FAST RADIO TECHNOLOGIES FOR UNINTERRUPTED TRAIN
TO TRACKSIDE COMMUNICATIONS

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# Deliverable D1.2
# List of requirements for high-performance radio networks and additional prototype improvements

## Version 1.0

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## Abstract

The aim of this report is to provide for the FAST-TRACKS architecture, concepts and methods for requirements engineering, incorporating state of the art knowledge and also provide the complete list of requirements in close cooperation with WP2.

The list of requirements for high-performance radio networks and additional prototype improvements was prepared starting from the deliverable D1.1, with specific emphasis on key technologies involved at each layer of the FAST-TRACKS wireless network architecture.

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# 1 Introduction

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Nowadays, the introduction of Telecommunication Network within the railway environment have created an increasing need to implements vanguard and innovative products to support requests throughput and high data rate communications. However, the wireless coverage of the existing railway technological infrastructure does not ensure full operational standards, capacity and robustness required for a large-scale use in support of the railway signaling. The different existing solutions on the market are “general purpose” solutions, not specifically developed for the railway market, made by static and not redundant architecture for only indoor or outdoor functioning, with difficulty to adapt to the needs of mobility and the dynamics of a complex rail system.

Urban transport authorities have also deployed various specialized, and often proprietary, wireless systems: there are usually a system for signaling and control in unlicensed bands and another system for operational voice. Nevertheless, these systems are difficult to integrate and they are limited in terms of their data capabilities. This therefore significantly limits the possibility to enhance the operational efficiency, passenger security and quality of transport.

FAST-TRACKS project is a disruptive innovation based on the development of a low cost re-programmable radio infrastructure that implements simultaneously different radio propagation standard allowing efficient planning of the network, redundancy techniques, automatic-adaptive reconfiguration, able to support the constrained requirements of the railway telecommunications. The proposed telecommunication infrastructure permits to support both vital and not vital data on separate networks and independent radios.

This technique allows the increase of the life time of the hardware (both of the radio base station that the user terminal) removing the risk of obsolescence; the re-programmability of the radio allows also the reuse of the hardware in case of new services or new generation systems will make their entry into the field, thus reducing OPEX and CAPEX.

The main parts of the deliverable are organized as follows: In Chapter 2, the FAST-TRACKS overall architecture, focusing on FCP, RCP and MCP layers is introduced. Chapter 3 describes the FAST-TRACKS requirements engineering process. Chapter 4 presents the final list of functional and non-functional requirements, derived by Task T.1.3 and T1.4 and deliverable D1.1. Chapter 5 finalizes the deliverable discussing the prototype improvements and business requirements of the FAST-TRACKS architecture.

The following member organizations have allocated manpower in Task T.1.3 and T1.4:

| ID | Short Name | Full Partner Name |
|---|---|---|
| 1 | COM | Comesvil |

**Table 1-1 – Member organizations in Task T.1.3 and T1.4**

# 2 FAST-TRACKS reference architecture

This section introduces the FAST-TRACKS high-level architecture, a novel wireless architecture able to seamlessly and efficiently support train-to-ground communications. FAST-TRACKS layering structure is shown in Figure 1. It comprises (bottom-up view):

1. The Mobile Communication Plane (MCP)
2. The Fixed Communication Plane (FCP)
3. The Radio Control Plane (RCP)
4. The Radio Monitoring Plane (RMP)

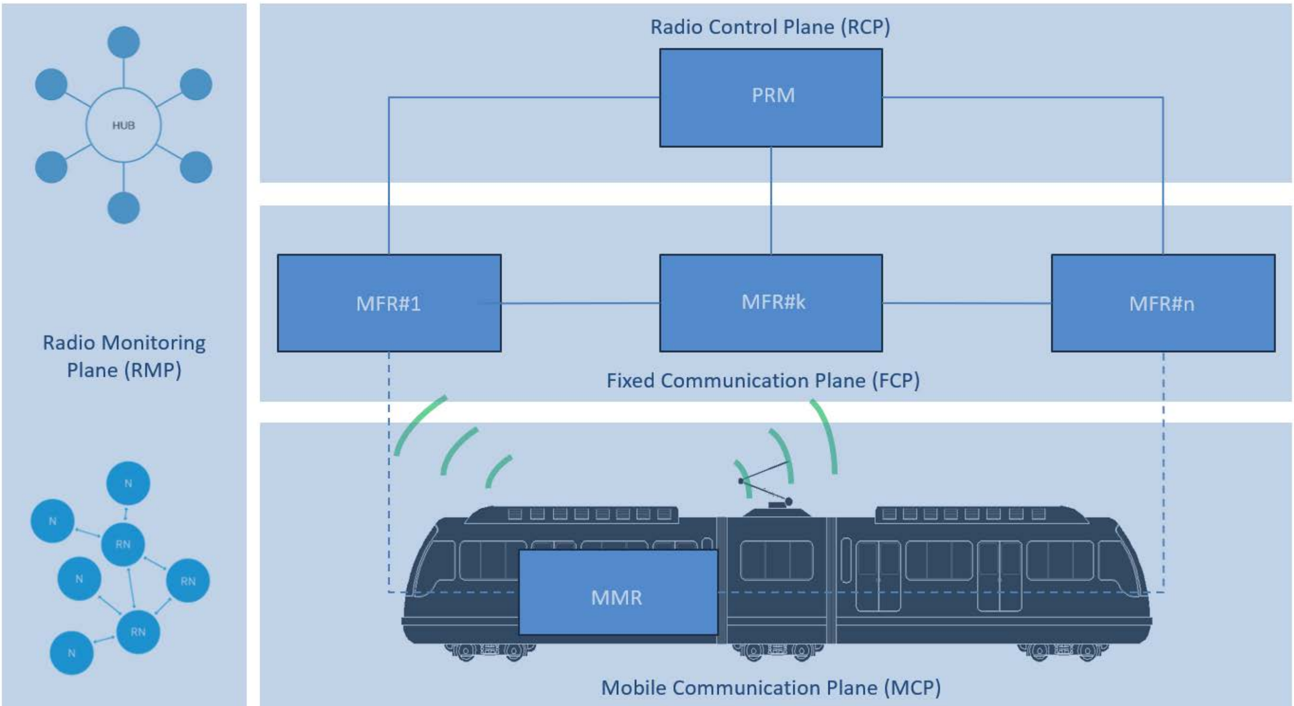


**Figure 1 – Reference model for FAST-TRACKS high-level architecture**

**MCP** is the mobile communication plane devoted to the transmission over the air of vital and non-vital data between train and wayside. This layer comprises hardware, firmware and software and involves mainly the train side of the network infrastructure (mobile radio).

**FCP** is the fixed communication plane devoted to the transmission over the air of vital and non-vital data between wayside and train. This layer comprises hardware, firmware and software and involves a plurality of fixed radio installed on the wayside.

**RCP** is the control plane devoted to the the implementation of protocols to connect radio dynamically, using both mesh and hub-spoke configurable patterns, to provide advanced transport services.

**RMP** is the infrastructure responsible for the realtime collection, management and monitoring of the wireless network data and parameters by means of resource abstraction and partitioning.

The novelty in the FAST-TRACKS architecture lies in the combination of the following three layers: Mobile Communication Plane (MCP), the Fixed Communication Plane (FCP) and the the Radio Control Plane (RCP).

Mobile radio and Fixed radio, basic elements of the MCP and FCP, are based on the concept of Cognitive Radio (CR) and Multi-Transport Radio (MTR), introduced for the first time by Comesvil within the FAST-TRACKS phase 1 project [1]. Currently the concept is enhanced adding a set of distruptive ideas and special features, designed for railway infrastructure and covered by the European Patent [2] filed to the EPO [3]. The advantages of the CR and MTR, within the train to ground communication are the high adaptability of the radio to the continuous evolution of wireless standards and the development of an innovative and not yet on the market product. The proposed infrastructure, due to the high-speed capacity, dual embedded radio and configurable approach, permits to integrate vital and non-vital services on the same wireless backbone, simply dedicating different radio to different services operating with a “full mesh” redundant network architecture. Thus, the system proposed will contribute to:

- Establish a high speed, reliable and continuous communication between a train in motion and the trackside, allowing capacity enhancement
- Support Communication Based Train Control (CBTC) services
- Collect data of CCTV (Close Circuit TV)
- Provide support for VoIP and Personal Information Systems (PIS) services
- Enable preventive maintenance
- Ensure passengers’ safety and security during their journey
- Improve travel comfort

The following sections shows the basic technologies involved at each layer of the FAST-TRACKS architecture. In details:

- Software Defined Radio
- Software Defined Networks
- Protocols for high performance wireless communications
- Cloud Computing
- Virtualization

## 2.1 Software Defined Radio

Nowadays, Software Defined Radio has gained a lot of importance as it provides flexibility to the radio communication by implementing radio functionality in software rather than in hardware. Some of the major advantages of software radio are that they can be reconfigured "on-the-fly". Their features can be quickly and easily upgraded, and they can be used to build smart or cognitive radios.

Reconfigurability in radio development is not such a new technique as one might think. Already during the 1980s reconfigurable receivers were developed for radio intelligence in the short-wave range. These receivers included interesting features like automatic recognition of the modulation mode of a received signal or bit stream analysis. Reconfigurability became familiar to many radio developers with the publication of the special issue on software radios of the IEEE Communication Magazine in April 1995. We refer to a transceiver as a software radio (SR) if its communication functions are realized as programs running on a suitable processor. Based on the same hardware, different transmitter/receiver algorithms, which usually describe transmission standards, are implemented in software. An SR transceiver comprises all the layers of a communication system.

The baseband signal processing of a digital radio (DR) is implemented on a digital processor and or an FPGA. An ideal SR directly samples the antenna output. A software-defined radio (SDR) is a practical version of an SR: the received signals are sampled after a suitable band selection filter.

The next figure illustrates the block diagram of a software-defined radio.

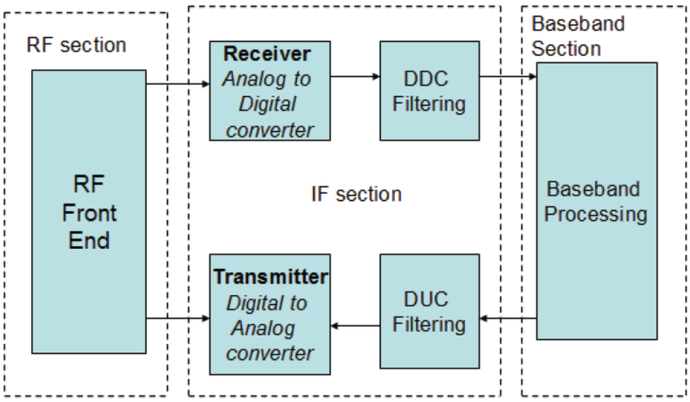


**Figure 2 – SDR Tranceiver**

A cognitive radio (CR) is an SDR that additionally senses its environment, tracks changes, and reacts upon its findings. A CR is an autonomous unit in a communications environment that frequently exchanges information with the networks and it is able to access as well as with other CRs. According to its operational area an SDR can be considered as:

- A multiband system which is supporting more than one frequency band used by a wireless standard (e.g., GSM 900, GSM 1800, GSM 1900)
- A multistandard system that is supporting more than standard. Multistandard systems can work within one standard family (e.g., UTRA-FDD, UTRA-TDD for UMTS) or across different networks (e.g., DECT, GSM, UMTS, WLAN)

- A multiservice system which provides different services (e.g., telephony, data, video streaming)
- A multichannel system that supports two or more independent transmission and reception channels at the same time.

FAST-TRACKS project is conceived around a multimode system, which is the combination of multiband and multistandard systems. The SDR approach allows different levels of reconfiguration within a transceiver:

- Reconfiguration at commissioning time: the configuration of the system is done once at the time of product shipping, when the costumer has asked for a dedicated mode (standard or band).
- Reconfiguration at downtime: reconfiguration is only done a few times during product lifetime, for example, when the network infrastructure changes. The reconfiguration will take some time, where the transceiver is switched off. This may include the exchange of components.
- Reconfiguration on a per call basis: reconfiguration is a highly dynamic process that works on a per call decision. That means no downtime is acceptable. Only parts of the whole system (e.g., front-end, digital baseband processing) can be rebooted.
- Reconfiguration per timeslot: reconfiguration can even be done during a call. In this case, an SDR transceiver can be reconfigured via a control bus supplying the processing units with the parameters which describe the desired standard. In this case such a configuration, called a parameter-controlled (PaC) SDR, guarantees that the transmission can be changed instantaneously if necessary (e.g., for interstandard handover).

## 2.2 Software Defined Networks

Traditional network architectures are suited to meet the requirements of today's enterprises, carriers, and end users. Thanks to a broad industry effort spearheaded by the Open Networking Foundation (ONF), SoftwareDefined Networking (SDN) is transforming networking architecture. In the SDN architecture, the control and data planes are decoupled, network intelligence and state are logically centralized, and the underlying network infrastructure is abstracted from the applications. As a result, enterprises and carriers gain unprecedented programmability, automation, and network control, enabling them to build highly scalable, flexible networks that readily adapt to changing business needs. The ONF is a non-profit industry consortium that is leading the advancement of SDN and standardizing critical elements of the SDN architecture such as the OpenFlow™ protocol [4], which structures communication between the control and data planes of supported network devices. OpenFlow is the first standard interface designed specifically for SDN, providing high-performance, granular traffic control across multiple vendors' network devices. OpenFlow-based SDN is currently being rolled out in a variety of networking devices and software, delivering substantial benefits to both enterprises and carriers, including:

- Centralized management and control of networking devices from multiple vendors;
- Improved automation and management by using common APIs to abstract the underlying networking details from the orchestration and provisioning systems and applications;
- Rapid innovation through the ability to deliver new network capabilities and services without the need to configure individual devices or wait for vendor releases;
- Programmability by operators, enterprises, independent software vendors, and users (not just equipment manufacturers) using common programming environments, which gives all parties new opportunities to drive revenue and differentiation;
- Increased network reliability and security as a result of centralized and automated management of network devices, uniform policy enforcement, and fewer configuration errors;
- More granular network control with the ability to apply comprehensive and wide-ranging policies at the session, user, device, and application levels; and
- Better end-user experience as applications exploit centralized network state information to seamlessly adapt network behavior to user needs.

SDN is a dynamic and flexible network architecture that protects existing investments while future-proofing the network. With SDN, today's static network can evolve into an extensible service delivery platform capable of responding rapidly to changing business, end-user, and market needs.

Software Defined Networking (SDN) is an emerging network architecture where network control is decoupled from forwarding and is directly programmable. This migration of control, formerly tightly bound in individual network devices, into accessible computing devices enables the underlying infrastructure to be abstracted for applications and network services, which can treat the network as a logical or virtual entity. The figure above depicts a logical view of the SDN architecture. Network intelligence is (logically) centralized in software-based SDN controllers, which maintain a global view of the network. As a result, the network appears to the applications and policy engines as a single, logical switch. With SDN, enterprises and carriers gain vendor-independent control over the entire network from a single logical point, which greatly simplifies the network design and operation. SDN also greatly simplifies the network devices themselves, since they no longer need to understand and process thousands of protocol standards but merely accept instructions from the SDN controllers

Perhaps most importantly, network operators and administrators can programmatically configure this simplified network abstraction rather than having to hand-code tens of thousands of lines of configuration scattered among thousands of devices. In addition, leveraging the SDN controller's centralized intelligence, IT can alter network behavior in real-time and deploy new applications and network services in a matter of hours or days rather than the weeks or months needed today. By centralizing network state in the control layer, SDN gives network managers the flexibility to configure, manage, secure, and optimize network resources via dynamic, automated SDN programs. Moreover, they can write these programs themselves and not wait for features to be embedded in vendors' proprietary and closed software environments in the middle of the network. In addition to abstracting the network, SDN architectures support a set of APIs that make it possible to implement common network services, including routing, multicast, security, access control, bandwidth management, traffic engineering, quality of service, processor and storage optimization, energy usage, and all forms of policy management, custom tailored to meet business objectives. For example, an SDN architecture makes it easy to define and enforce consistent policies across both wired and wireless connections on a campus. Likewise, SDN makes it possible to manage the entire network through intelligent orchestration and provisioning systems. The Open Networking Foundation is studying open APIs to promote multi-vendor management, which opens the door for on-demand resource allocation, self-service provisioning, truly virtualized networking, and secure cloud services. Thus, with open APIs between the SDN control and applications layers, business applications can operate on an abstraction of the network, leveraging network services and capabilities without being tied to the details of their implementation. SDN makes the network not so much "application-aware" as "application-customized" and applications not so much "network-aware" as "network-capability-aware". The application of the SDN in the FAST-TRACKS project is proposed as enabler to separate the forwarding-plane from the control-plane, opening the implementation of high performance wireless communication protocols, which permits to implement a constrained traffic engineering enabling the on-fly configuration of mesh/hub&spoke reliable network.

## 2.3 Protocols for high-performance wireless communication

This section presents a set of routing protocols and computation elements, which permits to enhance the performance of wired and wireless networks. These protocols are actually used to implement the constrained traffic engineering and resilience in optical networks switches. The idea, within the FAST-TRACKS project, is to reuse the same protocol architecture to ehnace wireless data transfer in a train to wayside communication scenario. The next section introduces briefly the following protocols:

- Optimized Link State Routing Protocols (OLSR)
- Multi Protocol Label Switching (MPLS)
- Generalized Multiporotocol Label Switching (GMPLS)
- Path Computation Element (PCE)

### 2.3.1 Optimized Link State Routing protocol (OLSR)

Optimized Link State Routing (OLSR) [5] is a proactive routing protocol for mobile wireless ad hoc networks. The protocol hinerits the stability of the link state algorithm. Due to its proactive nature, it is an advantage of having the routes immediately available when needed. In a pure link state protocol, all the links with neighbor nodes are declared and are flooded in the entire network. OLSR protocol is an optimization of a pure link state protocol for mobile ad-hoc networks. First, it reduces the size of control packets: instead of all links, it declares only a subset of links with its neighbors who are its multipoint relay selectors. Secondly, it minimizes flooding of this control traffic by using only the selected nodes, called multipoint relays, to diffuse its messages in the network. Only the multipoint relays of a node retransmit its broadcast messages. This technique significantly reduces the number of retransmissions in a flooding or broadcast procedure. This protocol is particularly suitable for large and dense networks, such train-to-ground communications networks, where the FAST-TRACKS architecture aims to enhance.

### 2.3.2 Multi Protocol Label Switching (MPLS)

MPLS [6] is a scalable, protocol-independent transport. In an MPLS network, data packets are assigned labels. Packet-forwarding decisions are made solely on the contents of this label, without the need to examine the packet itself. This allows one to create end-to-end circuits across any type of transport medium, using any protocol. MPLS operates at a layer that is generally considered to lie between traditional definitions of OSI Layer 2 (data link layer) and Layer 3 (network layer), and thus is often referred to as a layer 2.5 protocol. It was designed to provide a unified data-carrying service for both circuit-based clients and packet-switching clients, which provide a datagram service model. This protocol is a valid alternative to implement robust mesh networks as support of the FAST-TRACKS architecture.

### 2.3.3 Genelalyzed Multi Protocol Label Switching (GMPLS)

GMPLS [7] (Generalized Multiprotocol Label Switching), also known as Multiprotocol Lambda Switching, is a technology that provides enhancements to Multiprotocol Label Switching (MPLS) to support network switching for time, wavelength, and space switching as well as for packet switching. In particular, GMPLS will provide support for photonic networking, also known as optical communications. As GMPLS evolves, it will require changes to existing protocols and will spur the evolution of new ones. The Link Management Protocol, for example, arose in part as a consequence of GMPLS evolution. GMPLS also involved changes to the Open Shortest Path First (OSPF) protocol and IS-IS intradomain routing protocol. GMPLS allows for a greatly increased number of parallel links between nodes in a network. This is important in photonic networking, where hundreds of parallel links (individual fibers in a bundled fiber optic cable, for example) may exist between a pair of nodes. GMPLS also facilitates rapid fault detection, fault isolation, and switchover to alternate channels, minimizing network downtime. In FAST-TRACKS network architecture the GMPLS will be considered and analyzed from a twofold point of view. Enhance the optical backbone of the train-to-signalling network and reuse the OSPF protocol / RSVP protocol extensions [8] [9] in the wireless network architecture. The usage of this pattern needs a network controller capable to orchestrate both the protocols, obtaining a continous monitoring of the network before reconfiguration action: the path computation element.

### 2.3.4 Path Computation Element (PCE)

Path Computation Element (PCE) is a software controller capable of computing a network path or route based on a network graph, applying computational constraints during the computation [10]. In details, the PCE supplies optimal routes and interacts with the control plane for the set-up of the proposed paths upon receiving requests sent by client nodes (PCC), to determine the path from a source to a destination. A PCE Communication Protocol (PCEP) [11] was defined to specify both PCC-PCE and PCE-PCE communication aimed at the computation of LSPs. When a new request subject to QoS constraints arrives, the PCC uses a discovery method to locate PCEs and it locally preserves PCE capabilities to select one of them according to the specific computation; then it submits an inquiry to the selected PCE using PCC-to-PCE communication. In the FAST-TRACKS scenario the PCE is a functional element that cooperates with similar entities and with network devices to compute the best possible path through multiple domains. The PCE function may be implemented either as a centralized service or as a distributed architecture involving one agent in each device. Our proposal assumes that network devices are able to provide PCEs with energy consumption and RSSI information.

Along with the process of identifying the requirements and development of the architecture accordingly, a plethora of work is underway at the PCE IETF WG aimed at defining new PCE communication protocols and introducing extensions to existing underlying routing protocols. Request for Comments (RFC) 4655 specifies a PCE-based architecture. RFC 4657 covers PCE communication protocol generic requirements, and RFC 4674 discusses the requirements for PCE discovery [12].

## 2.4 Cloud Computing

The National Institute of Standards and Technology identifies the following classification for Cloud services: Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a service (SaaS) [13]. In the FAST-TRACKS architecture, we focus on IaaS because it offers the highest level of control over the infrastructure. The basic enabler of the IaaS is the native virtualization (or type 1) where a layer of software, called hypervisor, supports the execution of several virtual machines (VMs). In this scenario, network and IT resources are elastic, in the sense that in the Cloud we can instantiate or delete VMs dynamically.

The convergence of IT, wired and wireless network service management is an important outcome for FAST-TRACKS to reach a high level of resiliency and security of the whole architecture [14]. This convergence could support greater flexibility and efficiency in the way IT departments operate but also how they enact outsourcing of IT capability. Next-generation wireless networks, in close cooperation with enhanced networking models such as Software Defined Networks will enable cost-efficient provisioning of flexible radio services between fixed and mobile transport infrastructure, scaling up to 867Mb/s per radio for a maximum transport capacity of 1.733 Gb/s on a single radio.

## 2.5 Virtualization

Virtualization is a software technology, which uses a physical resource such as a server and divides it up into virtual resources called virtual machines (VMs). Virtualisation allows for efficiently sharing physical network+IT resources (computing, networks and storage) to accommodate the demand of customers, while meeting the business expectations of ICT providers. Physical resources are virtualised to create multiple logical resources, such as virtual machines or virtual nodes and links. Virtualisation technologies aim to conceal the virtualisation layer from the users while giving them the impression of directly using the real resources, by meeting requirements such as: isolation, security, accountability, etc.

Infrastructure virtualisation is a very active topic in the industry. It spans both software and hardware technologies, with open-source and proprietary approaches that can be hosted privately by an organisation, or remotely by a third party. Virtualisation has also strong implications on non-technical issues, being the driving force that is changing the business models around ICT technologies.

Virtualisation is a key technology in the FAST-TRACKS project, whose focus is on the composition, orchestration and management of heterogeneous virtualised infrastructures (network+IT), rather than on basic virtualisation technologies research. The main role of the virtualization within the FAST-TRACKS architecture is the storage and monitoring as support of the wireless radio planes.

# 3 The FAST-TRACKS requirements engineering process

This section introduces the requirement engineering process and methodologies used in the FAST-TRACKS project for the identification and specification of the technical functional and non-functional requirements. Functional requirements capture the intended behaviour of the FAST-TRACKS system. This behaviour may be expressed as services, tasks or functions the system is required to perform. We distinguish between Functional and non-Functional requirements as:

- Functional requirements may be calculations, technical details, data manipulation and processing and other specific functionalities that define what a system is supposed to accomplish. Functional requirements are supported by non-functional requirements.

- Non-functional requirements (also known as quality requirements), are constraints imposed on the design or implementation (such as performance, security, cost, robustness, portability, reliability, interoperability) of the overall system.

Functional requirements drive the application architecture, while non-functional requirements drive the technical architecture of the FAST-TRACKS system. The rationale behind the FAST-TRACKS functional and non-functional requirements identification is based on different fundamentals on “Requirements Engineering” [15]. We will focus on three main approaches:

1) Capability Maturity Model Integration (CMMI) approach in Process Areas Categories for Engineering (REQM) Requirements Management and RD (Requirements Development), which will be tailored to FAST-TRACKS specific scope [16], work packages structure and requirements management tools. Central concepts of the methodology are:

- Traceability of the requirements across the entire project, starting from requirements definition based on the regulatory, standards and research inputs to the testing specifications and testing results. The requirement template will be used to trace the requirements with the test procedures and test specification used to guarantee complete thoroughness and coherence of the test and measurement activities across the project.

- Change Management, to support any changes in the requirements due to a modification of the regulation, standardization or research input, across all the deliverables of the FAST-TRACKS project. Change management will be based on a tailored version of the change request process defined in [16]. A change request is created to modify one or more requirements. To reduce the overhead and simplify the overall process, change requests will be grouped in correspondence to the milestones of the project. A group of change requests will produce a new version of the WP deliverables. The changes will be extended to the other work packages of FAST-TRACKS to produce new versions of the deliverables and of the Requirement Traceability Template. The formal Requirement Traceability Template is performed using the following table:

| Requirement | |
|---|---|
| Number | <Unique identifier> |
| Name | <short name of the requirement> |
| Organization name | <lead producer> |
| Description | < description of the requirement> |
| Related use case | <short name/number of the related scenario / use case> |
| Prioritisation | Novelty: [3-high, 2-medium, 1-low] <rationale><br>Business value: [3-high, 2-medium, 1-low] <rationale><br>Prior Knowledge: [3-high, 2-medium, 1-low] <rationale><br>Exploitability: [3-high, 2-medium, 1-low] <rationale> |
| Test Notes | Metric: <how is achievement of the requirement measured?><br>Success: <how is success indicated?> |
| Requirement Type | <type of the requirement: functional/non-functional> |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 3-1 – FAST-TRACKS Requirements Traceability Template**

2) Goal Question Metric [17] approach, originally defined for evaluating defects for a set of projects in the NASA Goddard Space Flight Center environment. A central concept of the methodology is the measurement model, based on three levels:

- Conceptual level (goal) - A goal is defined for an object based on a variety of reasons, such as various models of quality, from various points of view and relative to a particular environment.
- Operational level (question) - A set of questions are used to define models of the study object and then focuses on that object which characterizes the assessment or achievement of a specific goal.
- Quantitative level (metric) - Based on the models, a set of metrics is associated with every question in order to answer it in a measurable way.

The literature typically describes GQM in terms of a six-step process. The first three steps use business goals to drive the identification of the right metrics. The last three steps are about gathering the measurement data and making effective use of the measurement results in order to drive decision-making and create improvements. Basili [18] described his six-step GQM process as follows:

- Develop a set of corporate, division and project business goals and associated measurement goals for productivity and quality
- Generate questions (based on models) that define those goals as completely as possible in a quantifiable way
- Specify the measures needed to answer those questions, track process and product conformance to the goals

- Develop mechanisms for data collection
- Collect, validate and analyze the data in real time to provide feedback to projects for corrective action
- Analyze the data in a post mortem fashion to assess whether conformance to the goals was achieved and to make recommendations for future improvements.

3) Brainstorming approach to set down as many requirements as possible, focusing on the breadth of requirements, as opposed to its depth (requirement generation) and analyze all the requirements generated (requirements reduction and prioritizing) [19].

CMMI and Brainstorming approaches are mainly used to define the final List of FAST-TRACKS functional and non-functional requirements. We distinguish the following phases:

**Collection Phase** - The objective of this phase is to collect all the necessary information in order to understand what needs to be covered by the technology. This information can be obtained via different sources, as listed below:

- Inputs from the regulatory, industry and research domains, which represent the main collective source (which can be regulators, industry and research) for each deliverable. This may include government recommendations, standard specifications and research references, etc.
- Projects related to FAST-TRACKS and other wireless-aware technologies. This may include, FP7 (7th Framework Programmes) and H2020 projects.
- Previous research such as reference papers, other activities and documents related to train to ground communications, wireless networks, cognitive radio and software defined networks.

**Analysis Phase** - This phase comprises information gathered in the Collection Phase, and will be analyzed in an exhaustive and efficient way so that the information can be grouped and summarized into different use cases and scenarios for the FAST-TRACKS project. The definition and template for each identified usage case and scenario will be given in subsequent documents.

**Classification Phase** - This phase will define a general taxonomy for the requirement set (functional, non-functional) which will be specified, so that a coherent classification of requirements is established. A general taxonomy with seven well-identified areas will be established as a first approach to the requirement set for the FAST-TRACKS project. This initial taxonomy is shown in Section 4.

**Specification Phase** - The requirement specification is one of the most important phases in the methodology described here, since an accurate requirement specification will make the subsequent phases of the system requirements process easier. In this phase, requirements will also be prioritized on the basis of the Collection and Analysis phases. The requirement traceability template will be used to trace the requirements with the test procedures and test specification to guarantee complete thoroughness and coherence of the test and measurement activities across the project.

The collection, analysis, classification, and the specification phases could be considered as the "common denominator" of the FAST-TRACKS requirements engineering analysis. It applies to the Fixed and Mobile Communication Plane, Radio Control Plane and Radio Monitoring plane requirements. Consequently, this section is used as a basis for Section 4.

## 3.1 FAST-TRACKS Functional and non-Functional requirements taxonomy definition

This section presents a global picture of the FAST-TRACKS functional and non-functional requirements, identified in Task T1.3. The organization of the non-functional requirements is performed starting from a set of quality requirements, applicable to the FAST-TRACKS context:

- **Openness**, the ability to open access to interfaces, information and resources needed by a system
- **Scalability**, a desirable property of a system, which indicates its ability to either handle growing amounts of work in a graceful manner or to be readily enlarged
- **Reliability**, the ability of a system or component to perform its required functions under stated conditions for a specified period of time
- **Usability**, the clarity with which the interaction with a computer program or a web site is designed
- **Consistency**, uniformity in notation, symbology, appearance, and terminology within itself
- **Robustness**, the ability of a network system to cope with errors during execution or the ability of an algorithm to continue to operate despite abnormalities in input, calculations, etc.
- **Customisability**, the ability for network system to be changed by the user or programmer
- **Responsiveness**, the ability of a system or functional unit to react to a given input.
- **Costless**, in terms of device, accessories and maintenance

For each different layer of the FAST-TRACKS architecture, the proposed taxonomy shows the related category of the non-functional requirements defined in Task T.1.3.

| FASTTRACKS Architecture | | Fixed Communication Plane | Mobile Communication Plane | Radio Control Plane | Radio Monitoring Plane |
|---|---|---|---|---|---|
| Requirements Type | | | | | |
| Non Functional | **Requirements category** | | | | |
| | **Openness** | FCP_19 - Interoperability | MCP_19 - Interoperability | | |
| | **Scalability** | | | RCP_07 - Scalability of RCP | RMP_17 - Dynamic scaling |
| | **Reliability** | FCP_16 - Support for Accounting Authentication and Authorization | MCP_16 - Support for Accounting Authentication and Authorization | RCP_13 - Support for Accounting Authentication and Authorization | RMP_14 - Support for Accounting Authentication and Authorization |
| | **Usability** | FCP_20 - Flexibility at installation and maintenance time | MCP_20 - Flexibility at installation and maintenance time | | |
| | **Consistency** | | | | RMP_18 - Monitoring service Planning, Design and Development |
| | **Robusteness** | | | RCP_10 - Network recovery strategies involving differentnetwork layers | |
| | **Customisability** | FCP_11 - Full firmware customization<br>FCP_21 - Easy to configure | MCP_11 - Full firmware customization<br>MCP_21 - Easy to configure | | |
| | **Responsiveness** | FCP_12 - Seamless handover | MCP_12 - Seamless handover | | |
| | **Costless** | | | | |

**Table 3-2 – FAST-TRACKS non-functional requirements taxonomy**

This section presents a global picture of the FAST-TRACKS functional requirements identified in Task 1.3. Functional requirements organization is performed starting from the set of functional requirements meaningful in the FAST-TRACKS context:

- **General requirements**, are general functional requirements meaningful in the FAST-TRACKS context
- **Network technologies**, indicates the group of physical requirements related to the network technologies involved in the FAST-TRACKS architecture
- **Monitoring and accounting**, groups functional requirements related physical the metering and accounting of physical resources
- **Power Signal**, explain functional requirements related the power signal management and control of the FAST-TRACKS devices
- **Energy Efficiency**, explain functional requirements related the energy management and control of the FAST-TRACKS devices
- **Management of wireless networks**, indicates requirements for wireless networks resource configuration and control
- **Security issues**, indicates functional requirements related the security of the FAST-TRACKS system
- **Virtual Infrastructure planning**, indicates the functional requirements related to the virtual infrastructure organization, behind the RMP

| FASTTRACKS Architecture | | Fixed Communication Plane | Mobile Communication Plane | Radio Control Plane | Radio Monitoring Plane |
|---|---|---|---|---|---|
| Functional | **General Requirements (independent)** | **FCP_01** - Programmable Radio<br>**FCP_13** - Railway ready design | **MCP_01** - Programmable Radio<br>**MCP_13** - Railway ready design | **RCP_01** - Programmable Controller | |
| | **Network Technologies** | **FCP_02** - Triple Core Radio<br>**FCP_08** - Modular Radio<br>**FCP_04..09** - Multiple Standard<br>**FCP_10** - Tunable throughput<br>**FCP_12** - Seamless handover<br>**FCP_14** - High Interference Rejection<br>**FCP_15** - Optical Transport Interface<br>**FCP_21** - Adaptive Frame Rate | **MCP_02** - Triple Core Radio<br>**MCP_08** - Modular Radio<br>**MCP_04..09** - Multiple Standard<br>**MCP_10** - Tunable throughput<br>**MCP_12** - Seamless handover<br>**MCP_14** - High Interference Rejection<br>**MCP_15** - GPS on board (hw and sw) | **RCP_02** - Double Core Controller<br>**MCP_08** - Modular Controller | |
| | **Monitoring and accounting** | **FCP_17** - Local Control and Monitoring Tools | **MCP_17** - Local Control and Monitoring Tools | | **RMP_05** - Local control and monitoring tools<br>**RMP_13** - Mechanisms for billing the used bandwidth |
| | **Power Signal** | **FCP_22** - Adaptive Power Signal | **MCP_22** - Adaptive Power Signal | **RCP_12** - Advertisement of "RSSI" parametrs and wireless power signal routing computation | **RMP_01** - Power signal data collection<br>**RMP_02** - Power signal data monitoring |
| | **Energy Efficiency** | **FCP_18** - Power consumption measurement and energy saving procedures | **MCP_18** - Power consumption measurement and energy saving procedures | **RCP_11** - Advertisement of "green TE" parametrs and energy-aware routing computation | **RMP_03** - Power consumption data collection<br>**RMP_04** - Power consumption data monitoring<br>**RMP_06** - Power consumption measurement and energy saving procedures |
| | **Management of wireless networks** | | | **RCP_04** - Network Resource Discovery<br>**RCP_05** - Dynamic bandwidth allocation<br>**RCP_08** - Unicast connections with end-point selection assisted by the RCP<br>**RCP_09** - Anycast connections - destination selected from an explicit set of end-points | **RMP_15** - Resource Discovery<br>**RMP_16** - Transparent Resource Relocation<br>**RMP_17** - Dynamic Scaling |
| | **Security issues** | **FCP_16** - Support for Accounting Authentication and Authorization | **MCP_16** - Support for Accounting Authentication and Authorization | **RCP_16** - Support for Accounting Authentication and Authorization | **RMP_16** - Support for Accounting Authentication and Authorization |
| | **Virtual Infrastructure Planning and Cloud Support** | | | | **RMP_07** - Enable Virtual Infrastructure Configuration<br>**RMP_08** - IT resource virtualization<br>**RMP_09** - Operational Support System to Cloud Computing<br>**RMP_10** - On-demand attachment and scheduling of database resources to virtual infrastructures<br>**RMP_11** - Dynamic physical infrastructure resource selection<br>**RMP_12** - On-demand resource provisioning |

**Table 3-3 – FAST-TRACKS functional requirements taxonomy**

## 3.2 Analysis of the FAST-TRACKS requirements and variance

Developing a product line requires not only the management of requirements but also management of its variance through the collection of options, which are associated with requirements. These options often result in optional features during requirements engineering, as variation points in the design phase and different implementations. The variance of requirements may also identify different features of the same product or sometimes separate products targeting different marketing segment. The reference paper [20] and related work on the subject proposes a systematic approach to identify and document variability implementation mechanisms. In particular its method of utilisation of Kiviat graphs, would be useful to identify the completeness and variability of requirements and finally to make an assessment to see if some specific part of the system has been described more exhaustively than others. Applying the above concept to the FAST-TRACKS architecture requirements analysis we have the following results:

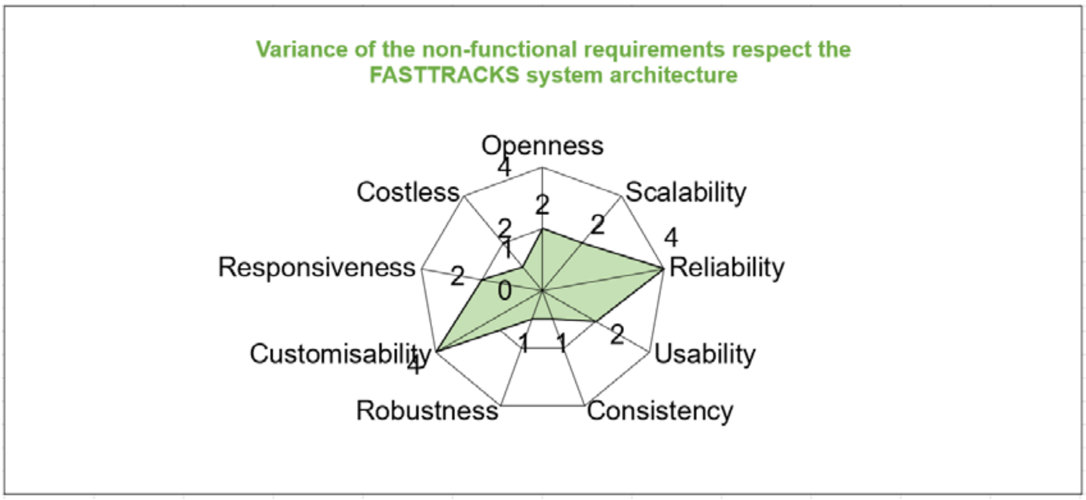


**Figure 3 – Variance of the FAST-TRACKS non-functional requirements respect the system architecture**

We use the Kiviat-graph as a graphical device for plotting FAST-TRACKS non-functional requirements occurrence on the same axes. Each axis represents one requirement. On each axis the point gets marked which represents the ranking of this requirements. This technique permits to monitor the requirements of the FAST-TRACKS system tracking of a large number of interrelated parameters. In details, the definition of FAST-TRACKS non-functional requirements makes in evidence that the technical architecture of FAST-TRACKS could be mainly conceived as a reliable, open and customizable.

The proposed methodology and tool could be applied also to the FAST-TRACKS functional requirements analysis, driving the FAST-TRACKS application architecture.

The following results are observed:

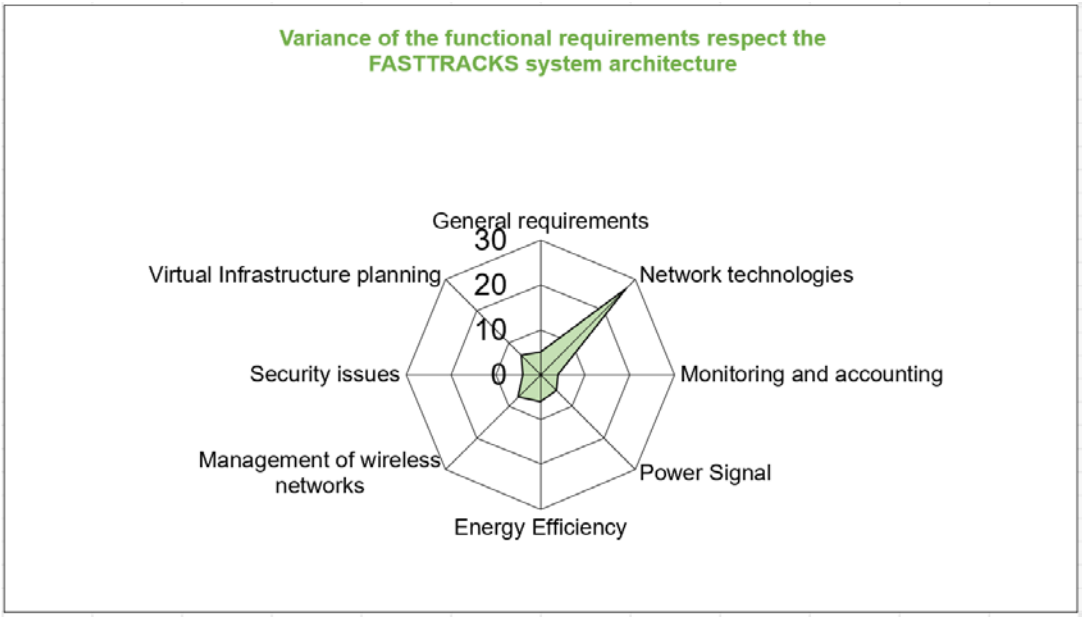


**Figure 4 – Variance of the FAST-TRACKS functional requirements respect the system architecture**

In this second figure, the Kiviat diagrams is used to graphically present FAST-TRACKS functional requirements occurrence on the same axes. In particular, the definition of FAST-TRACKS functional requirements shows that the whole architecture of FAST-TRACKS could be mainly conceived as a network architecture implementing management of wireless networks on top of a virtual infrastructures.

# 4 List of functional and non-functional requirements

FAST-TRACKS project proposes the development and commercialization of a low-cost telecommunication system, which addresses the main problems faced at present in the integration of a traditional Wi-Fi system within the railway technological infrastructure. The project is based on the design of a reprogrammable radio supporting different Wi-Fi, Cellular and LTE standards at the same time, which will foster and guarantee the convergence between automatic train control systems and network telecommunication standards. The innovative solution proposed is able to support each type of railway communication, using a full programmable infrastructure based on Fixed Radio, Mobile Radio and Programmable Radio Manager. The following table shows a brief classification of the functional and non-functional requirements of the FT project:

| Classification | Name | Number | Type of requirement |
|---|---|---|---|
| | | | |
| Fixed Communication Plane (FCP) requirements | Programmable Radio [SDR based] | FCP_01 | Functional |
| | Triple Core Radio | FCP_02 | Functional |
| | Modular Radio | FCP_03 | Functional |
| | Multiple Standard - IEEE 802.11 a, b, g, n | FCP_04 | Functional |
| | Multiple Standard - IEEE 802.11 ac | FCP_05 | Functional |
| | Multiple Standard - TETRA | FCP_06 | Functional |
| | Multiple Standard - LTE | FCP_07 | Functional |
| | Multiple Standard - GSM | FCP_08 | Functional |
| | Multiple Standard - LORA | FCP_09 | Functional |
| | Tunable throughput [1Mb/s – to 1.3Gb/s] | FCP_10 | Functional |
| | Full Firmware Customization | FCP_11 | Non-functional |
| | Seamless handover | FCP_12 | Functional/ Non-functional |
| | Railway ready design | FCP_13 | Functional |
| | High Interference Rejection (HIR) | FCP_14 | Functional |
| | Optical Transport interface | FCP_15 | Functional |
| | Support for Accounting Authentication and Authorization | FCP_16 | Functional/ Non-functional |
| | Local Control and Monitoring tools | FCP_17 | Functional |
| | Power consumption measurement and energy saving procedures | FCP_18 | Functional |
| | Interoperable | FCP_19 | Non-functional |
| | Flexibility at installation and maintenance time | FCP_20 | Non-functional |
| | Easy to configure | FCP_21 | Non-functional |
| | Adaptive Frame Rate | FCP_22 | Functional |
| | Adaptive Power Signal | FCP_23 | Functional |

| | | | |
|---|---|---|---|
| **Mobile Communication Plane (MCP) requirements** | Programmable Radio [OEM based] | MCP_01 | Functional |
| | Triple Core Radio | MCP_02 | Functional |
| | Modular Radio | MCP_03 | Functional |
| | Multiple Standard - IEEE 802.11 a, b, g, n | MCP_04 | Functional |
| | Multiple Standard - IEEE 802.11 ac | MCP_05 | Functional |
| | Multiple Standard - TETRA | MCP_06 | Functional |
| | Multiple Standard - LTE | MCP_07 | Functional |
| | Multiple Standard - GSM | MCP_08 | Functional |
| | Multiple Standard - LORA | MCP_09 | Functional |
| | Tunable throughput [1Mb/s – to 1.3Gb/s] | MCP_10 | Functional |
| | Full Firmware Customization | MCP_11 | Non-functional |
| | Seamless handover | MCP_12 | Functional/ Non-functional |
| | Railway ready design | MCP_13 | Functional |
| | High Interference Rejection (HIR) | MCP_14 | Functional |
| | GPS on board (Hardware & Software) | MCP_15 | Functional |
| | Support for Accounting Authentication and Authorization | MCP_16 | Functional/ Non-functional |
| | Local Control and Monitoring tools | MCP_17 | Functional |
| | Power consumption measurement and energy saving procedures | MCP_18 | Functional |
| | Interoperability | MCP_19 | Non-functional |
| | Flexibility at installation and maintenance time | MCP_20 | Non-functional |
| | Easy to configure | MCP_21 | Non-functional |
| | Adaptive Frame Rate | MCP_22 | Functional |
| | Adaptive Power Signal | MCP_23 | Functional |
| | | | |
| **Radio Control Plane (RCP) requirements** | Programmable Controller [SDN based] | RCP_01 | Functional |
| | Dual Core Controller | RCP_02 | Functional |
| | Modular Controller | RCP_03 | Functional |
| | Network resource discovery | RCP_04 | Functional |
| | Dynamic bandwidth allocation | RCP_05 | Functional |
| | Constrained Traffic Engineering | RCP_06 | Functional / Non-functional |
| | Scalability of RCP | RCP_07 | Non-functional |
| | Unicast connections with end-point selection assisted by the RCP | RCP_08 | Functional |
| | Anycast connections – destination selected from an explicit set of end-points | RCP_09 | Functional |
| | Network recovery strategies involving different network layers | RCP_10 | Non-functional |
| | Advertisement of “green TE” parameters and “energy-aware” routing computation | RCP_11 | Functional |
| | Advertisement of “RSSI” parameters and wireless power signal routing computation | RCP_12 | Functional |
| | Support for Accounting Authentication and Authorization | RCP_13 | Non-functional |
| | Flexibility at installation and maintenance time | RCP_14 | Non-functional |
| | Easy to configure | RCP_15 | Non-functional |

| | | | |
|---|---|---|---|
| Radio Monitoring Plane (RMP) requirements | Power signal data collection | RMP_01 | Functional |
| | Power signal data monitoring | RMP_02 | Functional |
| | Power consumption data collection | RMP_03 | Functional |
| | Power consumption monitoring | RMP_04 | Functional |
| | Local Control and Monitoring tools | RMP_05 | Functional |
| | Power consumption measurement and energy saving procedures | RMP_06 | Functional |
| | Enable virtual infrastructure configuration | RMP_07 | Functional |
| | IT resource virtualization | RMP_08 | Functional |
| | Operational Support System to cloud | RMP_09 | Functional |
| | On-demand attachment and scheduling of resources to virtual infrastructures | RMP_10 | Functional |
| | Dynamic physical infrastructure resource selection | RMP_11 | Functional |
| | On-demand resource provisioning | RMP_12 | Functional |
| | Mechanisms for billing the used bandwidth | RMP_13 | Functional |
| | Support for Accounting Authentication and Authorization | RMP_14 | Non-functional |
| | Resource Discovery | RMP_15 | Functional |
| | Transparent Resource Relocation | RMP_16 | Functional |
| | Dynamic Scaling | RMP_17 | Functional/ Non-functional |
| | Service Planning, Design and Development | RMP_18 | Non-functional |
| | | | |

**Table 4-1 – FAST-TRACKS functional and non-functional requirements**

## 4.1 Fixed Communication Plane (FCP) requirements

This section presents the requirements, both functional and non-functional, relative to the Fixed Communication Plane. The section is structured and presented using the template introduced in the section 3.

| Requirement: Fixed Communication Plane | |
|---|---|
| Number | FCP_01 |
| Name | Programmable Radio |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS architecture must provide mechanisms to dynamically re-plan the allocation of the physical radio resources in order to guarantee the implementation of different transmission standards with the same device. SDR (Software Defined Radio) is one of the possible technology that will be used to cover this requirement. |
| Related use case | Train To Ground communication using Wi-FI (DCS); Point to point communication via TETRA radio implementation; Multipoint to point connection of LORA devices with the wayside radio working as LORA Gateway. |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [2-medium]<br>Exploitability: [3-high] |
| Test Notes | Metric: Flexibility<br>Success: building a prototype or a device easlily programmable which implements at least 3 different radio standards |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-2 – Programmable Radio**

| Requirement: Fixed Communication Plane | |
|---|---|
| Number | FCP_02 |
| Name | Triple Core Radio |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS architecture must provide more than one Radio Core, in order to allow simultaneous data transmission using a mesh pattern. This requirement permits to solve redundancy and resiliency problems, well known in the railway environment. |
| Related use case | Mesh network supporting Train To Ground Wi-Fi communication; |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [2-medium]<br>Exploitability: [2- medium] |

| | |
|---|---|
| Test Notes | Metric: Redudancy<br>Success: create a mesh network allowing at least two links always active |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-3 – Triple Core Radio**

| Requirement: Fixed Communication Plane | |
|---|---|
| Number | FCP_03 |
| Name | Moduler Radio |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS architecture must provide modular devices. In other words, both the wayside, train and the controller will be conceived to be modular, in order to facilitate the configuration, installation and maintenance of the whole radio infrastructure. |
| Related use case | Train To Ground communication using Wi-FI (DCS): wayside and train radio based on the same mainboard and differentiated with the additional hardware modules (radio core, GPS module, optical module, etc) |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [2-medium]<br>Exploitability: [3-high] |
| Test Notes | Metric: Maintenance<br>Success: building a prototype supporting at least three pluggable hardware modules |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-4 – Modular Radio**

| Requirement: Fixed Communication Plane | |
|---|---|
| Number | FCP_04 … FCP_09 |
| Name | Multiple Standards |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS architecture must implements multiple radio standards (IEEE802.11 a, b, g, n, ac, TETRA, LTE, GSM, LORA). |
| Related use case | Train To Ground communication using Wi-FI (DCS); Point to point communication via TETRA radio implementation; Multipoint to point connection of LORA devices with the wayside radio working as LORA Gateway. |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [2-medium] |

| | |
|---|---|
| | Exploitability: [3-high] |
| Test Notes | Metric: Standard compliance<br>Success: building a prototype supporting at least three different standards |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-5 – Multiple Standards**

| Requirement: Fixed Communication Plane | |
|---|---|
| Number | FCP_10 |
| Name | Tunable Throughput |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS architecture must implements multiple radio standards allowing different tunable throughputs (IEEE802.11 a, b, g, n, ac, TETRA, LTE, GSM, LORA). |
| Related use case | Train To Ground communication using Wi-FI (DCS); Point to point communication via TETRA radio implementation; Multipoint to point connection of LORA devices with the wayside radio working as LORA Gateway. |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [2-medium]<br>Exploitability: [2- medium] |
| Test Notes | Metric: Troughput Range<br>Success: building a prototype supporting at least three different tunable ranges |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-6 – Tunable Throughput**

| Requirement: Fixed Communication Plane | |
|---|---|
| Number | FCP_11 |
| Name | Firmware customization |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS radio architecture allows the customization of the firmware environment. This permits to build new features starting from an opensource base release. |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [2-medium]<br>Business value: [2-medium] |

| | |
|---|---|
| | Prior Knowledge: [1-low]<br>Exploitability: [2-medium] |
| Test Notes | Metric: Customization degree<br>Success: building a prototype starting from OpenWRT firmware or equivalent linux operative system |
| Requirement Type | Non-Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-7 – Firmware customization**

| Requirement: Fixed Communication Plane | |
|---|---|
| Number | FCP_12 |
| Name | Seamless Handover |
| Organization name | COMESVIL |
| Description | The handover represents one of the most critical feature of the FASTTRACK project. It implement the roaming with disassociation/reassociation between two adjacent Access Points |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [2-medium]<br>Exploitability: [2-high] |
| Test Notes | Metric: Reliability<br>Success: building a prototype implementing the handover procedure in at least 30ms |
| Requirement Type | Functional/Non-Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-8 – Seamless Handover**

| Requirement: Fixed Communication Plane | |
|---|---|
| Number | FCP_13 |
| Name | Railway-ready design |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS radio must implements all the physical and electrical features needed to be certificated in railway environment |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [1-low]<br>Business value: [3-high]<br>Prior Knowledge: [1-low] |

| | |
|---|---|
| | Exploitability: [2-medium] |
| Test Notes | Metric: Certification<br>Success: building a certificated product (i.e. EN50155) |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-9 – Railway-ready design**

| Requirement: Fixed Communication Plane | |
|---|---|
| Number | FCP_14 |
| Name | High Interference Rejection |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS radio needs to implements a signal interference rejection mechanism, in order to avoid signal loss. |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the Train |
| Prioritisation | Novelty: [2-medium]<br>Business value: [2-medium]<br>Prior Knowledge: [1-low]<br>Exploitability: [2-medium] |
| Test Notes | Metric: Reliability<br>Success: implements a prototype with high rejection to interference |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-10 – High Interference Rejection**

| Requirement: Fixed Communication Plane | |
|---|---|
| Number | FCP_15 |
| Name | Optical Transport Interface |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS fixed radio must implements at least an optical port, in order to integrate it in the DCS backbone network. Thi requirement needs the redesign of the Access Point PCB (Printed Circuit Board). |
| Related use case | Train To Ground communication using Wi-FI (DCS); |
| Prioritisation | Novelty: [2-medium]<br>Business value: [2-medium]<br>Prior Knowledge: [1-low]<br>Exploitability: [2-medium] |

| | |
|---|---|
| Test Notes | Metric: Backbone Integrability<br>Success: building a new prototype including at least an optical port. |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-11 – Optical Transport Interface**

| Requirement: Fixed Communication Plane | |
|---|---|
| Number | FCP_16 |
| Name | AAA Support |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS radio architecture must integrate the features of Authorization, Authentication and Accounting implementing the related standards (i.e. Radius) |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [2-medium]<br>Business value: [2-medium]<br>Prior Knowledge: [1-low]<br>Exploitability: [2-medium] |
| Test Notes | Metric: Security<br>Success: building a prototype implementing basic AAA standards |
| Requirement Type | Functional/Non Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-12 – AAA Support**

| Requirement: Fixed Communication Plane | |
|---|---|
| Number | FCP_17 |
| Name | Local Control and Monitoring tools |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS radio architecture must implements local monitoring tools, in order to enhance the routing features offered by the network controller. |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [1-low]<br>Exploitability: [2-medium] |
| Test Notes | Metric: Monitoring<br>Success: building a prototype implementing monitoring tools for management of critical metrics (i.e. power consumption, RSSI). |
| Requirement Type | Functional |

| Details | |
|---|---|
| | <Details of the requirement (if needed)> |

**Table 4-13 – Local Control and Monitoring tools**

| Requirement: Fixed Communication Plane | |
|---|---|
| Number | FCP_18 |
| Name | Power consumption measurement and energy saving procedures |
| Organization name | COMESVIL |
| Description | To create energy-aware network devices, the FAST-TRACKS radio architecture needs to implements power consumption procedures. |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [1-low]<br>Exploitability: [2-medium] |
| Test Notes | Metric: Low power consumption<br>Success: building a prototype integrating energy saving procedures |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-14 – Power consumption measurement and energy saving procedures**

| Requirement: Fixed Communication Plane | |
|---|---|
| Number | FCP_19 |
| Name | Interoperability |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS radio architecture needs to implements radio standards in order to open the interoperability with legacy devices. |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [2-medium]<br>Business value: [2-medium]<br>Prior Knowledge: [1-low]<br>Exploitability: [2-medium] |
| Test Notes | Metric: Interoperability degree<br>Success: building a prototype implementing open standards |
| Requirement Type | Non-Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-15 – Interoperability**

| Requirement: Fixed Communication Plane | |
|---|---|
| Number | FCP_20 |
| Name | Flexibility at installation and maintenance time |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS radio architecture must be modular, in order to facilitate installation and maintenance activities |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [1-low]<br>Exploitability: [2-medium] |
| Test Notes | Metric: Modularity<br>Success: building a modular prototype according to the design presented in D1.1 |
| Requirement Type | Non-Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-16 – Flexibility at installation and maintenance time**

| Requirement: Fixed Communication Plane | |
|---|---|
| Number | FCP_21 |
| Name | Easy to configure |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS radio must present a graphical user interface that allows to configure each device in easy way. |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [2-medium]<br>Business value: [3-high]<br>Prior Knowledge: [1-low]<br>Exploitability: [2-medium] |
| Test Notes | Metric: Configurability<br>Success: building a prototype having an easy to use configuration system |
| Requirement Type | Non-Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-17 – Easy to configure**

| Requirement: Fixed Communication Plane | |
|---|---|
| Number | FCP_22 |
| Name | Adaptive Frame Rate |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS radio needs to implements a mechanism to manage dynamic |

| | |
|---|---|
| | requests of additional bandwidth, automatically. |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [1-low]<br>Exploitability: [2-medium] |
| Test Notes | Metric: Robustness<br>Success: building a prototype implementing feature as described in the patent pending [11] |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-18 – Adaptive Frame Rate**

| Requirement: Fixed Communication Plane | |
|---|---|
| Number | FCP_23 |
| Name | Adaptive Power Signal |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS radio needs to implements a mechanism to adapt the power signal dynamically. |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [2-medium]<br>Exploitability: [2-medium] |
| Test Notes | Metric: Reliabiluty<br>Success: building a prototype implementing feature as described in the patent pending [11] |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-19 – Adaptive Power Signal**

## 4.2 Mobile Communication Plane (MCP) requirements

This section presents the requirements, both functional and non-functional, relative to the Mobile Communication Plane. The section is structured and presented using the template introduced in the section 3. Since both the Fixed than the Mobile Communication plane are specular, most of the requirements are the same between the two planes. So, this section introduces only the differences.

| Requirement: Mobile Communication Plane | |
|---|---|
| Number | MCP_01 |
| Name | Programmable Radio [OEM based] |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS architecture must provide mechanisms to dynamically re-plan the allocation of the physical radio resources in order to guarantee the implementation of different transmission standards with the same device. OEM based processors is one of the possible technology that will be used to cover this requirement. |
| Related use case | Train To Ground communication using Wi-FI (DCS); Point to point communication via TETRA radio implementation; Multipoint to point connection of LORA devices with the wayside radio working as LORA Gateway. |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [2-medium]<br>Exploitability: [3-high] |
| Test Notes | Metric: Frequency<br>Success: building a prototype or a device easlily programmable which implements at least 3 different radio standards |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-20 – Programmable Radio**

| Requirement: Mobile Communication Plane | |
|---|---|
| Number | MCP_15 |
| Name | GPS on board |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS architecture must provide a mechanism that monitors the the relationship between the Received Signal Streight Indication (RSSI) and the position of the train. This feature is foundamental to produce information about the radiocoverage of the running telecommunication system system and discover possible coverage faults during in the wayside |
| Related use case | Train To Ground communication using Wi-FI (DCS); Point to point communication via TETRA radio implementation; Multipoint to point connection of LORA devices with the wayside radio working as LORA Gateway. |

| | |
|---|---|
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [2-medium]<br>Exploitability: [3-high] |
| Test Notes | Metric: RSSI Geolocalization<br>Success: Design and implements the RSSI geolocalization and integrate it in the Mobile Radio. |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-21 – GPS on board**

## 4.3 Radio Control Plane (RCP) requirements

This section presents the requirements, both functional and non-functional, relative to the Radio Control Plane. The section is structured and presented using the template introduced in the section 3.

| Requirement: Radio Control Plane | |
|---|---|
| Number | RCP_01 |
| Name | Programmable Controller [SDN based] |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS architecture must provide mechanisms a network controller which dynamically re-plan the allocation of the physical radio resources between different access points. Software Defined Networks is one of the possible technology that will be used to cover this requirement. |
| Related use case | Train To Ground communication using Wi-FI (DCS); Point to point communication via TETRA radio implementation; Multipoint to point connection of LORA devices with the wayside radio working as LORA Gateway. |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [2-medium]<br>Exploitability: [3-high] |
| Test Notes | Metric: Flexibility<br>Success: building a controller or a device easlily programmable which implements at least 3 different radio standards |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-22 – Programmable Controller**

| Requirement: Radio Control Plane | |
|---|---|
| Number | RCP_02 |
| Name | Dual Core Controller |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS architecture must provide more than one Radio Core, in order to allow simultaneous data transmission using a mesh pattern. This requirement permits to solve redundancy and resiliency problems, well known in the railway environment. |
| Related use case | Mesh network supporting Train To Ground Wi-Fi communication; |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [2-medium]<br>Exploitability: [2- medium] |

| | |
|---|---|
| Test Notes | Metric: Redudancy<br>Success: control a mesh network allowing at least two links always active |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-23 – Dual Core Controller**

| Requirement: Radio Control Plane | |
|---|---|
| Number | RCP_03 |
| Name | Moduler Controller |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS architecture must provide modular devices. In other words, both the wayside, train and the controller will be conceived to be modular, in order to facilitate the configuration, installation and maintenance of the whole radio infrastructure. |
| Related use case | Train To Ground communication using Wi-FI (DCS): wayside and train radio based on the same mainboard and differentiated with the additional hardware modules (radio core, GPS module, optical module, etc) |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [2-medium]<br>Exploitability: [3-high] |
| Test Notes | Metric: Maintenance<br>Success: building a prototype supporting at least three pluggable hardware modules |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-24 – Modular Controller**

| Requirement: Radio Control Plane | |
|---|---|
| Number | RCP_04 |
| Name | Network Resource Discovery |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS architecture must provide a Network Resource Discovery mechanism in order to facilitate the configuration, and management of the whole radio infrastructure. |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [2-medium]<br>Exploitability: [3-high] |

| | |
|---|---|
| Test Notes | Metric: Network Management<br>Success: building a controller able to discover the managed network automatically |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-25 – Network Resource Discovery**

| Requirement: Radio Control Plane | |
|---|---|
| Number | RCP_05 |
| Name | Dynamic Bandwidth Allocation |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS architecture must provide a Dynamic Bandwidth Allocation mechanism in order to facilitate the allocation of the network resource, preserving the vital data streams (CBTC). |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [2-medium]<br>Exploitability: [3-high] |
| Test Notes | Metric: Network Management<br>Success: building a controller able to allocate the network bandwidth dynamically |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-26 – Dynamic Bandwidth Allocation**

| Requirement: Radio Control Plane | |
|---|---|
| Number | RCP_06 |
| Name | Constrained Traffic Engineering |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS architecture must implements mechanisms to route the traffic starting from well-defined metrics (i.e. RSSI, power consumption) |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [2-medium]<br>Exploitability: [3-high] |
| Test Notes | Metric: Network Management<br>Success: building a controller able implements traffic engineering and routing metrics |
| Requirement Type | Functional/Non-Functional |

| Details | |
|---|---|
| | <Details of the requirement (if needed)> |

**Table 4-27 – Constrained Traffic Engineering**

| Requirement: Radio Control Plane | |
|---|---|
| Number | RCP_07 |
| Name | Scalability of the Radio Control Plane |
| Organization name | COMESVIL |
| Description | In the FAST-TRACKS architecture, the RCP protocols should scale in terms of the number of controlled elements, so that the provisioning and recovery performance are not hindered due to a too large control network. |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [2-medium]<br>Exploitability: [3-high] |
| Test Notes | Metric: Scalability<br>Success: measured in terms of maximum number of resources to assure a good performance |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-28 – Scalability of the Radio Control Plane**

| Requirement: Radio Control Plane | |
|---|---|
| Number | RCP_08 |
| Name | Unicast connections with end-point selection assisted by RCP |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS RCP need optionally implement the “assisted unicast” connection model where the RCP receives a set of possible pairs of end-points from the application layer and provides a forecast about the related point-to-point connections, regarding network performance and cost. |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [2-medium]<br>Exploitability: [3-high] |
| Test Notes | Metric: Efficiency in the end-point selection<br>Success: Computation of the values associated with the network performance and cost for multiple destination Radio end-points |
| Requirement Type | Functional |
| Details | |

| | |
|---|---|
| | <Details of the requirement (if needed)> |

**Table 4-29 – Unicast connections with end-point selection assisted by RCP**

| Requirement: Radio Control Plane | |
|---|---|
| Number | RCP_09 |
| Name | Anycast connections – destination selected from an explicit set of end-points |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS RCP need optionally implement the “restricted anycast” connection model: the RCP receives a set of equivalent pairs of source and destination end-points from the application layer, selects the best pair taking into account radio network criteria and finally establishes the point-to-point connection.<br>The main difference with respect to the “assisted unicast” model is the decision point: in this case the selection of the end-points is completely delegated to the RCP, while in the previous case it was performed by the application layer. |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [2-medium]<br>Exploitability: [3-high] |
| Test Notes | Metric: Efficiency in the end-point selection<br>Success: Selection of the optimal destination end-point, successful network resource provisioning |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-30 – Anycast connections – destination selected from an explicit set of end-points**

| Requirement: Radio Control Plane | |
|---|---|
| Number | RCP_10 |
| Name | Network recovering strategies involving different network layer |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS RCP need optionally implement mechanisms for cross-layer recovery, needed in case of failures in network connections built with hierarchical Link State Packets (LSPs). |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [2-medium]<br>Exploitability: [3-high] |
| Test Notes | Metric: Recovery efficiency<br>Success: Detection of network failures and success of the recovery procedures |

| | |
|---|---|
| | involving different network layers. |
| Requirement Type | Non-Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-31 – Network recovering strategies involving different network layer**

| Requirement: Radio Control Plane | |
|---|---|
| Number | RCP_11 |
| Name | Advertisement of “green TE” parameters and “energy-aware” routing computation |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS RCP need optionally extend RSVP signalling in order to advertise parameters related to the energy consumption for radio network resources. These “green” parameters should model both fixed (i.e. network equipment power-consumption) and dynamic values (i.e. traffic load, number of signal regeneration points on the path).<br>The PCE computation algorithms must be able to take into account constraints related to the attributes describing the energy consumption for radio network resources. These constrained-based algorithms should be able to optimize the routes (and the selection of the Radio Fixed/Mobile Access Points if needed) according to the combined impact of resource types. |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [2-medium]<br>Exploitability: [3-high] |
| Test Notes | Metric: Energy efficiency<br>Success: The routing protocols must be able to advertise parameters associated with the energy consumption; route computation algorithms must be able to minimize the energy consumption for wireless network resources. |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-32 – Advertisement of “green TE” parameters and “energy-aware” routing computation**

| Requirement: Radio Control Plane | |
|---|---|
| Number | RCP_12 |
| Name | Advertisement of “RSSI” parameters and wireless power signal routing computation |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS RCP need to extend RSVP signalling in order to advertise parameters related to the Received Signal Strength Indication (RSSI) for radio network resources. These power signal parameters should model the mesh network |

| | |
|---|---|
| | topology dynamically. The PCE computation algorithms must be able to take into account constraints related to the attributes describing the energy consumption for radio network resources. These constrained-based algorithms should be able to optimize the routes (and the selection of the Radio Fixed/Mobile Access Points if needed) according to the combined impact of resource types. |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [2-medium]<br>Exploitability: [3-high] |
| Test Notes | Metric: Power Signal<br>Success: The routing protocols must be able to advertise parameters associated with the RSSI; route computation algorithms must be able to decide the network topology strating from the power signal of the wireless network resources involved. |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-33 – Advertisement of “RSSI” and wireless power signal routing computation**

| Requirement: Radio Control Plane | |
|---|---|
| Number | RCP_13 |
| Name | AAA Support |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS controller architecture must integrate the features of Authorization, Authentication and Accounting implementing the related standards (i.e. Radius) |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [2-medium]<br>Business value: [2-medium]<br>Prior Knowledge: [1-low]<br>Exploitability: [2-medium] |
| Test Notes | Metric: Security<br>Success: building a prototype implementing basic AAA standards |
| Requirement Type | Functional/Non Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-34 – AAA Support**

| Requirement: Radio Control Plane | |
|---|---|
| Number | RCP_14 |
| Name | Flexibility at installation and maintenance time |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS controller architecture must be modular, in order to facilitate installation and maintenance activities |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [3-high]<br>Business value: [3- high]<br>Prior Knowledge: [1-low]<br>Exploitability: [2-medium] |
| Test Notes | Metric: Modularity<br>Success: implements a modular controller according to the design presented in D1.1 |
| Requirement Type | Non-Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-35 – Flexibility at installation and maintenance time**

| Requirement: Radio Control Plane | |
|---|---|
| Number | RCP_15 |
| Name | Easy to configure |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS controller must present a graphical user interface that allows to configure each device in easy way. |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [2-medium]<br>Business value: [3-high]<br>Prior Knowledge: [1-low]<br>Exploitability: [2-medium] |
| Test Notes | Metric: Configurability<br>Success: implements a controller having an easy to use configuration system |
| Requirement Type | Non-Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-36 – Easy to configure**

## 4.4 Radio Monitoring Plane (RMP) requirements

This section presents the requirements, both functional and non-functional, relative to the Radio Monitoring Plane. The section is structured and presented using the template introduced in the section 3.

| Requirement: Radio Monitoring Plane | |
|---|---|
| Number | RMP_01 |
| Name | Power signal data collection |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS architecture must provide power signal data collection and storage mechanisms. |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [2-medium]<br>Exploitability: [3-high] |
| Test Notes | Metric: Monitoring<br>Success: building a network monitoring system for power signal data collection and sharing |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-37 – Power signal data collection**

| Requirement: Radio Monitoring Plane | |
|---|---|
| Number | RMP_02 |
| Name | Power signal data monitoring |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS architecture must provide power signal data monitoring and control mechanisms. |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [2-medium]<br>Exploitability: [3-high] |
| Test Notes | Metric: Monitoring<br>Success: building a network monitoring system for power signal data management |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-38 – Power signal data monitoring**

| Requirement: Radio Monitoring Plane | |
|---|---|
| Number | RMP_03 |
| Name | Power consumption data collection |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS architecture must provide power consumption data collection and storage mechanisms. |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [2-medium]<br>Exploitability: [3-high] |
| Test Notes | Metric: Monitoring<br>Success: building a network monitoring system for power consumption data collection and sharing |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-39 – Power consumption data collection**

| Requirement: Radio Monitoring Plane | |
|---|---|
| Number | RMP_04 |
| Name | Power consumption monitoring |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS architecture must provide power consumption monitoring and control mechanisms. |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [2-medium]<br>Exploitability: [3-high] |
| Test Notes | Metric: Monitoring<br>Success: building a network monitoring system for power consumption management |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-40 – Power consumption monitoring**

| Requirement: Fixed Communication Plane | |
|---|---|
| Number | RMP_05 |
| Name | Local Control and Monitoring tools |

| | |
|---|---|
| Organization name | COMESVIL |
| Description | The FAST-TRACKS Monitoring Plane must implements local monitoring tools, in order to measure and manage the overall network infrastructure. |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [1-low]<br>Exploitability: [2-medium] |
| Test Notes | Metric: Monitoring<br>Success: building a monitoring plane implementing tools for management of critical metrics analysis (i.e. power consumption, RSSI). |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-41 – Local Control and Monitoring tools**

| Requirement: Radio Monitoring Plane | |
|---|---|
| Number | RMP_06 |
| Name | Power consumption measurement and energy saving procedures |
| Organization name | COMESVIL |
| Description | To create energy-aware network devices, the FAST-TRACKS RMP needs to implements power consumption procedures. |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [2-medium]<br>Business value: [2-medium]<br>Prior Knowledge: [1-low]<br>Exploitability: [2-medium] |
| Test Notes | Metric: Low power consumption<br>Success: building a monitoring plane integrating energy saving procedures |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-42 – Power consumption measurement and energy saving procedures**

| Requirement: Radio Monitoring Plane | |
|---|---|
| Number | RMP_07 |
| Name | Enable virtual infrastructure configuration |
| Organization name | COMESVIL |
| Description | This requirement is mandatory and permits to configure a commercial cloud environment in order to create a virtual infrastructure, devoted to the support of |

| | |
|---|---|
| | the Radio Monitoring Plane. A possible choice to implementi it is the VMWARE virtualization toolkit (ESXi). |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [2-medium]<br>Business value: [2-medium]<br>Prior Knowledge: [1-low]<br>Exploitability: [2-medium] |
| Test Notes | Metric: Virtualization<br>Success: building a monitoring plane virtualized on top of physical resources |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-43 – Enable virtual infrastructure configuration**

| Requirement: Radio Monitoring Plane | |
|---|---|
| Number | RMP_08 |
| Name | IT resource virtualization |
| Organization name | COMESVIL |
| Description | This requirement is mandatory and permits to configure a commercial virtualization and cloud environment in order to create one or more virtual infrastructure, devoted to the support of the Radio Monitoring Plane. |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [1-low]<br>Exploitability: [2-medium] |
| Test Notes | Metric: Virtualization<br>Success: building a monitoring plane virtualized on top of physical resources |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-44 – IT resource virtualization**

| Requirement: Radio Monitoring Plane | |
|---|---|
| Number | RMP_09 |
| Name | Operational support system to cloud |
| Organization name | COMESVIL |
| Description | This requirement is mandatory and permits to associate the virtualized infrastructure on a public cloud using appropriate secure and interoperable interfaces. |

| | |
|---|---|
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [1-low]<br>Exploitability: [2-medium] |
| Test Notes | Metric: Virtualization<br>Success: building a monitoring plane virtualized on top of physical resources |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-45 – Operational support system to cloud**

| Requirement: Radio Monitoring Plane | |
|---|---|
| Number | RMP_10 |
| Name | On demand attachment and scheduling of resources to virtual infrastructures |
| Organization name | COMESVIL |
| Description | This requirement is optional and permits to manage scheduling issues and perform implementation of time control mechanisms for assuring virtual infrastructure creation and provisioning, as well as data coherence throughout its life cycle. |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [1-low]<br>Exploitability: [2-medium] |
| Test Notes | Metric: Virtualization<br>Success: building a monitoring plane virtualized on top of physical resources |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-46 – On demand attachment and scheduling of resources to virtual infrastructures**

| Requirement: Radio Monitoring Plane | |
|---|---|
| Number | RMP_11 |
| Name | Dynamic physical structure resource selection |
| Organization name | COMESVIL |
| Description | This requirement is optional. It implements a dynamic resource selection mechanisms to enable the planning and re-planning of functionalities. The selection mechanism will be implemented as a function of the parameters most |

| | |
|---|---|
| | representative and decided within the FAST-TRACKS scope (e.g. power signal and energy efficiency). |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [1-low]<br>Exploitability: [2-medium] |
| Test Notes | Metric: Virtualization<br>Success: building a monitoring plane virtualized on top of physical resources |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-47 – Dynamic physical structure resource selection**

| Requirement: Radio Monitoring Plane | |
|---|---|
| Number | RMP_12 |
| Name | On-demand resource provisioning |
| Organization name | COMESVIL |
| Description | This requirement is optional. It implements the on-demand resource provisioning for mesh network infrastructure. |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [1-low]<br>Exploitability: [2-medium] |
| Test Notes | Metric: Virtualization<br>Success: building a monitoring plane virtualized on top of physical resources |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-48 –On-demand resource provisioning**

| Requirement: Radio Monitoring Plane | |
|---|---|
| Number | RMP_13 |
| Name | Mechanisms for billing the used bandwidth |
| Organization name | COMESVIL |
| Description | This requirement is optional. It implements a mechanism to monitor costs related for the usage of additional bandwidth. In the future, network providers would also like more information over a billing model. |

| | |
|---|---|
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [1-low]<br>Exploitability: [2-medium] |
| Test Notes | Metric: Virtualization<br>Success: building a monitoring plane virtualized on top of physical resources |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-49 – Mechanisms for billing the used bandwidth**

| Requirement: Radio Monitoring Plane | |
|---|---|
| Number | RCP_14 |
| Name | AAA Support |
| Organization name | COMESVIL |
| Description | The FAST-TRACKS Radio Monitoring Plane must integrate the features of Authorization, Authentication and Accounting implementing the related standards (i.e. Radius) |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [2-medium]<br>Business value: [2-medium]<br>Prior Knowledge: [1-low]<br>Exploitability: [2-medium] |
| Test Notes | Metric: Security<br>Success: building the RMP implementing basic AAA standards |
| Requirement Type | Non Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-50 – AAA Support**

| Requirement: Radio Monitoring Plane | |
|---|---|
| Number | RMP_15 |
| Name | Resource Discovery |
| Organization name | COMESVIL |
| Description | The Radio Monitoring Plane must provide a Resource Discovery mechanism in order to facilitate the configuration, and management of the whole FAST-TRACKS infrastructure. |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |

| | |
|---|---|
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [2-medium]<br>Exploitability: [3-high] |
| Test Notes | Metric: Network Monitoring<br>Success: building a monitoring system able to discover the FAST-TRACKS resources automatically |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-51 –Resource Discovery**

| Requirement: Radio Monitoring Plane | |
|---|---|
| Number | RMP_16 |
| Name | Transparent Resource Relocation |
| Organization name | COMESVIL |
| Description | This requirement is optional. FAST-TRACKS should support the transparent dynamic relocation of any involved resource via a request to the RCP. |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [2-medium]<br>Exploitability: [3-high] |
| Test Notes | Metric: Network Monitoring and Planning<br>Success: building a monitoring system able to discover the FAST-TRACKS resources automatically |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-52 – Transparent Resource Relocation**

| Requirement: Radio Monitoring Plane | |
|---|---|
| Number | RMP_17 |
| Name | Dynamic Scaling |
| Organization name | COMESVIL |
| Description | This requirement is optional. FAST-TRACKS should support the dynamic and transparent adaption / scaling of involved resources according to changed application demands. This involves e.g. scaling of network parameters (bandwidth, latency, etc.). |

| | |
|---|---|
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [2-medium]<br>Exploitability: [3-high] |
| Test Notes | Metric: Network Monitoring<br>Success: building a monitoring system able to discover the FAST-TRACKS resources automatically |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-53 – Dynamic Scaling**

| Requirement: Radio Monitoring Plane | |
|---|---|
| Number | RMP_18 |
| Name | Service Planning, Design and Development |
| Organization name | COMESVIL |
| Description | This requirement is optional. To design, specify and simulate the operations, constraints and interactions of services at any layer, independently of the technology used to develop them. The architecture must include the necessary interfaces for building and composing telecommunication services on top of the FAST-TRACKS infrastructure. |
| Related use case | Train To Ground communication using Wi-FI (DCS); Internet on the train |
| Prioritisation | Novelty: [3-high]<br>Business value: [3-high]<br>Prior Knowledge: [2-medium]<br>Exploitability: [3-high] |
| Test Notes | Metric: Network Monitoring<br>Success: building a monitoring system able to discover the FAST-TRACKS resources automatically |
| Requirement Type | Functional |
| Details | |
| | <Details of the requirement (if needed)> |

**Table 4-54 – Service Planning, Design and Development**

# 5 Prototype improvements according to the new requirements identified

FAST-TRACKS aims at covering a functional gap in the railway radio telecommunication infrastructure. The project is based on the design of a reprogrammable radio (based on CR and multi transport radio concepts) supporting different communication standards at the same time, which will foster and guarantee the convergence between automatic train control systems and railway network telecommunication.

The idea behind the FAST-TRACKS project was conceived within SME phase 1 project, started July 2015 [1]. The final deliverable of the project concluding with the presentation of a working prototype configured to establish a fixed communication between two wi-fi stations, using the 802.11 n standard. The following figure shows the status of the prototype at the end of the project and the basic features implemented:

| Comesvil Radio features | Prototype developed during the FAST-TRACK project |
|---|---|
| Wi-Fi Access Point  | IEEE 802.11 a, b, g, n |
| Frequency range | 2.4-5.8 GHZ |
| LTE | No |
| Network controller | No |
| Handoff | No |
| Throughput | Middle – tunable (300Mb/s) |
| Firmware customization | Yes |
| Interference rejection | Middle |
| Optical Interface | No |
| Specific features for Railway | No |
| Cost | Low |

**Figure 5 – Prototype designed during the SME phase 1 project**

However, the product developed implements some important features, do not full matches with customer requirements. In other words, in a train to ground communication scenario, a number of issues affects the prototype developed and the goal of this project is to cover it, implementing the requirements analysed in the above chapter of the deliverable. In details, the prototype needs the following mandatory improvements:

1) **Increase the throughput** (limited today to about 100 Mb/s). This affects the number of the access box needed to be installed on the trackside of the line and, as consequence, the costs of the equipment, maintenance and installation. The action needed to cover this improvement is the integration of new enhanced standards suc IEEE 802.11 ac, which guarantee till to 1.3 Gb/s of throughput.

2) **Integrate the fixed radio in the optical transmission network**, usually used for the backbone. Today, the fixed radio doesn't provide the optical output, which is a specific feature of the fixed radio, needed for the connection to the backbone equipments. The action needed to cover this improvement is the redesign of the Access Point PCB (Printed Circuit Board) with the addition of at least one optical port.

3) **Duplicate the radio within the same box**. The Wi-Fi prototype developed is based on a mono-radio architecture that affects the whole system in terms of costs and resiliency. In order to create a redundant network, each trasmission point needs to be duplicated with two different radio. In this way, the implementation of the new device permits to transmit two different data streams:
    - The vital data, which is a low throughput flow (<1Mb), used to control the train (CBTC). It needs to be redundant
    - The non-vital data, which is a high throughput flow (>10Mb, <100Mb) used to transfer Wi-Fi data for passenger, camera and so on. It not needs to be redundant

4) **Enhance the intervention at installation and maintenance time**. The maintenance of the actual prototype is difficult: actually, the system does not allow to change subparts of the radio in case of fault. The action we propose to solve this issue is the design of a modular access point, which allows to substitute only the subparts.

5) **Seamless handover**. The actual prototype does not implement the roaming with disassociation/reassociation between two adjacent Access Points. Our goal is to implement a mechanism covering the railway requirements about the handover: <30ms or seamless (0ms) with 0% of loss packets.

6) **Dynamic bandwidth management**. The current prototype presents a fixed throughput. This approach does not permit to manage a dynamic request of additional bandwidth derived by dynamic train coupling scenario or additional passenger requests. Our challenge is to design and implement a new mechanism able to cover it.

7) **RSSI monitoring.** The current prototype, do not to monitor the relationship between the Received Signal Streight Indication (RSSI) and the position of the train. This feature is foundamental to produce information about the radiocoverage of the running telecommunication system and discover possible coverage faults during in the wayside. Our goal is to design and implement a new mechanism able to cover it.

The next table shows the list of mandatory improvements needed to transform the prototype in a marketable device for railway telecommunications.

| Railaway radio equirements | Current prototype | Improvements needed to align the prototype to the new requirements identified |
|---|---|---|
| Wi-Fi | IEEE 802.11 a, b, g, n | IEEE 802.11 ac *(1. Increase throughput)* |
| Frequency range | 2.4-5.8 GHZ | 2.4-6 GHZ |
| LTE | No | LTE module supported by hardware module |
| Network controller | No | Hub and spoke/ mesh controller based on SDN *(6. Dynamic bandwidth management, 7. RSSI monitoring)* |
| Handoff | No | Standard IEEE 802.11r and implementation of the fast handover *(5. Seamless handover)* |
| Throughput | 100Mb/s | High – tunable (1.3Gb/s) |
| Firmware customization | No | Yes - OpenWRT and GNURadio |
| Interference rejection | Middle | Extension of the IEEE 802.11e standard |
| Optical Interface | No | Yes *(2.)* |
| Specific features for Railway | No | Yes *(3. Duplicate radio, 4. Modular, Certification)* |
| Cost | Medium | Low |

**Table 5-1 – Mandatory improvements needed to align the prototype to the new requirements identified**

# 6 Conclusions

In this deliverable, we have presented the final set of functional and non-functional requirements for the FAST-TRACKS architecture. Some of these are well known, some are emerging and some are innovative. We have presented the methodologies for functional and non-functional requirements extraction and analysis. The key functional and non-functional requirements for each layer of the FAST-TRACKS architecture have been presented, from a bottom up point of view.

We have first analyzed the non-functional requirements of the FAST-TRACKS architecture that could be considered "vertical". We have then discussed and identified requirements of the Mobile/Fixed Communication Plane, The Radio Control Plane, The Radio Monitoring Plane and finally applications.

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# 8 Acronyms

| | |
|---|---|
| **[CAPEX]** | [Capital expenditures] |
| **[CBTC]** | [Communication based train control] |
| **[CR]** | [Cognitive Radio] |
| **[DCS]** | [Data Communication System] |
| **[ERTMS]** | [European Rail Traffic Management System] |
| **[ETCS]** | [European Train Control System] |
| **[FCP]** | [Fixed Communication Plane] |
| **[GMPLS]** | [Generalized Multi Protocol Label Switching] |
| **[GSM-R]** | [Global System for Mobile Communications Railway] |
| **[LoRa]** | [Long Range] |
| **[LTE]** | [Long Term Evolution] |
| **[LTE-R]** | [Long Term Evolution Railway] |
| **[MCP]** | [Mobile Communication Plane] |
| **[MIMO]** | [Multiple Input - Multiple Output] |
| **[MFR]** | [Mobile Fixed Radio] |
| **[MMR]** | [Mobile Modular Radio] |
| **[NCP]** | [Network Control Plane] |
| **[OTN]** | [Optical Transport Network] |
| **[OFDM]** | [Orthogonal frequency division multiplexing] |
| **[OPEX]** | [Operational Expenditure] |
| **[PAAS]** | [Platform-as-a-Service] |
| **[PHY]** | [Physical Layer] |
| **[PI]** | [Physical Infrastructure] |
| **[PMR]** | [Professional Mobile Radio] |
| **[PSC]** | [Project Steering Committee] |
| **[QOS]** | [Quality of Service] |
| **[RCP]** | [Radio Control Plane] |
| **[RMP]** | [Radio Monitoring Plane] |
| **[RSSI]** | [Received Signal Strenght Indication] |
| **[SDN]** | [Software Defined Networks] |
| **[SDR]** | [Software Defined Radio] |
| **[SME]** | [Small Medium Enterprises] |
| **[Telco]** | [Telecommunications companies] |
| **[TETRA]** | [TErrestrial Trunked RAdio] |
| **[VIMS]** | [Virtual Infrastructure Management System] |
| **[VM]** | [Virtual Machines] |