Whether dedicated spectrum is required for operational rail communications depends on whether the Member State has chosen to support rail operational communications using a private, dedicated network, a private network shared with other mission-critical applications such as PPDR, or a public commercial network provided by an MNO.
- Finding 21. If the Member State has chosen an approach to operational rail or passenger rail communications where coverage of rail routes by one or more commercial MNOs is needed, this could be achieved by means of coverage obligations in a future spectrum auction (for example, in the coming auctions for 700 MHz spectrum).
- Finding 22. For a dedicated network, whether dedicated exclusively to rail or shared with other mission-critical uses, it is the Member State's responsibility to ensure that the network is deployed.
- Finding 30. Making the most of opportunities introducing bearer independence provides flexible solutions and alternatives to complex radio issues such as saturation of networks, interferences or extreme spectrum scenario.

As regards mobility management:

- Finding 31. Addressing and routing using rail-specific identities has not yet been specified in a manner consistent with bearer independence. Number translation is missing.
- Finding 32. The bearers available to on-board equipment will continually be in flux as the train moves. Full bearer independence makes this hand-off problem considerably more complex than it is today under GSM-R. The choice of bearer(s) might perhaps best be address by coordination between on-board equipment and infrastructure. This is not a solved problem.
- Finding 33. Mobility management has implications for security that are not yet well defined.

As regards the ecosystem for rail operational systems:

- Finding 37. The shift to bearer independence implies the need for re-thinking of the ecosystem of rail operation transmission systems and rail operational applications. Both must be active in the market if rail operational communications are to be successful, and to evolve over time to benefit from technological and market evolution.
- Finding 34. The same de-coupling of transport from application that provides bearer independence could also potentially enable rail operational software by third party providers that are independent of the firms that provide the transmission equipment. In some cases, applications that have general commercial application might be used, with or without rail-specific enhancements, to meet operational rail communication needs.

- Finding 35. If third parties are to be able to supply operational rail applications (especially in on-board systems), attention must be paid to ensure (1) open operating system platforms with well documented interfaces, (2) open well documented communications Application Programming Interfaces (APIs), (3) competitive constraints are not allowed to impede entry of new players, (4) the certification and approval process needs to carefully consider how to enable this kind of innovation without sacrificing safety, and (5) legal and regulatory requirements need to be fully thought through.
- Finding 38. Making it possible for third parties to provide applications potentially addresses a number of long-standing operational rail needs, including skill shortages for application developers and security experts.
- Finding 39. If 3GPP standardisation efforts were to fail to deliver the 3GPP features needed to fulfil railway functional requirements, an alternative will be needed. Fully bearer independent PTT applications could provide the answer, and third party PTT apps might possibly be the most effective way to ensure availability of the necessary applications.

As regards network neutrality:

- If a commercial MNO were to support operational rail communications, network neutrality rules (Regulation 2015/2120) are inapplicable because operational rail communications do not provide access to the Internet, and do not serve the general public. Even if they were applicable, operational rail communications would clearly represent a *specialised service*. Network neutrality does not appear to pose an impediment to the use of public mobile networks for operational rail.
- Finding 29. Network neutrality (Regulation 2015/2120) does not appear to be applicable to rail passenger communications, as long as the services are offered only to passengers. To the extent that they are offered to the public at large (in train stations, for example), then the network neutrality rules might well be applicable.

As regards operational maintenance:

- Finding 40. End-to end management is a key enabler for the successful realisation of the bearer independence concept.
- Finding 41. Key goals in terms of vehicle maintenance are (1) to minimise the duration of human maintenance operations during periodic maintenance cycles; (2) to allow remote and secure maintenance operations outside periodic maintenance cycles without the need of standing vehicles at maintenance depots; and (3) to reduce OPEX. These are also the goals today under GSM-R. The introduction of bearer independence must not interfere without attainment of these goals.

10.4 Recommendations

A numbered List of Recommendations appears at the beginning of this document, following the List of Findings. For each recommendation, the List of Recommendations indicates the page on which the recommendation is initially presented.

Our recommendations in terms of the evolution of standards and technology are:

- Recommendation 1. The IEC TCN communication architecture may represent a good basis on which to design additional rail safety operations. Collaboration with IEC members should be considered in order to avoid redundant work on train to ground communication systems.
- Recommendation 2. Lessons learned from initiatives such as the ITxPT initiative should be considered by the rail sector as a means of overcoming the challenges of implementing SOA models.
- Recommendation 3. Lessons learned from initiatives such as the First Responder Network Authority (FirstNet) that the US is in the process of being deploying should be considered by the rail sector as a means of overcoming the challenges of implementing a single network that supports both mission-critical and non-mission-critical services.
- Recommendation 4. Lessons learned from initiatives such as the Cooperative-ITS (C-ITS) initiative should be considered by the rail sector as a means of overcoming the challenges of implementing bearer independent mission-critical communications.
- Recommendation 5. ERA should consider more detailed study of various network designs that are either being implemented or else are under consideration to determine the degree to which lessons learned are potentially applicable to European operational rail communications. Candidates for further study include the ITxPT initiative, FirstNet in the US, and the Cooperative-ITS (C-ITS) initiative.
- Recommendation 6. ERA should use its good offices to promote or encourage interaction between the operational rail communications community and the standards bodies responsible for technologies that are potentially of interest. Technologies where increased engagement may be warranted include the Open Wireless Architecture (OWA) and especially Software-Defined Radio (SDR), Network Functionality Virtualization (NFV), Software Defined Networks (SDN), and Multi-Access Edge Computing (MEC).
- Recommendation 7. In order to ensure that standards are in place to enable the full realisation of bearer independence, ERA should use its good offices to ensure (1) that all relevant functional specifications are updated so as to eliminate dependence on bearer-specific capabilities beyond those embodied in basic transmission standards for most bearers; (2) that a gap analysis is conducted to identify capabilities that would need to be implemented at the Application Layer in order to provide necessary functionality going forward (presumably equivalent to that available under GSM-R today); and (3) that standards are developed that address the gaps identified. Where necessary and appropriate, ERA might ask the Commission to issue mandates to the European Standards Organisations (ESOs).
- Recommendation 8. De-coupling of ETCS is called for, both in terms of specifications and of implementation. The introduction of middleware between the Euroradio Safety Layer and the Euroradio Communication Layer should be considered. ERA should consider launching studies as to how best to achieve the de-coupling.

In terms of management of mobility, our recommendations are:

- Recommendation 9. ERA should use its good offices to ensure that a bearer independent solution is found that addresses the need for addressing (including number translation) and routing using rail-specific identities.
- Recommendation 10. ERA should ensure that technical solutions are found to identifying the correct bearer(s) as the train moves. A study might be appropriate as a first step.
- Recommendation 11. ERA should ensure that a security architecture for bearer independent operational rail communications is developed. A security risk assessment based on major threat use cases, vulnerability of each assets, and potential impact is needed. The results could be reflected in a future revision of the UIC User Requirements Specification (URS).ERA should use its good offices to ensure that a bearer independent solution is found that addresses the need for addressing (including number translation) and routing using rail-specific identities.

The development of a suitable ecosystem for operational rail transmission and applications requires special attentions. The decoupling of the two offers many new opportunities.

- Recommendation 12. ERA's support for bearer independence should be undertaken in such a way as to make possible the development and deployment of third party operational rail applications.
- Recommendation 13. ERA should consult with stakeholders, and launch studies if appropriate, to determine how best to ensure that operational rail (on-board) equipment is based on open and well documented operating systems and communication APIs so as to enable deployment of independently developed operational rail applications.
- Recommendation 14. ERA should consult with stakeholders, and launch studies if appropriate, to determine whether actions at European level would be needed to ensure through standards and through IM and RU procurement policies that unnecessary barriers are not erected to market entry of third party operational rail applications.
- Recommendation 15. ERA should consider carefully, consulting with stakeholders and launching studies if appropriate, how to evolve the certification and approvals process so as to support bearer independence in general and the introduction of third party applications in particular.

In terms of the interaction of bearer independence with migration plans, our recommendations are:

- Recommendation 16. Migration plans to new bearers may need coordination at a European level, and must be harmonised with updates to the CCS TSI. Consider establishing a requirement at European, national or IM level for RUs to support NG (the Next Generation successor to GSM-R) by a predetermined and reasonable deadline, since RUs otherwise have little incentive to migrate.
- Recommendation 17. Consider expanding the register of infrastructure (RINF) tool and database to depict the routes where each of the bearers permitted under a future TSI is deployed, or is planned to be deployed.
- Recommendation 18. ERA should initiate a detailed study to explore a range of potential practical, legal and regulatory impediments to the future migration to bearers other than GSM-

R. Potential impediments include (1) the possible need for re-certification of the train; (2) legal and regulatory barriers; and (3) security concerns with over-the-air update of operational rail software.**Error! Reference source not found.**

11. ANSWERS TO THE QUESTIONS IN ERA'S TERMS OF REFERENCE

The Terms of Reference (TOR) of the study stipulate different questions to be addressed.

The findings and recommendations developed in this study collectively answer the questions that were posed. In this chapter, we identify key elements of the response.

For each of the questions identified in the list of TOR questions is presented below and against each one a reference is made to the relevant section in this report that deals with the question.

11.1 Conditions for rolling stock

a. What may be needed to allow bearer independency: system architecture?

In terms of technical standards and systems architecture, ERA should use its good offices to ensure (1) that all relevant functional specifications are updated so as to eliminate dependence on bearer-specific capabilities beyond those embodied in basic transmission standards for most bearers; (2) that a gap analysis is conducted to identify capabilities that would need to be implemented at the Application Layer in order to provide necessary functionality going forward (presumably equivalent to that available under GSM-R today); and (3) that standards are developed that address the gaps identified. Where necessary and appropriate, ERA might ask the Commission to issue mandates to the European Standards Organisations (ESOs). Migration plans to new bearers may need coordination at European level, and must be harmonised with updates to the CCS TSI.

b. Availability of on-board applications to achieve the overall functionality.

This needs to be approached with a view of the operational rail ecosystem. The shift to bearer independence implies the need for re-thinking of the ecosystem of rail operation transmission systems and rail operational applications. Both must be active in the market if rail operational communications are to be successful, and to evolve over time to benefit from technological and market evolution. ERA's support for bearer independence should be undertaken in such a way as to make possible the development and deployment of third party operational rail applications. ERA should consult with stakeholders, and launch studies if appropriate, to determine how best to ensure that operational rail (on-board) equipment is based on open and well documented operating systems and communication APIs so as to enable deployment of independently developed operational rail applications. ERA should consult with stakeholders, and launch studies if appropriate, to determine whether actions at European level would be needed to ensure through standards and through IM and RU procurement policies that unnecessary barriers are not erected to market entry of third party operational rail applications.

c. Identification of possible constraints, such as:

- product availability in relation to the timing of the start of migration
- development and implementation costs
- delays in standardisation
- other economic constraints.

ERA should initiate a detailed study to explore a range of potential practical, legal and regulatory impediments to the future migration to bearers other than GSM-R. Potential impediments include (1) the possible need for re-certification of the train; (2) legal and regulatory barriers; and (3) security concerns with over-the-air update of operational rail software.

d. Deployment plan of the RUs ("dual mode" or "single mode" on-board equipment; expected schedule for deployment): impact on the European implementation (coordinated migration scenario vs non-coordinated).

ERA should consider establishing a requirement at European, national or IM level for RUs to support NG (the Next Generation successor to GSM-R) by a predetermined and reasonable deadline, subject to the CCS TSI allowing the use of NG. A coordinated approach may be necessary, since RUs otherwise have little incentive to migrate.

*In previous work,[17] we identified the need for RUs to deploy dual-mode GSM-R / NG equipment **before** IMs deploy NG, and certainly before IMs phase out GSM-R.*

11.2 Conditions for spectrum usage

a. What may be needed to allow bearer independency: reception of different spectrum bands and use of different technologies?

   The answers are generally the same as for 11.1(a).

b. Availability of radio terminal equipment to achieve the overall functionality: spectrum emission masks better than the ones currently available for LTE; prevention of blocking and intermodulation.

   Spectrum issues are very important for the migration to next generation operational rail technology, and on-board equipment with the ability to operate in the bands that will ultimately be used for the next generation successor should be deployed opportunistically as equipment is brought in for maintenance. The migration to bearer independence is, however, generally independent of the migration to next generation operational rail technology.

c. Identification of possible constraints, such as:
   - product availability in relation to the timing of the start of migration
   - development and implementation costs of radio terminals (SDR or others) that can use the GSM-R spectrum band and others
   - delays in standardisation (definition of the R-GSM band in the 3GPP re114 and beyond)
   - dependency on the allocation of spectrum.

[17] Systra (2016) Final Report ERA 2015 04 1 RS Study on migration of railway radio communication system from GSM-R to other solutions

The answers are generally the same as for 11.1(c).

d. Extreme spectrum scenarios: locations where not the full R-GSM band is available (at network borders).

Again, spectrum issues are very important for the migration to next generation operational rail technology. The migration to bearer independence is, however, generally independent of the migration to next generation operational rail technology.

Bearer independence provides opportunities to solve spectrum issues such as extreme spectrum scenario detailed in Section 5.3.7 Opportunities. At network borders where not the full R-GSM dedicated band might not be available, flexibility of failing over to another bearer upon degradation or capacity limitation of active bearer due to limited availability of spectrum could bring solutions to Railways, thanks to bearer independence.

e. Possible deployment strategy: linked to the migration scenarios described (see Annex I), consider the benefits of using 1,4 MHz in the R-GSM band first and to use the full 3 MHz when GSM-R will be switched off; synergies with PPDR.

Again, spectrum issues are very important for the migration to next generation operational rail technology. The migration to bearer independence is, however, generally independent of the migration to next generation operational rail technology.

11.3 Conditions for the infrastructure

a. What may be needed to allow bearer independency: system architecture?

The answers are generally the same as for 11.1(a).

b. Justification of the need to use dedicated networks, or under which circumstances could public networks be used.

In theory, public networks could be used to the extent that they meet the requirements of the relevant operational rail applications in terms of (1) coverage, (2) quality of service (including latency), (3) reliability and robustness, and (4) security. In practice, it may be either difficult or prohibitively expensive for commercial mobile networks to meet those requirements; at the same time, however, multi-bearer might facilitate solutions where commercial mobile networks play a complementary role to dedicated networks. In any solution where commercial networks contribute to the fulfilment of mission-critical operations, resource allocation and sharing between commercial versus mission-critical use will be challenging.

c. Availability of applications to achieve the overall functionality with more than one network providing services (i.e. at least GSM-R and another one).

The answers are generally the same as for 11.1(b).

d. Identification of possible constraints, such as:

- network management for various technologies/types of networks (i.e. at least GSM-R and another one)
- subscriber management
- international services (roaming)
- relation to the timing to start the migration
- development and implementation costs; other economic constraints.

The answers are generally the same as for 11.1(c).

e. Deployment plan of the IMs: impact on European implementation (coordinated migration scenario vs non-coordinated); conditions to stop GSM-R services in a region.

ERA should consider establishing a requirement at European, national or IM level for RUs to support NG (the Next Generation successor to GSM-R) by a predetermined and reasonable deadline, subject to the CCS TSI allowing the use of NG. A coordinated approach may be necessary, since RUs otherwise have little incentive to migrate. Migration plans to new bearers may need coordination at European level, and must be harmonised with updates to the CCS TSI.

11.4 Conditions for the legal framework

a. Different legal frameworks in the MSs related to telecommunication services and obligations, in particular regarding the provision of internet services and information to passengers.

Legal and regulatory frameworks at European level and among the Member States have very little impact on bearer independence (and vice versa). As long as rail communications are either (1) operational or (2) delivered only to passengers but not to the public at large, they do not constitute Electronic Communication Services (ECS), and thus are not subject to most provisions of the Regulatory Framework for Electronic Communications (RFEC). Network neutrality is likewise inapplicable.

b. Additional regulation that may impose the rights of passengers to have access to wireless connections (to understand the possible impact on vehicle architecture).

Whether imposed by regulation or not, passengers will increasingly demand wireless connections, and RUs will need to plan for them. The open question is whether it is cost-effective to deliver them using the same networks as operational services given the huge differences in bandwidth, latency, and reliability requirements between rail operations and passenger entertainment communications.

11.5 Conditions related to security aspects

a. Justification of the need to use dedicated networks, or under which circumstances could public networks be used.

In theory, as noted in the response to 11.3(b), public networks could be used to the extent that they meet the requirements of the relevant operational rail applications in terms of (1) coverage, (2) quality of service (including latency), (3) reliability and robustness, and (4) security. In practice, it may be either difficult or prohibitively expensive for commercial mobile networks to meet those requirements.

b. Considerations related to security to support the bearer independency for the applications and networks used (such as user management, security of the communication link, etc.).

ERA should ensure that a security architecture for bearer independent operational rail communications is developed. A security risk assessment based on major threat use cases, vulnerability of each assets, and potential impact is needed. The results could be reflected in a future revision of the UIC User Requirements Specification (URS).

12. ANNEXES

12.1 Annex A – Definition of bearer

The current view from the railway domain on GSM-R as a circuit-switched technology is that one bearer could be seen by the on-board as one communication channel.

Multiple point-to-point communications need multiple instances of the same bearer. It means that on-board equipment need multiple transceivers (transmitter/receiver) to manage more than one communication simultaneously.

A new vision has emerged with the introduction of **packet-switched** technology, in the context of ETCS over (E)GPRS project. On-board equipment could then establish end-to-end communications with more than one end-user. The transition from communication to session has begun to support simultaneous communications from a single on-board equipment (a single transceiver).

For most stakeholders of the questionnaire and what we can read in telecom and railway literature, is that a bearer is a wireless communication standard. On ERA website, it is stated that "GSM-R is also the **data communication bearer** for the European Train Control System (ETCS), in particular for the Level 2 and Level 3". UNISIG and UNIFE papers are dealing with "communication bearer".

A **bearer** is defined in the dictionary as a person who carries messages or deliveries. Synonyms are **carrier** (not to be confused with "the carriers", used as a reference to Mobile Network Operators), transporter, messenger, porter. In the telecommunication domain (3GPP, ITU), a bearer is a telecommunication service providing capability of transmission of signals between access points. It can be seen as layers 1 to 3 or 1 to 2 in the OSI (Open Systems Interconnection) communication model but we will address this issue in the next section regarding definition of bearer independence.

Some of the stakeholders use the term **vector** as existing and emerging wireless communication standards or de-facto set of standards.

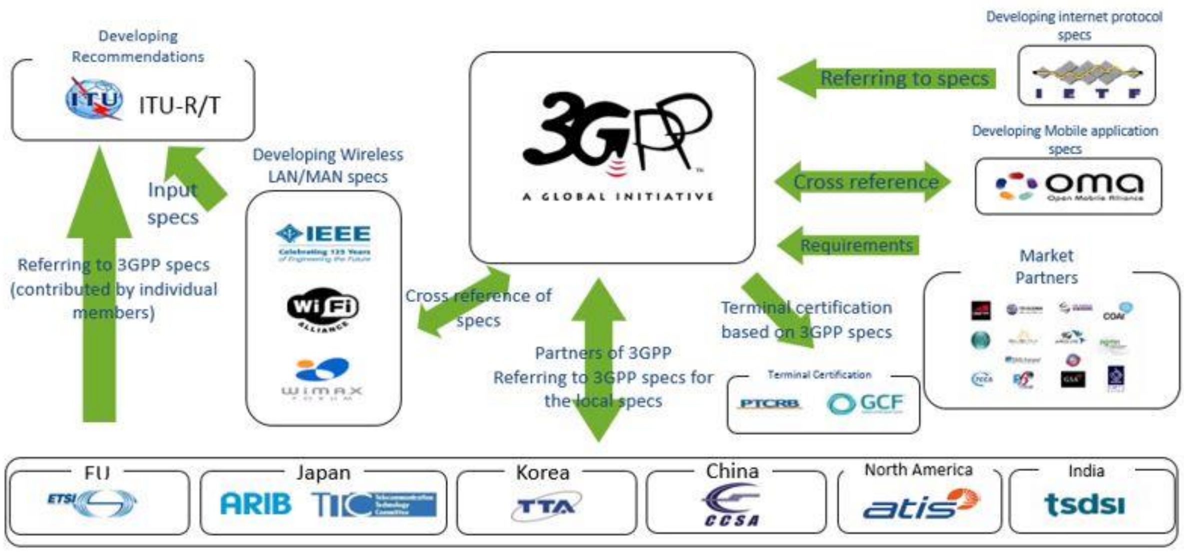
The term **Medium** or **Media** is also used in Intelligent Transport System (ITS) to define a physical entity that supports the transmission of signals carrying information between ITS communication nodes, e.g. a set of wires supporting Ethernet signals or the space between two antennas that supports electromagnetic, optical, or acoustical transmissions.

As a candidate definition of bearer, it could be defined as a **Digital Telecommunication Technology Standard** based on:

- ✓ Open standards: standards made available to the general public and developed (or approved) and maintained via a collaborative and consensus driven process. Source of the definition: ITU-T.
- ✓ Terrestrial (wireless and wireline) and satellite technologies

- ✓ Existing, emerging, and future standards
- ✓ Circuit-switched (if GSM-R is considered here as a bearer) and packet-switched technologies

A picture of open standards in the international telecom industry could be provided by the 3rd Generation Partnership Project (3GPP) in charge of developing mobile system standards:



Source: 3GPP

Figure 53. Open standards

However, the definition of a bearer is much more than a digital technology standard: we need to describe the services to be supported, the protocols, the interfaces, the performance, the spectrum bands and access schemes, and the network models. One single bearer could match:

- ✓ Different bands and access schemes (Time-Division or Frequency-division multiple access including TDD/FDD, multiplexing & coding schemes techniques)
- ✓ Different spectrum access schemes (licensed, unlicensed or combined)
- ✓ Different network ownerships and controls
- ✓ But a single Radio Access Technology (RAT) and Core Network based on either circuit-switched or packet- switched mode

To define a specific bearer, all these characteristics need to be considered.

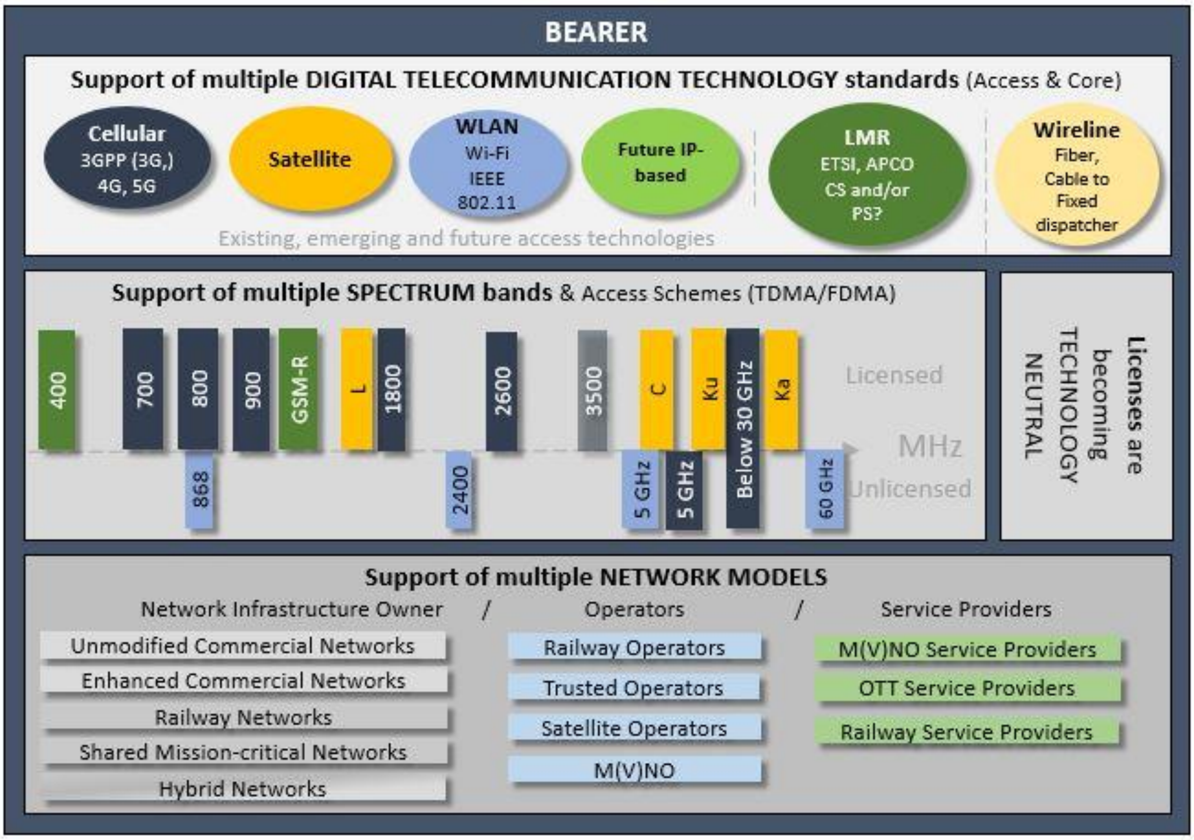


Figure 54. Overview of possible bearers

Based on the candidate definition of bearer, we could claim as examples that:

- ✓ GSM-R, GPRS and EDGE are considered to be different bearers
- ✓ GSM-R 900 MHz and GSM-R 1800 MHz are considered to be the same bearer
- ✓ LTE 800Mhz TDD and LTE 900 MHz FDD are considered to be the same bearer

More details on the support of multiple digital telecommunication standards (list of supported bearers), spectrum bands (list of supported bands) and network models (list of supported network models) will be addressed in the next sections related to objectives of bearer independence concept and key principles.

12.2 Annex B – Input data sources

Bearer independent communication concept as promising technology for rail is considered since few years through different study and working group. This sections presents these different sources of information.

The study on operational communications for the evolution of the railways communications system launched by ERA and produced by Analysis Mason, published in 2014, already introduced bearer independence as key considerations for future railway communication. Bearer independence can be seen in a multi technology approach and as a separation between application and bearer from an architectural point of view. Bearer independence is presented as a one of the principal issues for evolution and ETCS over (E)GPRS and IP telephony development can be seen as a first step of this evolution. It also indicated that specification of error performance and latency are important for the future bearer. Both application and railway functionality must use bearers. This study presents and evaluates 6 options of evolution from the current situation: (1) retain GSM-R, (2) new technology with same band, (3) new technology with new band, (4) new technology with third party, (5) multiple prescribed technologies; and (6) multiple technologies without prescription.

The IDATE report on the GSM-R evolution delivered to ERA in 2015 indicates also as key elements bearer independent applications capable of operating over a chosen range of bearer technologies already available or future ones. The two main recommendations in this area were firstly, there is a need to have relevant specifications to ensure operational interoperability including GSM-R and future system. A second recommendation concerns the possibility for the rail sector to use networks with no specific features for rail applications but retaining end-to-end performance and reliability requirements. It is still important to provide the communication bearer in a safe and secure way when it is required. To keep interoperability, CCS TSI would specify few varieties of radio bearers, and the Member State or Infrastructure Manager must choose one or more of them. Participants of IDATE workshop indicated that they would like to have IP-based bearer-independence that offers independence between the radio bearer and application layer. For that, the industry needs to develop IP suitable voice and ETCS application platforms.

In Europe, there are already different initiatives related to using different bearers to complete GSM-R coverage for voice service. Several IMs and RUs have agreements with public operators on 2G networks. Some of them have, or aim to have, a specific core network node to offer railway service for voice.

The study on feasibility of Satcom for railway applications, performed by INDRA/ALG and published in March 2017 also refers to bearer independent concept and multi-bearer possibilities. The main objective of this study is to conclude on the potential feasibility for railway applications of current and future commercial available satellite communication services and products, as part of an integrated communication architecture with terrestrial radio networks.

Additionally, there are different research and development projects that are linked to bearer independence. These projects are NGTC (Next Generation of Train Control Systems) and Shift^{2}Rail projects. The main scope of the NGTC project is to analyse the similarities / differences of the required functionality of ETCS and CBTC systems, and to determine the achievable commonality level of architecture, hardware platforms and system design. It started in 2013 and is expected to finish in

2016. NGTC must directly contribute to the Shift^{2}Rail project. It involves manufacturers and some railway and urban RUs.

Shift^{2}Rail is a large European research and innovation initiative on different subjects covering rolling stock, infrastructure and signalling. The main target is to increase attractiveness of rail in Europe. Activities started in 2016 and should continue up to at least 2020. The Innovation Programme (IP2) dedicated to Advanced Traffic Management & Control Systems includes development of prototypes in labs with the "Technology Demonstrators" (TDs) and to deliver on adaptable train-to-ground communications system usable for train control applications. The project includes multi-bearer solutions for the demonstration.

Additionally; recently the first European project known as the ERSAT EAV system and based on satellite technology to monitor and manage rail traffic has been successfully testing. This breakthrough is promising for all train operators, to improve their safety, modernise tracks, lower costs and improve performance.

Finally, in relation to standardisation, the initial UIC group working on GSM-R initiated the future railway communication system. The UIC decided to create in 2012 the Future Railway Mobile Communication System (FRMCS) project to prepare the necessary steps towards the introduction of a successor to GSM-R. The first step has now been achieved with the delivery of "User Requirements Specification". This document describes all the needs and functionalities for rail. It is a key input for the start of standardisation work. Now FRMCS has three different working groups that are focused on:

- FUnctional aspects (FRMCS-FU): This working group works on functional specifications. The document FRMCS URS (User Requirement Specification) in version 2.0 is now available on UIC website.
- SPectrum aspects (FRMCS-SP)
- Architecture and Technology Group (FRMCS-AT). This working group work in particular on network architecture model and document elaborates on the network functions necessary to support the different communication scenarios that are part of FRMCS URS (user requirement specification). Concepts well known in the telecommunication sector but new for rail are introduced such as OTT service (Over the Top) and IP multimedia Sub system (IMS). The network is now divided in 3 different parts aiming multiple radio access technologies. These parts are Core domain, Access domain and User equipment/terminal part.

In parallel and in liaison with the UIC, in ETSI (European Telecommunications Standard Institute), the Rail Telecommunications Technical Committee (ETSI TC-RT) has also started working on the successor to GSM-R. The Working Group Next Generation Radio for Rail (NG2R) aims to provide standards for voice, data services and other applications over broadband and narrowband air interfaces for the Rail Transportation domain.

As it has been demonstrated, the bearer independence concept has now become a major objective to achieve for GSM-R evolution for both data and voice services. Work is already under way in different projects and working groups but there is still some uncertainty on the evaluation of the difficulties and on the schedule. As explained previously, public mobile operators have started this evolution with the introduction of the UMTS, 3G since 2000 – 2005 and they had no specific operational/mission critical services to swap. For railways, it is now important to check the conditions and if possible to measure the difficulty and time to achieve this target for the introduction of radio bearers. Additionally, the introduction of new bearers and network access depend on the market situation. Furthermore, new standards developments are not carried out in isolation, it also requires implication and development from industry. Due to the limited size of the railway market, these elements are important and can impose some constraints on product availability.

To conclude this introduction, it must be noted that evolution in the railway sector takes much more time than the telecoms sector, because telecoms technology is primarily driven by market development and Return on Investment. As the milestones for the introduction of the Future Railway Mobile Communication System are in the next decade and as it is not reliable to predict the future for the next generation standardized telecom technology for mass-market mobile usage around the world, railways need a scalable and flexible architecture to support signalling, train radio and other critical railway applications.

12.2.1 Situations and different approaches

Many individual and collaborative initiatives with focus on Bearer Independency have been started so far for the evolution of railway radio taken by:

- ✓ European Union Agency for Railways (ERA) – The project evolution of Railway radio
- ✓ ETSI TC RT)
- ✓ UIC Future Rail Mobile Communications System (FRMCS)
- ✓ SEVENTH FRAMEWORK PROGRAMME Next Generation of Train Control systems (NGTC)
- ✓ SEVENTH FRAMEWORK PROGRAMME SECurity of Railways against Electromagnetic aTtacks (SECRET)
- ✓ HORIZON 2020 - Shift²Rail signalling and telecoms activities (S2R IP2 – Innovation Program 2)
- ✓ Radio communication sector of ITU (many reports are dealing with BIC-like concept) and ITU-T forums
- ✓ Industry Railway suppliers developing "Bearer Independent" products for their European and International Railway customers

Initiatives from other verticals (transport, PPDR, utilities…) have also investigated Bearer-independence concept:

- ✓ European Space Agency (ESA) – 3InSat and SBS-RailS
- ✓ ETSI TC Intelligent Transport Systems (ITS), CEN TC 278, ISO TC ITS and IEEE ITS
- ✓ ISO Intelligent Transport Systems - Communications Access for Land Mobile (ITS CALM)

- ✓ TETRA and Critical Communications Association (TCCA)
- ✓ 3GPP forums and GSM Association (GSMA)
- ✓ 5G Novel Radio Multiservice adaptive network Architecture (5G PPP NORMA) project

These different initiatives use different terminologies. Among the concepts established by those initiatives, we could mention some terminologies of particular interest:

- ✓ Bearer independent, from ERA, UIC and ETSI TC RT
- ✓ Carrier independent, from Internet Industry players
- ✓ Technology independent, from S2R and some Telecom industry players
- ✓ Multi-bearer, from ESA and UIC FRMCS (internal documents)
- ✓ (Multi-bearer) Adaptable communication, from S2R and SECRET
- ✓ Multi-channel router, from TCCA, UNISIG and some Telecom industry players
- ✓ Multi-vector architecture, from NGTC. Multi-vector is also used by ITS vertical markets to provide hybrid connectivity for short and long ranges between vehicles, vehicles and infrastructure. It provides handover mechanism between ITS-G5 (802.11p) and 4G (called vertical handover)
- ✓ Access-agnostic, from GSMA and some Railway users and Industry players
- ✓ Multi-connectivity, from 5G PPP NORMA

12.2.2 The different data sources

12.2.2.1 EUROPEAN COMMISSION

The European Commission has expressed principles for defining an appropriate post-GSM-R radio technology in the COMMISSION STAFF WORKING DOCUMENT on the state of play of the implementation of the ERTMS Deployment Plan (reference SWD (2014) 48 final). One of the main requirements to the future of the systems used for voice communication and for signalling data is related to BIC concept and must be considered in this study:

"The system should be flexible enough to allow the use of multiple technologies. One could consider several (IP-based) bearers: GSM-R (GPRS/EDGE); Wi-Fi, LTE, satellite, etc., but also simple digital (and cheap) technology. This could also foster the expansion of ETCS to other regions of the world."

Many other studies prepared for the European Commission (DG MOVE, DG CONNECT, ERA, ENISA) form the basis for this study:

- ✓ Study on use of commercial mobile networks and equipment for mission-critical high-speed broadband communications in specific sectors – SCF Associates – 2013
- ✓ Analysys Mason Final report of the study for the evolution of the railways communications system - 25/02/2014
- ✓ IDATE Evolution of GSMR FINAL Report for ERA (+ annexes) - V3.5 - April 2015
- ✓ How to protect signalling system against cybercrime – ENISA – 28/01/2015

12.2.2.2 ERA

Following the entry into force of the technical pillar of the 4th EU Railway Package on 15th June 2016, the European Union Agency for Railways replaces and succeeds the European Railway Agency.

The mission of the European Union Agency for Railways is: “Making the railway system work better for society.”

To achieve this, the Agency contributes, on technical matters, to the implementation of the European Union legislation aiming at improving the competitive position of the railway sector by:

- ✓ enhancing the level of interoperability of rail systems;
- ✓ developing a common approach to safety on the European railway system;
- ✓ contributing to creating a Single European Railway Area without frontiers guaranteeing a high level of safety.

In addition, the European Union Agency for Railways will become, from 2019 onwards, the European Authority to:

- ✓ issue single EU-wide safety certificates to railway undertakings;
- ✓ issue vehicle authorisations for operation in more than one country;
- ✓ grant approval for ERTMS infrastructure.

12.2.2.3 ENISA

The European Union Agency for Network and Information Security (ENISA) is a centre of expertise for cyber security in Europe. The Agency is located in Greece with its seat in Heraklion Crete and an operational office in Athens.

ENISA is actively contributing to a high level of network and information security (NIS) within the Union, since it was set up in 2004, to the development of a culture of NIS in society and in order to raise awareness of NIS, thus contributing to proper functioning of the internal market.

The Agency works closely together with Members States and private sector to deliver advice and solutions. This includes, the pan-European Cyber Security Exercises, the development of National Cyber Security Strategies, CSIRTs cooperation and capacity building, but also studies on secure Cloud adoption, addressing data protection issues, privacy enhancing technologies and privacy on emerging technologies, eIDs and trust services, and identifying the cyber threat landscape, and others. ENISA also supports the development and implementation of the European Union's policy and law on matters relating to NIS.

One of ENISA studies was considered of particular interest for this study:

- ✓ How to protect signalling system against cybercrime – ENISA – 28/01/2015

12.2.2.4 UIC FRMCS

International Union of Railways (UIC) Future Railway Mobile Communication system (FRMCS). (http://www.uic.org/frmcs) aims to prepare changes in the Technical Specifications for Interoperability (TSI) CCS to allow radio systems other than GSM-R, to facilitate transition to other systems. This prevents operational risks due to obsolescence of GSM-R technology.

The scope of the FRMCS project covers the following elements:

- ✓ Provide an appropriate replacement of EIRENE FRS
- ✓ Provide a set of technical preconditions for the successor of GSM-R
- ✓ Indicate and/or perform studies for further improvement or opportunities
- ✓ Sharing infrastructure, spectrum or other resources with other stakeholders
- ✓ Combination with and/or usage of commercial non-specific user applications and equipment

Up to now the UIC FRMCS has investigated and summarized their requirements for the next generation railway communication system in the Future Railway Mobile Communication User Requirements Specification.

12.2.2.5 ITU-R

ITU’s Radio communication Sector (ITU-R) is committed to building confidence and security in the use of ICT by creating an enabling environment through management of the international radiofrequency spectrum. Since the global use and management of frequencies requires a high level of international cooperation, one of our principal tasks in the ITU-R is to facilitate the complex intergovernmental negotiations needed to develop legally binding agreements between sovereign states. These agreements are embodied in the Radio Regulations and in world and regional plans adopted for different space and terrestrial services.

ITU-R also undertakes studies on the use of radio communication systems for public protection, disaster prediction, detection, alerting and relief (the so-called “PPDR”).

ITU-R publications constitute an essential reference source for all those wishing to remain abreast of the rapid and complex changes occurring in the world of international radio communications, such as government agencies, public and private telecommunication operators, manufacturers, scientific or industrial bodies, international organizations, consultancies, universities, technical institutions, etc.

ITU-R publishes regulatory texts such as the Radio Regulations, the Final Acts of World and Regional Radio communication Conferences and the Rules of Procedure, as well as ITU-R Recommendations, Reports and Handbooks drawn up by the Radio communication Study Groups.

Some of the ITU-R reports were considered as inputs for this study: PPDR requirements including network models and cybersecurity requirements for next generation radio communication for PPDR:

- ✓ M.2377 Radio communication objectives and requirements for Public Protection and Disaster Relief (PPDR) – ITU-R – 07/2015

12.2.2.6 3GPP

The 3rd Generation Partnership Project (3GPP) is a collaboration between groups of telecommunications associations (international telecommunication bodies, industrial representatives);

The initial scope of 3GPP was to make a globally applicable third-generation (3G) mobile phone system specification based on evolved Global System for Mobile Communications (GSM) specifications.

The scope was later enlarged to include the development and maintenance of:

- ✓ 2G and 2.5 standards such as GSM, GPRS and EDGE
- ✓ 3G standards such as UMTS, HSPA
- ✓ 4G particularly but not limited to LTE
- ✓ An evolved IP Multimedia Subsystem (IMS) developed in an access independent manner

- ✓ 3GPP standardization encompasses Radio, Core Network and Service architecture.

3GPP group is working with industry on the FRMCS requirement and must publish in September 2016 a study on Future Railway Mobile Communication System. As mentioned earlier this study must present a gap analysis between the requirements identified by the use cases and existing 3GPP functions and specifications. It must indicate which requirements can already be covered by existing functions and which requirements need additional work. It is also planned to analyse GSM-R interworking and proposals for normative work. It is a gap analysis.

This document (Technical Report TR 22.989 from 3GPP SA1 WG) was used as an input for the BIC concept study.

12.2.2.7 ETSI

ETSI, the European Telecommunications Standards Institute, produces globally-applicable standards for Information and Communications Technologies (ICT), including fixed, mobile, radio, converged, broadcast and Internet technologies. Our standards enable the technologies on which business and society rely. For example, our standards for GSM™, DECT™, Smart Cards and electronic signatures have helped to revolutionize modern life all over the world.

ETSI is officially recognized by the European Union as a European Standards Organization.

It is a not-for-profit organization with more than 800 member organizations worldwide, drawn from 66 countries and five continents. Members include the world's leading companies and innovative R&D organizations.

Two ETSI working groups were of particular interest for our study:

ETSI TC RT

The Technical Committee (TC) Railways Telecommunications (RT) is the "home" for those telecommunication aspects of railways, which are not part of the specification of the used transmission technologies themselves.

TC RT will in particular develop and maintain ETSI standards (if required) for application of GSM-R to railways as required by the European Directive on High Speed Train Interoperability and by other forthcoming European Directives for railways (including the European Directive on Conventional Lines interoperability).

ETSI TC RT Next Generation Radio for Rail (NG2R) Working Group must have responsibility:

- To provide standards for voice, data services and other applications over broadband and narrowband air interfaces for the Rail Transportation domain.
- To collect requirements from relevant stakeholders from the Rail Transportation domain, including urban, suburban, regional, long distance for Professional Mobile Radio Access systems.
- To contribute to develop ETSI existing and future standards to allow for taking into account these additional specific requirements.
- To ensure that work programs within ETSI TC RT are coordinated with other ETSI Technical Bodies, European and International Standardisation Bodies to avoid duplication of deliverables.

ETSI TC CYBER

The main responsibilities of ETSI TC CYBER are:

- ✓ To act as the ETSI centre of expertise in the area of Cyber Security
- ✓ Advise other ETSI TCs and ISGs with the development of Cyber Security requirements
- ✓ To develop and maintain the Standards, Specifications and other deliverables to support the development and implementation of Cyber Security standardization within ETSI
- ✓ To collect and specify Cyber Security requirements from relevant stakeholders
- ✓ To identify gaps where existing standards do not fulfil the requirements and provide specifications and standards to fill these gaps, without duplication of work in other ETSI committees and partnership projects
- ✓ To ensure that appropriate Standards are developed within ETSI in order to meet these requirements
- ✓ To perform identified work as sub-contracted from ETSI Projects and ETSI Partnership Projects
- ✓ To coordinate work in ETSI with external groups such as Cyber Security Coordination group in CEN CENELEC and ENISA
- ✓ To answer to policy requests related to Cyber Security, and security in broad sense in the ICT sector.

12.2.2.8 5G PPP

The 5G Infrastructure Public Private Partnership, in short 5G PPP, has been initiated by the EU Commission and industry manufacturers, telecommunications operators, service providers, SMEs and researchers. The 5G PPP must deliver solutions, architectures, technologies and standards for the ubiquitous next generation communication infrastructures of the coming decade.

Source: 5G PPP

Figure 55. 5G PPP simplified scope

The aim of 5G PPP is to ensure that the next generation of communication networks must be "Made in EU". The challenge for the 5G Public-Private Partnership (5G PPP) is to secure Europe's leading position in the particular areas where Europe is strong or where there is potential for creating new markets such as smart cities, e-health, intelligent transport, education or entertainment and media.

The total amount of public funds dedicated to the 5G Infrastructure PPP is expected to be around €700 million in Horizon 2020, which is to be matched by approximately €700 million committed by the private sector.

5G has a target to deliver solutions, architectures, technologies and standards for the ubiquitous next generation communication infrastructures of the coming decade. It includes intelligent transport market. For 5G, new concepts such as network virtualization for future networks or network slicing are developed. This concept allows running multiple logical networks as virtually independent business operations on a common physical infrastructure.

Within the 5G-PPP there are several cross-project work groups. The main aim is to identify shared issues and to develop supported EU program level position on technical and strategic items.

Among interesting workgroup for BIC study, we can mention (non-exhaustive list):

Some examples of 5G PPP working groups	Aims
Spectrum WG	Promote research results in the spectrum area obtained by 5G PPP/H2020 projects as well as relevant FP7 projects. Setting up of a dialogue between 5G PPP projects concerning potential synergies and common interests across projects in spectrum related issues. Pursue the convergence of results on spectrum topics from the different projects to maximize the achievable outcome towards relevant technical bodies. Establish a knowledge base from European and other Global project results concerning advances in spectrum research. Liaise with spectrum groups or entities in regulatory bodies and industry associations. Work for improved understanding of collaborative spectrum research.
5G Architecture WG	The goal of this Working Group is to serve as a common platform to facilitate the discussion between 5GPPP projects developing architectural concepts and components and foster the discussions based on the KPI's described in the 5GPPP contract. The group could also facilitate consensus building on the 5G architecture.
Security WG	This group brings together the projects within the 5G-PPP that have common interest in the development and progression of topics related to network security.

Table 30. **Examples 5G PP working group**

Elsewhere, the European Commission has already launched more than 10 EU projects to explore the technological options available leading to the future generation of "wired" (optical) and "wireless" communications.

These EU research projects address the architecture and functionality needs for 5G / beyond 4G networks.

The cluster of EU projects in the Radio Access and Spectrum (**RAS**) area for example, is looking more deeply into the 5G radio network architecture issues. The RAS is a cluster activity comprising a portfolio of more than 20 research projects investigating Radio Access and Spectrum aspects of future wireless networks.

Note than on spectrum aspects for 5G, the European Commission works through the Radio Spectrum Policy group on strategic roadmap towards 5G for Europe and in particular on spectrum aspects. A relevant item for railways is the frequency band below 1GHz. It is indicated that "*The RSPG is of the opinion that 5G will need to be deployed also in bands already harmonised below 1 GHz, including particularly the 700 MHz band, in order to enable nationwide and indoor 5G coverage.*"

METIS (Mobile and wireless communications Enablers for Twenty-twenty (2020) Information Society) technical goal was to provide a system concept that supports 1,000 times higher mobile system spectral efficiency, compared to current LTE deployments.

Build on the successful of **METIS, METIS-II** project must develop the overall 5G radio access network design and to provide the technical enablers needed for an efficient integration and use of the various 5G technologies and components currently developed.

The milestones of those research projects deliverables could not be aligned with our study and hence is considered out-of-scope together with Shift2Rail deliverables.

12.2.2.9 SHIFT2RAIL

Rising traffic demand, congestion, security of energy supply, and climate change are some of the major issues that the European Union and the wider world are facing. Tackling these challenges will call for the railway sector to take on a larger share of transport demand in the next few decades.

The European Commission is working towards the creation of a Single European Railway Area (SERA), and has promoted a modal shift from road to rail in order to achieve a more competitive and resource-efficient European transport system. However, rail's share in the European freight and passenger transport markets is still not satisfactory. EU research and innovation (R&I) must therefore help rail play a new, broader role in global transport markets, both by addressing pressing short-term problems that drain rail business operations, and by helping the sector to gain a stronger market position.

Shift2Rail will foster the introduction of better trains to the market (quieter, more comfortable, more dependable, etc.), which will operate on an innovative rail network infrastructure reliably from the first day of service introduction, at a lower life-cycle cost, with more capacity to cope with growing passenger and freight mobility demand. All this will be developed by European companies, thereby increasing their competitiveness in the global marketplace.

Shift2Rail will also contribute to the paradigm for the modal shift to attract users to rail. For EU passengers, this represents more travel options, more comfort and improved punctuality. For freight forwarder/shippers, rail freight will offer a more cost-effective, punctual and traceable shipment option.

Shift2Rail will impact all segments of the rail market: high-speed/mainline, regional, urban/metro & suburban, and freight; it will also make daily life easier for millions of European passengers and rail freight users.

Two Technical Demonstrators, part of the Innovation Program 2 (IP2 – Advanced Traffic Management and Control Systems), were of special interest for this study:

TD2.1 – Adaptable communications for all railways

- Definition, development, test of prototypes of a train-to-ground radio system answering to ETCS and CBTC systems - on all networks (high speed/mainline rail, urban dense and regional networks)

- Design a "technology independent" system, no specific railway solution to reduce initial cost. Evolutions of the (multi) radio bearer without impact on the reliability of the signaling system(s)

- Convergence of metro and railway (GSM-R/EIRENE) voice services, standardisation of function and services with a technology independent approach to share cost and allow interoperability

- New business model definitions supporting the shift from "network as an asset" to "network as a service" model vision. Possible use of public networks.

TD2.11 – Cyber Security

The milestones of those research projects deliverables could not be aligned with our study and hence are considered out-of-scope.

12.2.2.10 PPDR

Public Protection and Disaster Relief (PPDR), *www.cept.org/ecc/topics/public-protection-and-disaster-relief-ppdr*) is a CEPT project.

The aim is to investigate various solutions to address the safety and security community has needs for access to wideband and broadband services such as video, and has specific requirements in terms of priority, availability or security. Railways and PPDR share a large amount of functional and technical requirements even if some differences still exist. Now urban public transport (metro, tram, bus) uses the same standard as PPDR i.e. TETRA.

The **Public Safety Communications Europe (PSCE)** project defines the future of interoperable broadband radio applications, services, networks and devices for use by PPDR agencies: national police forces, fire brigades, emergency services and customs authorities, various militaries, post and telecom operators, etc. associated with mission critical services.

(TETRA and Critical Communications Association) TCCA project brings together TETRA manufacturers and actors to prepare the evolution of TETRA technology.

The TTCA's **CCBG (Critical Communications Broadband Group**) is working with public safety, transportation, utilities and other key stakeholder groups worldwide to drive the standardization of common, global mobile broadband technology solutions for critical communications users and lobby for appropriate spectrum. CCBG is working towards the definition of a robust LTE migration roadmap for PPDR.

12.2.2.11 CER

The Community of European Railway and Infrastructure Companies (CER) brings together more than 70 railway undertakings, their national associations as well as infrastructure managers and vehicle leasing companies. CER members represent 73% of the European rail network length, 80% of the European freight business and 96% of rail passenger operations in Europe.

CER's role is to represent the interests of its members on the EU policy-making scene, in particular to support an improved business and regulatory environment for European railway operators and railway infrastructure companies.

This study considered CER members as relevant stakeholders as so questionnaires were sent to them.

12.2.2.12 EIM

European Rail Infrastructure Managers (EIM) was established in 2002 following the liberalisation of the EU railway market to promote the interests of all rail infrastructure managers in the EU and the EEA.

Based in Brussels, EIM is registered as an international, non-profit association under Belgian law. It is one of 10 European railway organisations recognized by the European Commission as a 'representative body from the railway sector'. As such, EIM supports the work of the European Union Agency for Railways (ERA) in various working groups and occupies a seat on its Administrative Board.

The role of EIM is to provide a single voice to represent its members (infrastructure managers (IMs) vis-à-vis to the relevant European institutions and sector stakeholders. EIM also assists members to develop their businesses through the sharing of experiences and contributing to the technical and safety activities of the Agency (ERA).

This study considered EIM members as relevant stakeholders as so questionnaires were sent to them.

12.2.2.13 ROC IG

The Railway Operational Communications (ROC) Industry Group (IG) is a single interface to:

- ERTMS MoU Steering Committee
- International Railway Association UIC
- ERTMS users group
- ETCS Industry UNISIG
- European Union Agency for Railways

It gives a single voice to the GSM-R Industry for:

- The global promotion of the technology
- The continued development of the EIRENE standards
- Interoperable systems with seamless integration
- The long-term support of the GSM-R technology

The ROC Industry Group has currently nine members, dedicated to:

- The active global promotion of the GSM-R technology
- The supply of interoperable end-to-end systems
- The minimization of integration efforts and railway migration costs
- The continued development of the EIRENE standards in line with railway requirements
- Supporting UIC, European Union Agency for Railways and the ERTMS users group
- The smooth evolution and migration to a Future Railway Mobile Communication System (FRMCS)

The ROC Industry Group together with the associated organisations UIC (International Railways Association) and European Union Agency for Railways are committed to long-term support of GSM-R.

This study considered ROC IG members as relevant stakeholders as so questionnaires were sent to them.

Some members' initiatives (e.g. Frequentis, Kapsch) were of particular interest as inputs for the definition of the Bearer Independent Communication Concept.

12.2.2.14 UNISIG

UNISIG is an industrial consortium, which was created to develop the ERTMS/ETCS technical specifications. As an Associated Member of UNIFE, a recognized stakeholder, UNISIG actively contributes to the activities of the ERA in the field of ERTMS/ETCS technical specifications.

UNISIG was founded in 1998/99 at the specific request of the EU Commission with the task of drafting the technical specifications for ERTMS/ETCS. It has always been a technical body first working in close co-operation with the European Association for Railway Interoperability (AEIF) and, since its formation in 2005, with the ERA as part of the ERTMS Change Control Management (CCM) process.

The role of UNISIG today is to develop, maintain and update the ERTMS specifications in close cooperation with the ERA, which has been made the "system authority" for ERTMS. To do so, UNISIG actively contributes, together with the railway representative bodies, to the various related working groups of the Agency. Whilst the final version of the ERTMS specifications is published by the European Commission following the approval of the Member States, it is based on a recommendation from ERA. This recommendation is widely discussed with the railway sector, including UNISIG, and considerable work is undertaken by the consortium to define these specifications.

This study considered UNISIG members as relevant stakeholders as so questionnaires were sent to them.

12.2.2.15 CEPT/ECC

The Electronic Communications Committee (ECC) brings together 48 countries to develop common policies and regulations in electronic communications and related applications for Europe, and to provide the focal point for information on spectrum use. Its primary objective is to harmonise the efficient use of the radio spectrum, satellite orbits and numbering resources across Europe. It takes an active role at the international level, preparing common European proposals to represent European interests in the ITU and other international organisations.

The ECC's approach is strategic, open and forward-looking, and based on consensus between the member countries. It applies its expertise in partnership with all stakeholders, the European Commission and ETSI to facilitate the delivery of technologies and services for the benefit of society.

The ECC's Working Group Frequency Management (WG FM) is responsible for developing strategies, plans and implementation advice for the management of the radio spectrum.

A new Project Team (PT FM#56) dedicated to FRMCS spectrum needs has been created by ECC WG FM in 2017 (first meeting took place on 27-28 of March 2017). The following work plan has been agreed by the group, to be completed before the next WRC in 2019, in order to help to define the CEPT/ECC position on future railway communications (refer to agenda item 1.11):

1. First assess the spectrum requirements in a first ECC Report. ETSI TC RT SRDoc (TR 103 333) will serve as a basis with 2x10MHz band as a strong request from Railways.

2. Then evaluate the candidate bands for the implementation of the successor to GSM-R in a second ECC.

The two reports will be written and chaired by FM56 with inputs from other ECC WG such as WG SE (i.e. technical studies on candidate bands).

When the ECC reports will become available, a new ECC harmonisation deliverable and/or change/replacement of an existing one (e.g. ECC/DEC (02)05 and ECC/DEC (04)06) (ECC Decision or Recommendation) will most likely be created.

ECC deliverables were major sources for spectrum aspects of this study.

12.2.2.16 RSPG

The Radio Spectrum Policy Group (RSPG) is a high-level advisory group that assists the European Commission in the development of radio spectrum policy.

The RSPG is established under Commission Decision 2002/622/EC, which was one of the Commission initiatives following the adoption of the Radio Spectrum Decision 676/2002/EC and it adopts opinions, position papers and reports, as well as issuing statements, which are aimed at assisting and advising the Commission at strategic level on:

- radio spectrum policy issues,
- coordination of policy approaches and,
- harmonised conditions, where appropriate, with regard to the availability and efficient use of radio spectrum necessary for the establishment and functioning of the internal market.

The European Commission works through the Radio Spectrum Policy group on strategic roadmap towards 5G for Europe and in particular on spectrum aspects. A relevant item for railways is the frequency band below 1GHz. It is indicated that "*The RSPG is of the opinion that 5G will need to be deployed also in bands already harmonised below 1 GHz, including particularly the 700 MHz band, in order to enable nationwide and indoor 5G coverage.*"

12.2.2.17 BEREC

The Body of European Regulators for Electronic Communications (BEREC) was established by Regulation (EC) No 1211/2009 of the European Parliament and of the Council of 25 November 2009, as part of the Telecom Reform package. It replaced the European Regulators Group for electronic communications networks and services, which was established as an advisory group to the Commission in 2002.

BEREC commenced its activities in January 2010. In the course of 2011, it became fully functional and ready to fulfil all its assignments as required by the current regulatory framework.

“Committed to independent, consistent, high-quality regulation of electronic communications markets for the benefit of Europe and its citizens.”

BEREC contributes to the development and better functioning of the internal market for electronic communications networks and services. It does so, by aiming to ensure a consistent application of the EU regulatory framework and by aiming to promote an effective internal market in telecoms sector, in order to bring even greater benefits to consumers and businesses alike.

Furthermore, BEREC assists the Commission and the national regulatory authorities (NRAs) in implementing the EU regulatory framework for electronic communications. It provides advice on request and on its own initiative to the European institutions and complements at European level, the regulatory tasks performed at national level by the NRAs.

The NRAs and the Commission have to take utmost account of any opinion, recommendation, guidelines, advice or regulatory best practice adopted by BEREC.

BEREC was of particular interest for our study in the domain of market trends related to the current and future railway ecosystem.

12.2.2.18 ESA

The European Space Agency (ESA) is *Europe's gateway to space*. Its mission is to shape the development of Europe's space capability and ensure that investment in space continues to deliver benefits to the citizens of Europe and the world.

ESA is an international organisation with 22 Member States. By coordinating the financial and intellectual resources of its members, it can undertake programs and activities far beyond the scope of any single European country.

Some ESA Activities Supporting Satcom for railways were of particular interest for this study, such as:

- 3InSat, A demo project testing of IP-based multi-bearer communications (3/4G, TETRA, SATCOM) for ETCS data
- Space4Rail, an ESA initiative to support the railway community by raising awareness of the added value that space-based assets can bring to railway applications.

3InSat demo was of particular interest as inputs for the definition of the Bearer Independent Communication Concept.

12.2.2.19 NGTC

The main scope of the Next Generation Train Control (NGTC) project is to analyse the similarities and differences of the required functionality of both ETCS and CBTC systems, and to determine the achievable commonality level of architecture, hardware platforms and system design. This will be accomplished by building on the experience of ETCS and its standardized train protection kernel and by using the suppliers' experience gained by having developed very sophisticated and innovative CBTC systems around the world. Nevertheless, the goal is not to develop a one-size-fits-all system but to make progress in all railway domains in terms of increasing the commonality in system design and hardware. Benefits would include increased economies of scale for suppliers and customers being able to choose the most competitive supplier based on standardized functions and interfaces. Once in operation, NGTC will be able to address these major challenges of the 21st century in terms of safety, capacity, full interoperability and interchangeability between suppliers, and providing efficient solutions to "interconnect" the mainline, suburban and urban rail networks where needed and required by the customers.

All the main rail system signalling suppliers, together with mainline operators and infrastructure managers, as well as urban rail operators, joined the project consortium to cooperate in developing the next generation of train control systems.

Both urban and main line operators will be gathered to identify the requirements for all line types, spotting synergies and divergences of both systems in terms of hardware platforms, architectures and system designs. These results will lead to an architecture definition to be built around standardised modules, with the requirement of backward compatibility with ETCS Baseline 3 system.

The project will also increase the functionality of the ETCS to better suit both urban and mainline operator needs. This will result in more cost-effective implementation of ETCS systems and greater levels of interoperability.

NGTC needs to be seen in the wider context of rail research. It is one of the projects, which pave the way to SHIFT2RAIL, an initiative for an ambitious large-scale, industrially-driven and multi-annual research programme that aims to help the EU rail industry to retain its world leadership.

The results of NGTC will directly contribute to the SHIFT2RAIL Innovation Platform on Traffic Management and Control Systems, which aims at developing the future generation signalling and of train control.

The WP6 Technical Work Package "IP-based radio communication" was of particular interest as inputs for the definition of the Bearer Independent Communication Concept. Published documents from NGTC project will be considered as input documents.

12.2.2.20 UNIVERSITY OF BIRMINGHAM

Tom CHOTHIA, a Senior Lecturer in Computer Security and director of the M.Sc. in Computer Security at the University of Birmingham, presented a paper on June 2016 related to formal security analysis of the train to trackside communication protocols used in the European Railway Traffic Management System (ERTMS) standard, and in particular the EuroRadio protocol. This paper was of particular interest as input for security aspects.

12.2.2.21 RESTRICTED DATA

Some input data useful for the study and more particularly for the security aspects are restricted reports and not available to SYSTRA in particular:

- Information Security Audit of the European Railway Traffic Management System (ERTMS) – Adelard
- ERTMS Specification Security Audit Analysis of Attack Scenarios – Adelard
- ERTMS Cyber Security Risk Assessment – Adelard
- IT security threat identification, risk analysis and recommendations – KPMG IT Advisory on behalf of KMS WG – April 2013 – Public release
- Security Considerations for the Implementation of ERTMS – KPMG on behalf of NETWORK RAIL

It is recommended that any future work on the Bearer Independent Concept analyse the above documents.

12.3 Annex C – Questionnaire

Many initiatives have been initiated for the evolution of railway radio discussing similar concepts of bearer independence. However, these different initiatives use different terminologies like Bearer Independent, Technology independent, multi-bearer or multi-vector architecture.

Internet research is not the most valuable source of information because most outputs and deliverables of above projects are of restricted access. It was agreed with the Agency that a detailed questionnaire would be developed to address different Bearer Independency approaches (definitions of the overall concept, key principles, objectives of the project and related information to bearer independence or equivalent terminology).

The questionnaire was sent on 24th of November 2016 as a first round to different group representatives that already participate in projects or working groups where the Bearer Independent Concept is discussed (17 projects or companies -31 persons), including UIC FRMCS-AT members, ESA, Ansaldo STS, Siemens, Frequentis, Shift2Rail IP2 TD2.1, Funkwerk, SBB, DB Netz. We received and analysed 15 responses. A second round was organized and sent on 20th of December to ERA Coordination Group At the time of writing of this report no responses have been received.

The questionnaire was sent by e-mail with an introductory letter from ERA.

12.3.1 Introduction letter

Making the railway system work better for society.

To the attention of:
The interested organisations
(sent by email)

ERA/ERTMS/CS/PG/ap/D16-060

Valenciennes, 22 November 2016

Subject: **Study on the implications of the Bearer Independent communications concept**

Ref: *ERA 2016 17 RS*

Dear Madam, dear Sir,

The European Union Agency for Railways is currently leading a Program dealing with the evolution of the radio communication system for railways. This Program is relying on several studies investigating different scenarios for the provision of mobile communication services, from ownership model (dedicated vs. commercial networks), to radio resource strategy (with or without dedicated spectrum), and to radio technology possibilities. You or your company may have already contributed to these studies.

In the next step of this program, the Agency aims at analysing more in depth the implications of the bearer independent communication concept to find out the conditions/constraints that have to be overcome by the solutions proposed. The Agency has contracted Systra to provide support for this activity. Systra should provide the Agency with conclusions on the conditions and constraints for the application of different solutions and recommendations for being able to carry out the migration from GSM-R to the new system(s). The final report will be issued around July 2017.

In order to collect relevant information and data from different sources, one or more questionnaires as well as number of interviews will be conducted by Systra in the coming months. The discussions may include questions on different subjects related to the study. The Agency would highly appreciate if you could support Systra in this regard. The team of Mrs. Catherine Maton will be in charge of this task. The information provided will be used in the study and will be framed in the reports that will be published. Any information that would need to be handled with confidentiality should give rise to particular arrangements.

We thank you in advance for your cooperation in this important stage of our Program. The final report of the study will be kindly sent to you.

If you do not consider yourself to be the right addressee to deal with this request, please notify this and, if possible, indicate us the correct addressee in your organisation. For any question regarding this study, please contact Mrs. Begona Domingo (begona.domingo@era.europa.eu).

Yours sincerely,

Pio GUIDO
Head of ERTMS Unit

120 Rue Marc Lefrancq | BP 20392 | FR-59307 Valenciennes Cedex
Tel. +33 (0)327 09 65 00 | era.europa.eu 1 / 1

12.3.2 List of Questions

In order to collect information a questionnaire was prepared with 26 questions regarding the vision of the Concept of Bearer Independency. The purpose was to check if different stakeholders share views and objectives of Bearer Independency in order to define the key principles of bearer independence.

The Concept of Bearer Independency: Questionnaire regarding your vision of the Concept				
#	***Items***	***#***	***Sub-items/Details***	***To be answered***
1	***Project Program***	*1.1*	*Name of the project Program you are involved in*	
2	***Project Work Item***	*2.1*	*Name of the project Work Item you are involved in*	
3	***Concept Terminology***	*3.1*	*Terminology used in your project to refer to Bearer Independency*	
4	***Contact Name***	*4.1*	*Your Name*	
5	***Contact Email***	*5.1*	*Your Email*	
6	***Contact Phone Number***	*6.1*	*Your phone #*	
7	***Contact Company/Organisation***	*7.1*	*Your company/body/consortium related to the project Program*	
8	***Concept Objectives***	*8.1*	*Objectives of the Bearer Independency concept in your project*	
9	***Overall Concept description/definition***	*9.1*	*Concept description in your project*	
10	***Key principles of the Concept***	*Indicate in priority order the major principles you have considered to define the Concept in your project*		
		10.1	*Principle 1 of the concept in your project*	
		10.2	*Principle 2 of the concept in your project*	
		10.3	*Principle 3 of the concept in your project*	

		10.4	*Principle 4 of the concept in your project*	
		10.5	*Principle 5 of the concept in your project*	
11	***Bearer Independency***	11.1	*Are Applications decoupled from Bearers?* *(Bearer is considered here as a communication standard like GSM-R, 4G, 5G, Wi-Fi, Satcom…)*	*Yes (fully or partially) or No*
		11.2	*If Applications are decoupled from Bearers, which concept/architecture is considered by the Project to provide independency?*	
12	***Supported Applications in your project***	*Indicate by categories supported applications in your project*		
		12.1	*Vital/Mission-critical Voice*	
		12.2	*Vital/Mission-critical Data*	
		12.3	*Vital/Mission-critical Video*	
		12.4	*Non-mission critical Voice*	
		12.5	*Non-mission critical Data*	
		12.6	*Non-mission critical Video*	
13	***Supported Telecom Services in your project***	13.1	*Circuit-Switched Voice*	*Yes or No*
		13.2	*Packet-Switched Voice*	*Yes or No*
		13.3	*Circuit-Switched Data*	*Yes or No*
		13.4	*Packet-Switched Data*	*Yes or No*
		13.5	*Video*	*Yes or No*
14	***Supported Supplementary Services in your project (e.g. group calls with Push-To-Talk, broadcast calls, priority and pre-emption, geo-networking…)***	14.1	*Indicate supported supplementary services in your project*	

<table>
<tr><td rowspan="2">15</td><td rowspan="2">List of supported Vectors/Bearers/Access technologies (existing and foreseen) in your project

(Bearer is considered here as a communication standard like GSM-R, 4G, 5G, Wi-Fi, Satcom…)</td><td>15.1</td><td>Terrestrial and Satellite Wireless (specify if public or private/professional bearers are considered)</td><td></td></tr>
<tr><td>15.2</td><td>Wireline (if considered)</td><td></td></tr>
<tr><td rowspan="6">16</td><td rowspan="6">Protocol stack (OSI reference model)</td><td colspan="3">Indicate supported protocol stack in your project (Standardised or Proprietary protocols)</td></tr>
<tr><td>16.1</td><td>Layer 2</td><td></td></tr>
<tr><td>16.2</td><td>Layer 3</td><td></td></tr>
<tr><td>16.3</td><td>Layer 4</td><td></td></tr>
<tr><td>16.4</td><td>Layer 5</td><td></td></tr>
<tr><td>16.5</td><td>Layer 6</td><td></td></tr>
<tr><td rowspan="3">17</td><td rowspan="3">Management approach in your project</td><td>17.1</td><td>(Cyber)Security Management (if considered)</td><td></td></tr>
<tr><td>17.2</td><td>Resources Management (if considered)</td><td></td></tr>
<tr><td>17.3</td><td>Network management (if considered)</td><td></td></tr>
<tr><td rowspan="2">18</td><td rowspan="2">Selection of available vectors/bearers in your project</td><td>18.1</td><td>Which approach has been considered for selection of available bearers at a location and at a certain point in time to provide requested service? Did you consider a Hard-coded list of bearers or access to database or dynamic detection or other concept?</td><td></td></tr>
<tr><td>18.2</td><td>Did you consider assistance of lower layers to upper layers to decide on bearer availability or full independency?</td><td></td></tr>
</table>

19	***Selection of best/optimal vector/bearer in your project***	*19.1*	*Which approach has been considered for selection of best/optimal bearers at a location and at a certain point in time to provide requested service?* *Did you consider a Hard-coded list of prioritised bearers or access to database with associated policy or other concept?*	
		19.2	*Did you consider assistance of lower layers to upper layers to decide on best bearer or full independency?*	
20	***Roaming between bearers in your project***	*20.1*	*Automatic or Manual?*	
		20.2	*Conditions/Criteria for switching between bearers?*	
		20.3	*Dynamic supervision of radio environment?*	
		20.4	*Heart and responsible of the switching system?*	
		20.5	*Seamless (without losing connectivity)?*	
		20.6	*Estimated time of service loss for applications?*	
		20.7	*Does Handover mechanism between bearers have been considered and how?*	
21	***Link between vector/bearer and applications in your project***	*Indicate the links between applications and bearers that have been considered in your project*		
		21.1	*One application per bearer?*	*Yes or No*
		21.2	*A dedicated application on multiple and heterogeneous bearers?* *(e.g. One user using voice on 2G communicates with one other user using voice on TETRA)*	*Yes or No*

		21.3	*Multiple applications on a single bearer?*	*Yes or No*
		21.4	*Multiple applications working simultaneously?*	*Yes or No*
		21.5	*Multiple bearers working in parallel?* *For a dedicated application (cooperation) or each for a single application?*	*Yes or No (Details)*
		21.6	*Use of load-sharing between bearers for a single application? (e.g. a video application send data packets through 3G and 4G bearers in parallel to aggregate data flow and increase available bandwidth)*	*Yes or No*
		21.7	*Secondary Bearer(s) as fall-back if primary bearer becomes unavailable?*	*Yes or No*
		21.8	*Conditions that make a bearer suitable to an application? (e.g. static performance/QoS requirements or dynamic periodic measures of radio environment)*	
22	***Resilience in your project***	22.1	*Which approach has been considered (if considered)?*	
23	***Prioritisation/Scheduler of applications in your project***	23.1	*Which approach has been considered (if considered)?*	
24	***Reconfigurable Radio Systems in your project***	24.1	*Did you consider Software-Defined Radio (SDR) in your concept?*	*Yes or No*
		24.2	*Did you consider Cognitive Radio in your concept?*	*Yes or No*
25	***Access to Project documents (Public or Restricted Access and access details)***	25.1	*Deliverables*	*Yes or No (References and Web@ if public access)*

		25.2	*System Architecture*	*Yes or No (References and Web@ if public access)*
		25.3	*Functional requirements*	*Yes or No (References and Web@ if public access)*
		25.4	*Use cases*	*Yes or No (References and Web@ if public access)*
		25.5	*Brochures*	*Yes or No (References and Web@ if public access)*
		25.6	*Presentations*	*Yes or No (References and Web@ if public access)*
		25.7	*Useful external references*	*References and Web@ if public access*
26	***Additional Comments***	26.1	*If something is considered missing in this questionnaire regarding your project, feel free to add any additional elements*	

Table 31. **List of questions**