Alternative Bearers for Rail (AB4Rail)

Shift2Rail now Europe's Rail project

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Workshop
21 March 2022

Co-funded by the Horizon 2020 programme of the European Union

This project has received funding from the Shift2Rail Joint Undertaking (JU) under grant agreement No 101014517. The JU receives support from the European Union's Horizon 2020 research and innovation programme and the Shift2Rail JU members other than the Union.

Agenda

- The AB4Rail project
  - Motivations
  - Partners
  - Project Organization
    - Workstream 1 and Workstream 2
- Description of WP2’ results
- Description of WP3’ results
- Next Activities

Motivations

- The foreseen evolution of the ERTMS platform towards a more efficient and **competitive train management systems will largely depend on the telecommunication infrastructure performance impacting on cost, capacity and energy consumption**.
- The **Adaptable Communication System** (ACS) is one of the proposed solutions for the realization of future rail communication infrastructure
- AB4Rail will be targeting an improvement of ACS performance
  - manage **multi communication bearers** and heterogeneous connection link (**bearer independence concept**) to guarantee the best performance of a single (multiple) specific rail application(s), by complementing legacy communication bearers;
  - adopt a top-down approach for developing and managing rail applications in an **end-to-end** way to guarantee appropriate levels of Quality of Service (QoS) and Quality of Experience (QoE).

The AB4Rail Project

- The AB4Rail project contributes to the Shift2Rail work programme S2R-OC-IP2-02-2020
- It is a complementary project in X2Rail-5
- Project is started: 2 January 2021, duration: two years

Objectives: two separate workstreams

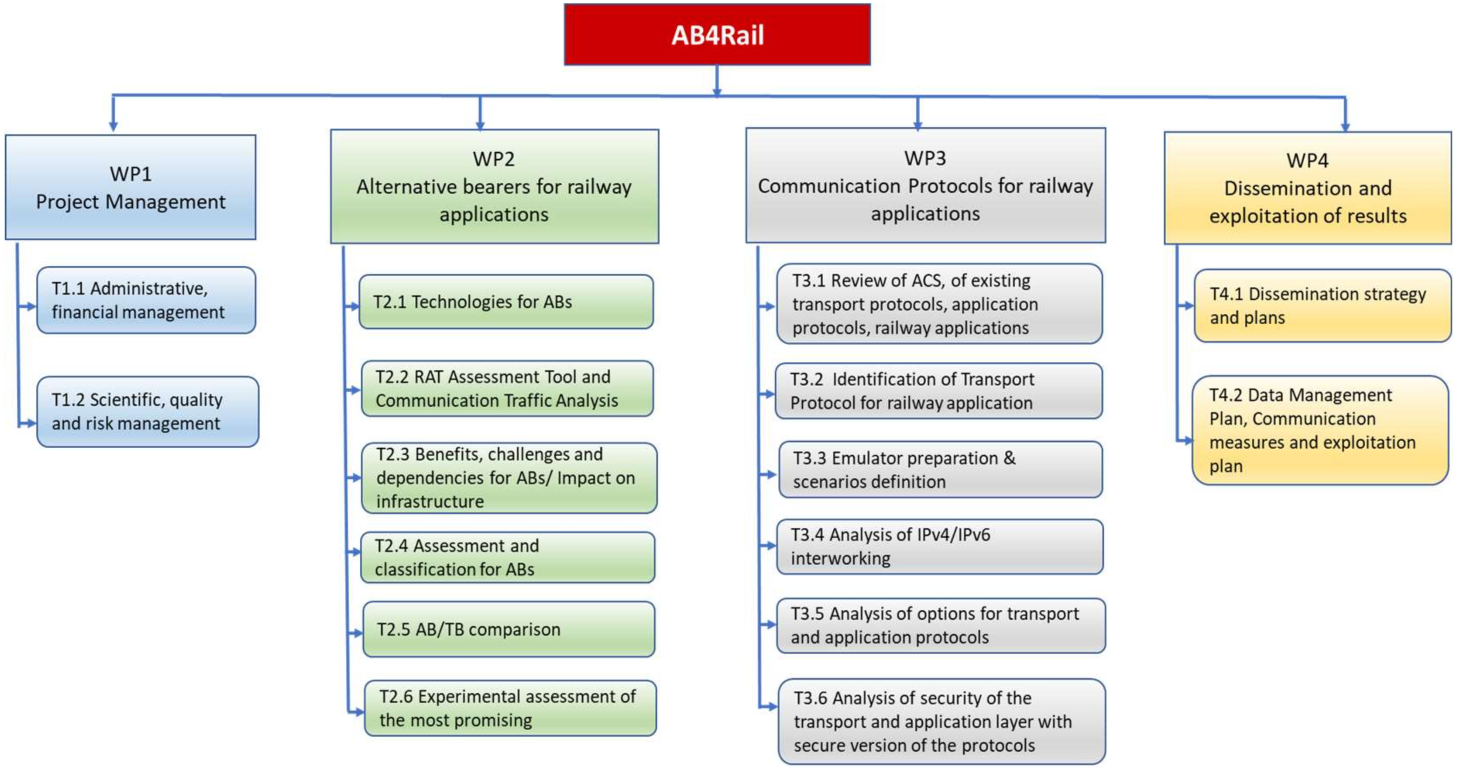
- Identifying alternative communication bearers (ABs) for the Adaptable Communication System (ACS)
- Study of communication protocols: transport and application level

Project's Partners

- *Consorzio Università Industria – Laboratori di Radiocomunicazioni* (Radiolabs) – (Main contractor)
- Main Participants
  - Franco Mazzenga
  - Anna Maria Vegni
  - Alessandro Vizzarri
- *Università degli studi Guglielmo Marconi* – (Partner)
- Main Participants
  - Romeo Giuliano
  - Ilaria Reggiani

AB4Rail Project Organization

Work Breakdown Structure (WBS)



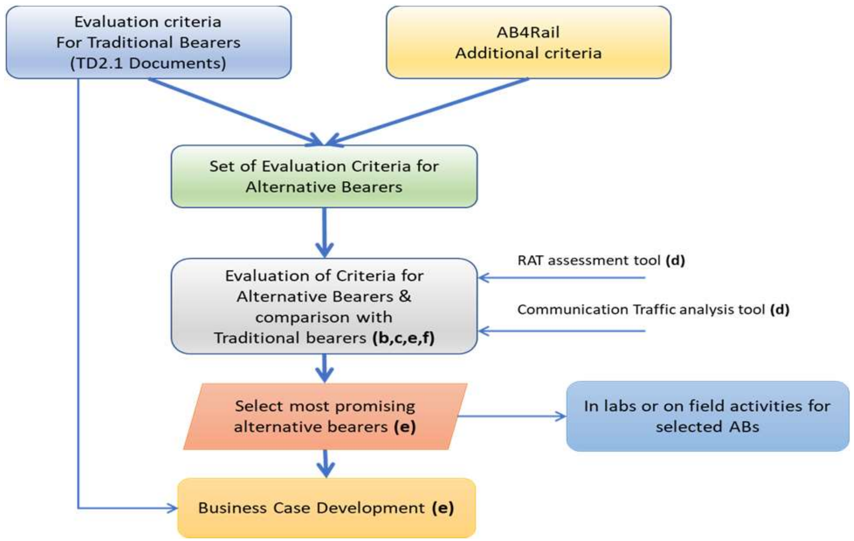
Workstream 1: Alternative Bearers for Railway

Considered AB technologies

Category	Technology	Examples of current/proposed Railway applications (including references)
Optics	Visible Light Communication (VLC)	• Monitoring of railways health state (*e.g.* vibrations and other critical data) to ensure the security of trains traffic [9] • Indoor positioning and venue navigation [10]
	Free Space Optics (FSO)	• To enable connectivity between trackside gateways [9] • High-speed communication services such as internet access and video-on-demand [11], [12]
PLC	Power Line Communications systems	• Transmission of data for control of railway (*e.g.* semaphore Signaling in Railway Tracks [13], automatic brake testing, train integrity checks, automatic coupling [14]) • Coach and train communication networks for Passenger Information Systems (PIS) services and video surveillance [15]
IoT (SR)	Bluetooth Low Energy (BLE)	• Monitoring the railway infrastructure such as bridges, rail tracks, track beds, [16] and track equipment along with vehicle health monitoring such as chassis, bogies, wheels, and wagons [16], for example for derailment detection and data collection in freight trains [17]
	ZigBee	
	6LoWPAN	
IoT (LR)	LPWAN (e.g. LoRa, NB-IoT)	• On-board monitoring with sensors and on-board LoRa gateway [18]
HAPS	High Altitude Platform Systems	• High-data-rate applications to trains [19] such as high-data rate internet access [20]
Update tech.	Novel Sat LEO constellations	• High-data-rate applications from infrastructure-to-train such as broadband internet service [21] • Novel antennas can work with traditional Satellites, as well as the new generation of compact LEO spacecraft in mega constellations (SpaceX, OneWeb, Amazon, Facebook etc.) [22].
Future tech.	Quantum communications	• They can be exploited for future high-data-rate applications from infrastructure-to-train
	THz communications	• High-data-rate applications such as on-board and wayside high definition (HD) video surveillance, on-board real-time high-data-rate connectivity, train operation information, realtime train dispatching HD video, and journey information [23] [24]

Methodology of Analysis

- a • Analysis and selection of Technologies for ABs
- b • Benefits, challenges and dependencies for ABs
- c • Impact on Infrastructure
- d • RAT Assessment Tool and Communication Traffic Analysis
- e • Assessment and Classification for ABs
- f • AB/TB comparison



Workstream 2: Communication Protocols

Considered Communication protocols

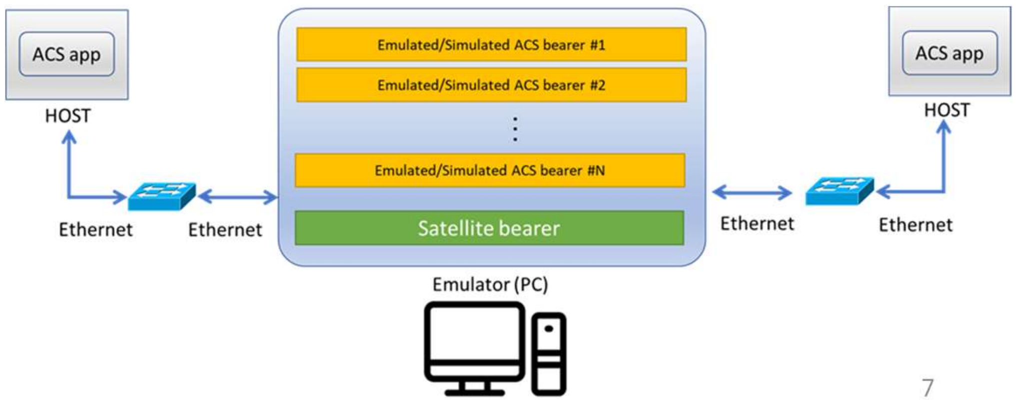
a) TCP/UDP and other transport protocols currently under study and/or development and/or testing in **IETF for data transfer over IP networks**. The analysis accounts for the main novelties introduced into the recently proposed transport protocols. The following alternatives to TCP will be reviewed and included in the successive AB4Rail investigation activities: **Stream Control Transmission Protocol (SCTP), Quick UDP Internet Connections (QUIC), Bottleneck Bandwidth and Round-trip propagation time (BBR). The Rail Safe Transport Application (RaSTA) protocol specifically designed for rail signalling and related requirements completes the review**.

b) the application protocols to be layered on top of the transport protocol. In principle, any application could craft its own network protocol. However, many applications are standardized, and they work with well-known and widely accepted application protocols. The most important protocols that will be considered in AB4Rail that are applicable to railway applications will be: **HTTP, FTP, and their secure counterparts (if any) such as HTTPS and SFTP. The applicability of RaSTA as a user-plane protocol is also reviewed.**

Methodology of Analysis

- a — Review of ACS, of existing transport protocols, application protocols, railway applications
- b — Analysis of IPv4/IPv6 interworking
- c — Emulator preparation & scenarios definition
- d — Identification of Transport Protocol for railway application
- e — Analysis of options for transport and application protocols
- f — Analysis of security of the transport and application layer with secure version of the protocols

Role and functionalities of AB4Rail Emulator



WP2 – activities
Workstream 1

AB Assessment procedure in AB4Rail: short summary

The AB4Rail project defined a three-steps methodology to assess if the considered AB can be used by the ACS GW.

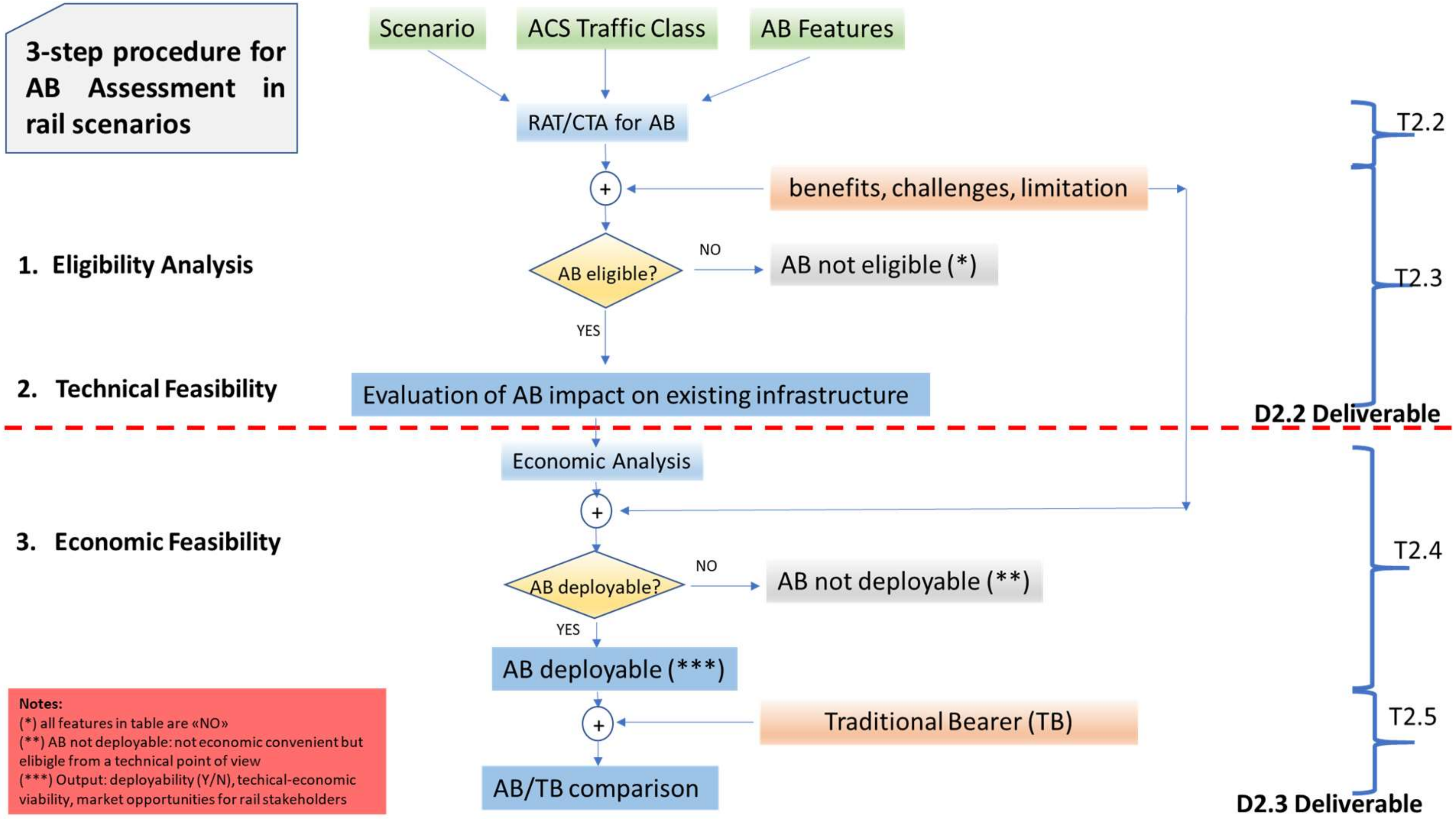
Eligibility Analysis
- The AB is defined as eligible of not for ACS traffic classes

Technical Feasibility
- The impact on the exixting infrastructure is analyzed

Economic Feasibility
- The AB is analyzed from a cost and business point of view. It defines if the deployment of the eligible AB is convenient economically

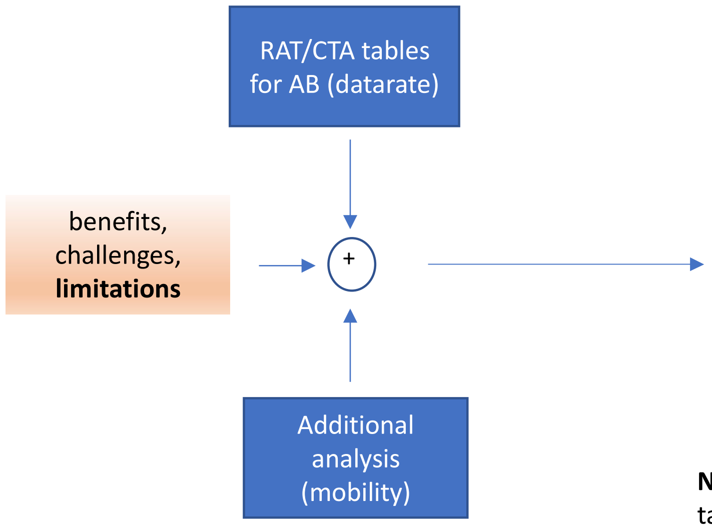
Three successive steps

WP2: overall AB assessment procedure



Technical evaluation of ABs for eligibility (datarate and mobility)

- Tables containing data from RAT and CTA
  - If necessary, assign a numeric judgement/evaluation to AB features reported in the tables from RAT and CTA (i.e. usage and visualization of these tables through radar diagram)
- To assess AB eligibility we need an **additional analysis** on the AB capabilities for each scenario and ACS traffic class corceirning:
  - **type of coverage** (continuous / discontinuos or spot)
  - AB Support for **device mobility** in the service area (handoff location area, user registration, service continuity over the service area)
  - Account for the **Radio Link Setup Time (RSLT)** to assess the usability of the AB in terms of its **radio coverage** and the **train speed**



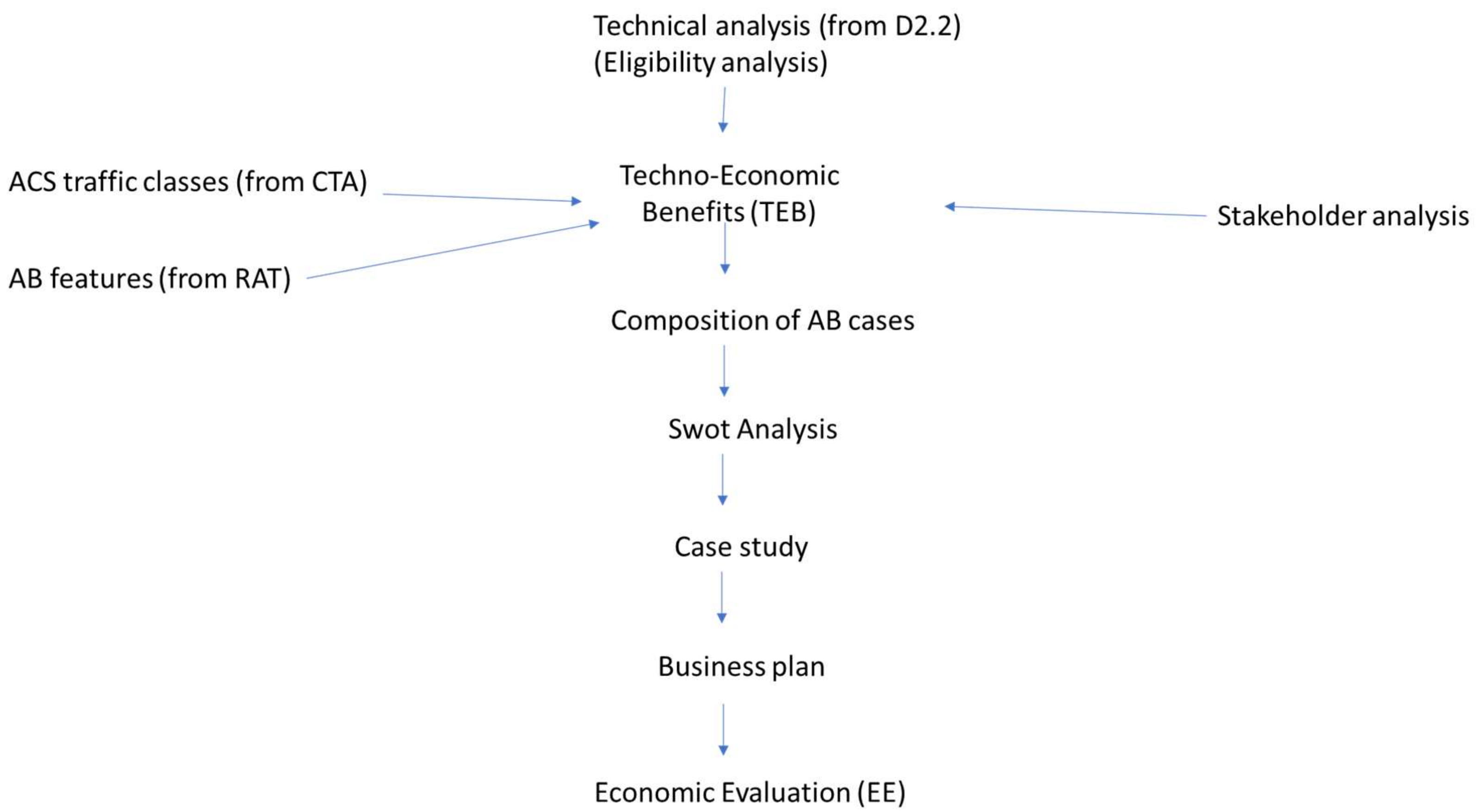
Scenario	Traffic Class	AB eligibility [Y/N]
Mainline		
	ACS traffic class	
	ACS traffic class	
Regional		
	ACS traffic class	
	ACS traffic class	
……		

Note: the AB results to be «NOT eligible» if the third column in the table only contains «NO»

Results: Eligible ABs – from the technical point of view

ID	AB Group	AB Name	AB Eligibility
1	Optical Wireless Communication (OWC)	Visible Light Communication (VLC)	Not Eligible
2	**Optical Wireless Communication (OWC)**	**Free Space Optics (FSO)**	**Eligible**
3	IoT-based Communication	BT5.2	Not Eligible
4	IoT-based Communication	Zigbee	Not Eligible
5	IoT-based Communication	UWB	Not Eligible
6	IoT-based Communication	NB-IoT	Not Eligible
7	IoT-based Communication	LoraWAN	Not Eligible
8	Power Line Communication (PLC)	PLC	Not Eligible
9	**Aerial Communication**	**Low Earth Orbit (LEO)**	**Eligible**
10	**Aerial Communication**	**High Altitude Platform (HAPS)**	**Eligible**

Economic Evaluation of eligible ABs: workflow



Results are contained in Deliverable D2.3

Stakeholders

List of Stakeholders for AB economic analysis

Stakeholder	Role
Railway Undertaking (RU)	Management of vehicles and traction
Infrastructure Manager (IM)	Management of ground systems, including traffic management and signalling
Passengers	End user of digital services
Manufacturer	Providing devices and components on FSO BS, satellite antennas and receivers, …
LEO Operator	LEO Satellite service management
HAPS Operator	HAPS service management
Telco Operators	Owner and management of additional optical transport network across the rail line. They also provide the connectivity to Internet
Internet Service Provider (ISP)	Connectivity to Internet

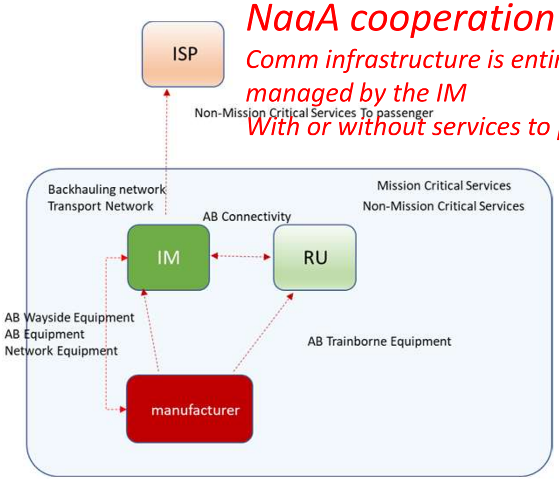
Stakeholder Analysis

- Three different models for cooperation among stakeholders (from MISTRAL project):
- Network As Asset (NaaA)
- Shared NaaA
- Network As a Service (NaaS)

NaaA cooperation model for ABs

Comm infrastructure is entirely realized and managed by the IM

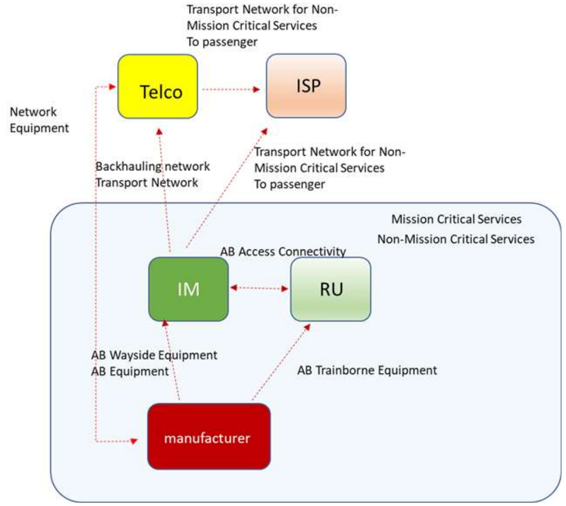
With or without services to passengers

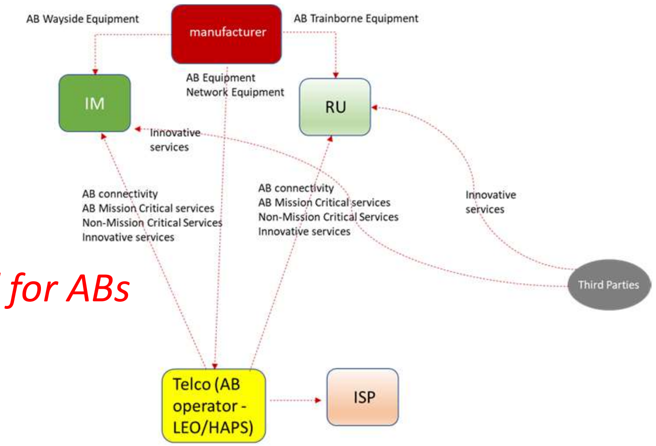


Shared NaaA cooperation model for ABs

IM and Telco cooperate to realize and manage the comm infrastructure

With or without services to passengers





NaaS cooperation model for ABs

(mainly for LeO and HAPS)

Conclusions (1/4)

FSO:

- It is suitable for NaaA and Shared NaaA models (refer to the Deliverable 2.3).
- **In NaaA model the IM is supporting the entire investment.**
- The achieved data rata with FSO deployment is very high and it far exceeds the needs of ACS.
  - **Using FSO for ACS services only <u>do not justify</u> the investment (overall investment over 32 M € in the three forecasted years).**
- In the FSO NaaA model, the IM can continue to invest in FSO infrastructure, but if commercial services are also provided, the investment required over the three years is reduced to 5.6 million €. A selling price of 6.5 € for each passenger must be considered for commercial services (i.e. Internet connectivity for passenger).

- Also the FSO Shared NaaA model where IM and Telco has been considered. When they mutually agree on both cost and revenue sharing approach. The needed investment is always equal to 6.4 M€, but it can be split between IM and Telco.

Three different cases for splitting have been discussed and main results are summarized below.

- ✓ **<u>Case #1</u>**. IM invests only in on-board FSO transceiver and in 50% of personnel cost, acquiring 15% of revenues (in proportion to ACS and commercial traffic). Telco invests in FSO trackside transceivers and in 50% of personnel cost, acquiring 85% of revenues. IM achieves positive EBITDA at Y2, Telco at Y3.
- ✓ **<u>Case #2</u>**. IM and Telco invest 50% in total costs and personnel costs, but they share the revenues proportionally with the amount of managed traffic (ACS and commercial services). IM acquires 20% of revenues, Telco 80%. IM never reaches a positive EBITDA, the Telco reaches it at Y3.
- ✓ **<u>Case #3:</u>** IM and Telco invest 50% in total costs and personnel costs. They share the revenues equally (50% for each). Both of them reach positive EBITDA at Y3.

Conclusions (2/4)

LEO:

- LEO technology is only suitable for NaaS model.
- In case of ACS only traffic, estimated total investment by IM is around 872 k€.
    - EBITDA is always negative in the three years forecasted.
- If ACS supports commercial services, the investment is around 144 k€ at Y1, considering a small selling price of 0.5 € per passenger for commercial services (i.e. Internet).
    - From Y2 onwards, EBITDA is positive. If the investment is made entirely by IM, it reaches a positive EBITDA already at Y2 (€ 250k), the same for Y3 (250 k€).

HAPS

- HAPS technology is only suitable for NaaS model.
- Considering 4G LTE-based HAPS, the total investment over the three years is approximately € 4.7 million.
- In case of ACS only traffic this is a cost over the three years.
- If ACS supporting commercial services is considered the investment is around 114 k€, but it is necessary to consider a selling price of at least 4.7 € per passenger for commercial services (i.e. Internet) to have a positive EBITDA at Y3.
    - If the investment is made entirely by IM, it reaches a positive EBITDA already at Y2 (around 10 k€), the same for Y3 (10 k€).
    - A positive EBITDA is achieved even if the telco participates in the investment at 50% of all costs and IM and Telco share the revenues by 50%. In this case, EBITDA is always positive but halves, both for IM and for Telco it is about 5k€.

Conclusions (3/4)

<u>AT/BT Comparison</u>

- **bearer requirements:**
  - 4G, 5G, and Sat-GEO present the highest scores (same trend), while the highest scores are achieved for LEO technology that presents also high score for traffic prioritization.
- **security and eligibility features**,
  - 4G, 5G and Sat-GEO present the highest scores, while 5G has the lowest score in terms of longevity (since it is a most recent technology).
  - FSO presents high performance except for the low availability of standard, as well as HAPS and SatLEO.
- All the considered TBs have the highest scores for the **backward compatibility**, **low dependence on existing infrastructure**, **high bearer controllability in ACS and high mobility support**.
- All the eligible ABs, as FSO, HAPS, and Sat-LEO, present high scores of backward compatibility, bearer controllability, and mobility support.
  - They also have a very low dependence on existing infrastructure and coexistence issues with TBs, since they are owned and managed by an external stakeholder (i.e., Telco).

Conclusions (4/4)

- AB/TB **integration**

- ABs acting as backhauling of TB network can be of interest.
  - In case of 4G LTE, FSO guarantee a considerable data rate able to manage up to 100 eNBs, but the deployment costs need to be calculated carefully.
- LEO can be used as backhauling of a couple eNBs located at large distance.
- HAPS can be used as 4G LTE backhauling of a single eNB due to the limited offered data rate.
  - Same conclusions for 5G backhauling, even though the number of managed gNBs is reduced with respect to LTE; gNBs (up to 10) rather than 100 eNBs (in LTE).
- ABs used to provide access to TB service networks:
  - in case of 4G LTE, LEO transmits LTE signals to the on-board ACS GW within the satellite (non-terrestrial) radio access network.
  - HAPS can host a standard eNB device, providing a service link within the LTE Band 28 at 700 MHz. Both LEO and HAPS are connected to the LTE EPC core network through a mmwave feeder link (at 70-80 GHz).
  - FSO technology is not suitable to be used as access network to 4G LTE. It is difficult (if not impossibile) to find LTE/5G terminals incorporating optical access technologies.
  - In case of 5G, LEO satellite transmits 5G signal to the on-board ACS GW within the 5G Non-Geostationary (NGSO) radio access network (Uu_NGSO interface). 5G NG RAN is connected to the terrestrial 5GC through the feeder link.
  - When considering HAPS as 5G access network, the HAPS can host a standard gNB and provide NR-Uu interface within the non-terrestrial radio access network.
  - Finally, FSO technology is not suitable to be used as access network to 5G.

WP3 activities
Workstream 2

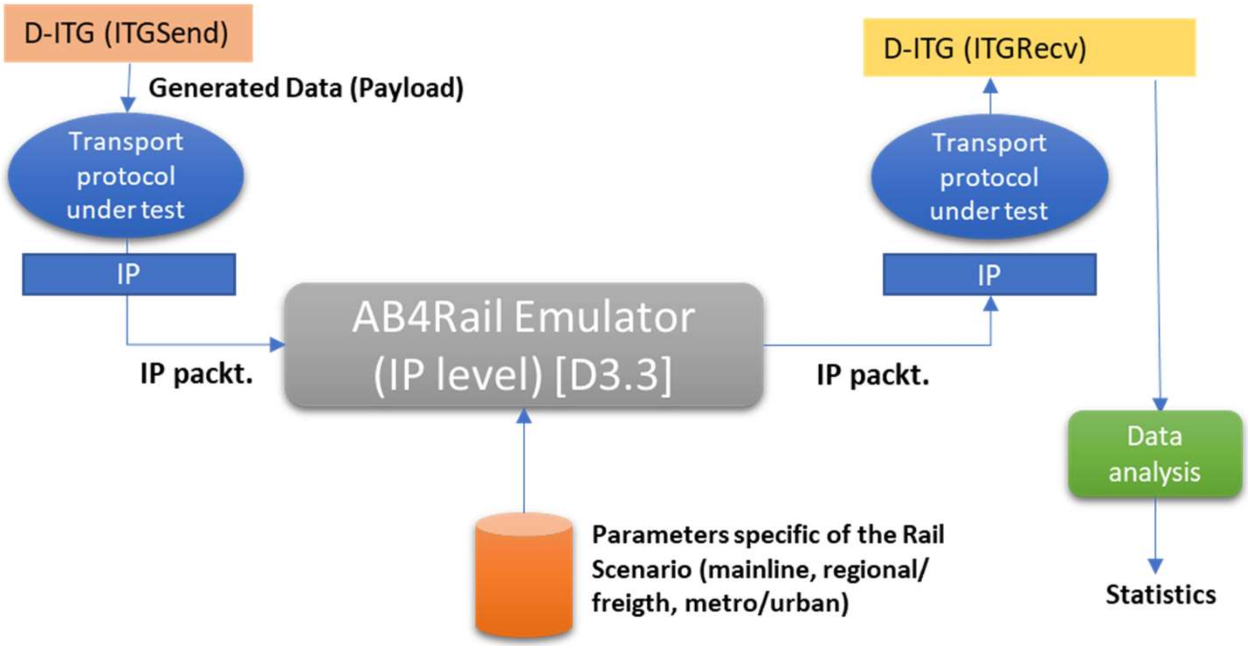
Purpose of WP3

- **Main aim**: Investigating the behavior of the communication transport and application protocols on realistic railway scenarios.
  - Emulation–based approach has been adopted instead of simulation
  - We have developed the transport and application protocol emulator at IP protocol level taking into account for the main ACS features (e.g. GRE tunnels) – emulator runs in Linux OS
- **Completed activities:** Analysis of transport protocol performance

- **Main assumptions**
- Considered traffic sources
  - Constant Bit Rate (CBR), i.e. applications for video streaming
  - Variable Bit Rate (VBR), i.e. skype call or video call
  - File transfer, i.e. file download/upload
- Considered transport protocols
  - Transport Control Protocol (TCP), Cubic
  - TCP Bottleneck bandwidth and round-trip propagation time (BBR);
  - User Datagram Protocol (UDP);
  - Stream Control Transmission Protocol (SCTP)
- IP level impairments (bandwidth, latency, jitter, packet error and packet loss) are varied with time
  - Bandwidth is evaluated taking into account for the number of trains in the same radio cell sharing the available transmission capacity (see after) i.e. **the train channel is characterized by time variable available transmission capacity**

Emulator and transport layer analysis

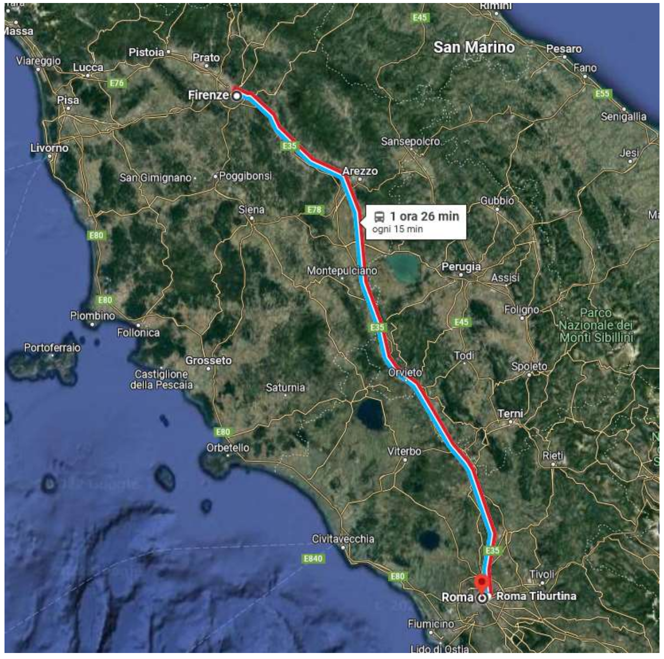
- Generating data traffic (CBR or VBR).
- Set specific rail scenario parameters
- Injecting traffic into the emulator
- Collect statistics: *one-way transmission latency, throughput, download time*
- Analysis of results

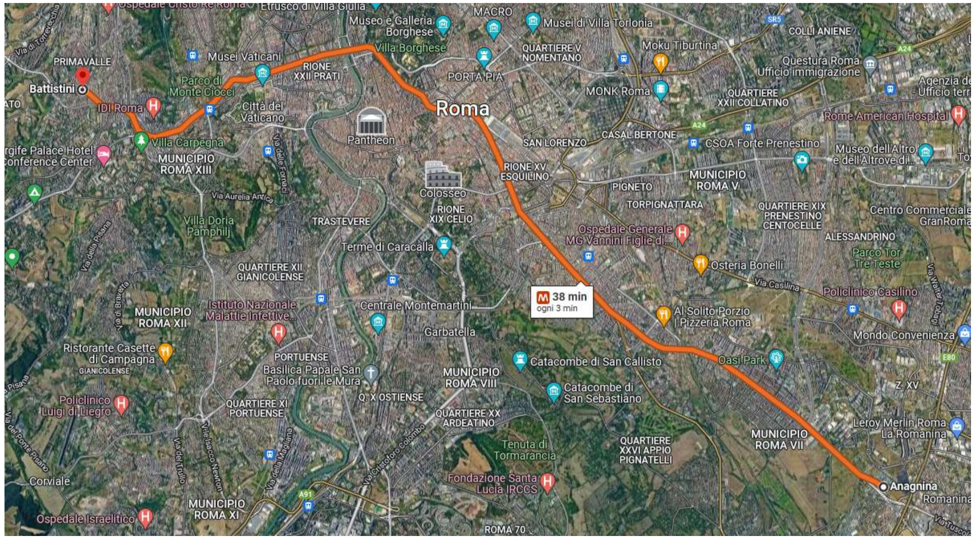


Rail lines

To avoid a too generic approach to performance evaluation we have considered some realistic scenarios

- Rome – Florence, high speed line
- Rome – Florence, regional line
- Metro A, Rome

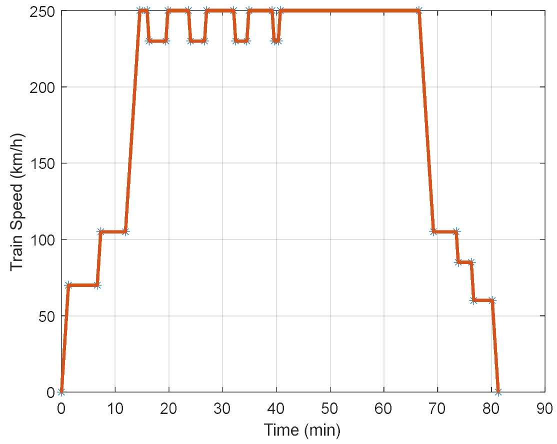




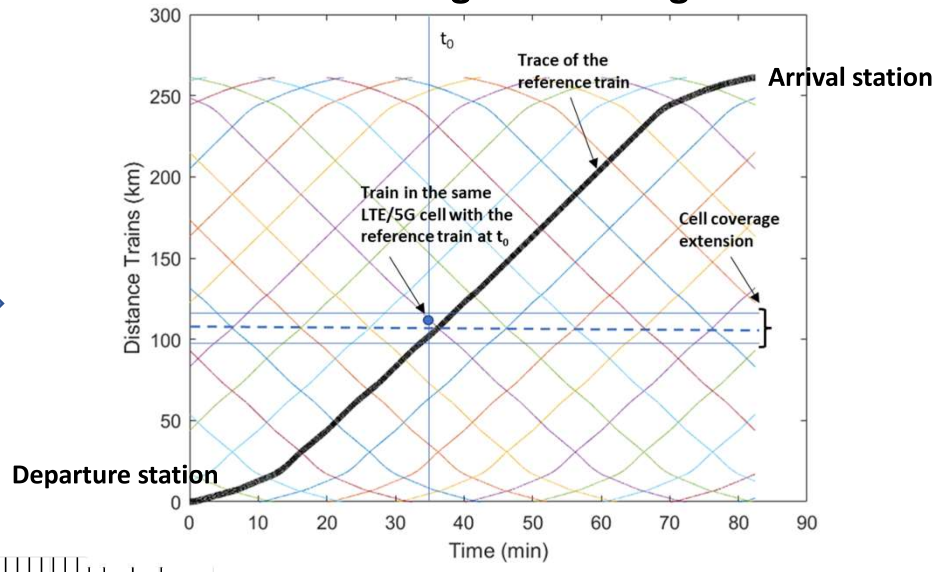
Train speed vs time profile and number of trains in an LTE cell

Firenze-Roma, high speed line

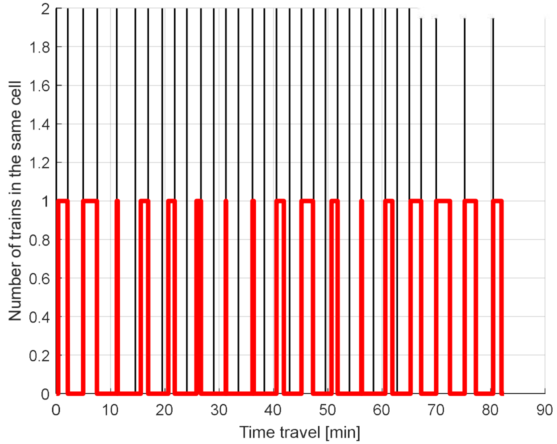
Train speed



Traces of starting and arriving trains

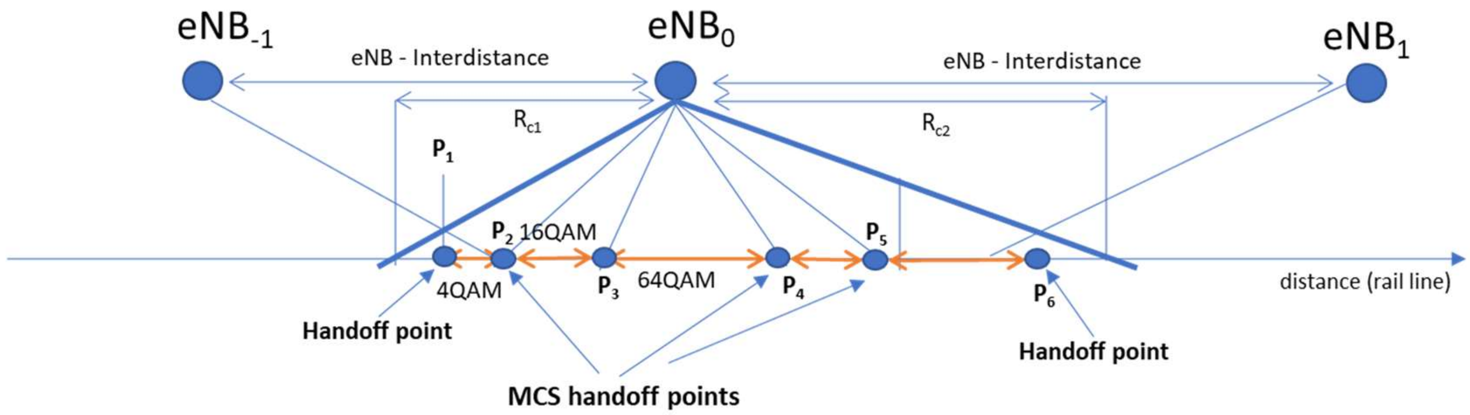


Number of additional trains in the same cell



LTE: eNB model and modulation/coding scheme (MCS)

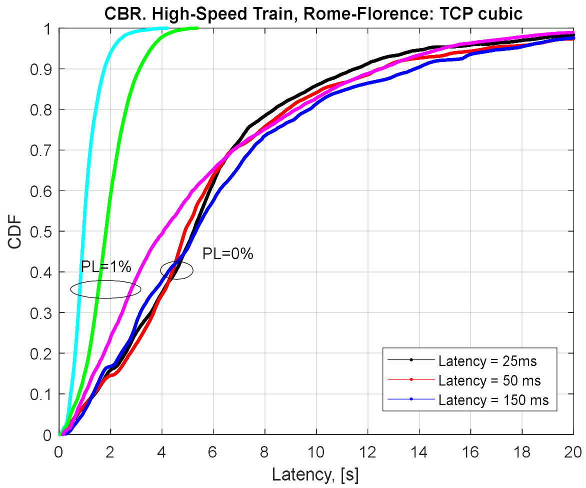
- eNBs have been positioned along the railway line
- Handover points, threshold = -115 dBm (at QPSK ¾)
- Propagation model: Okumura-Hata

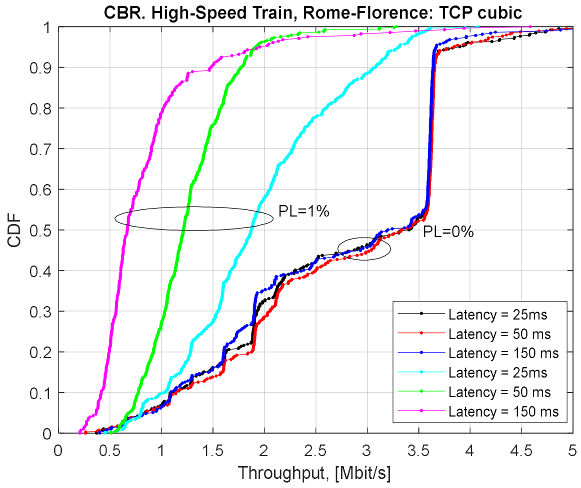


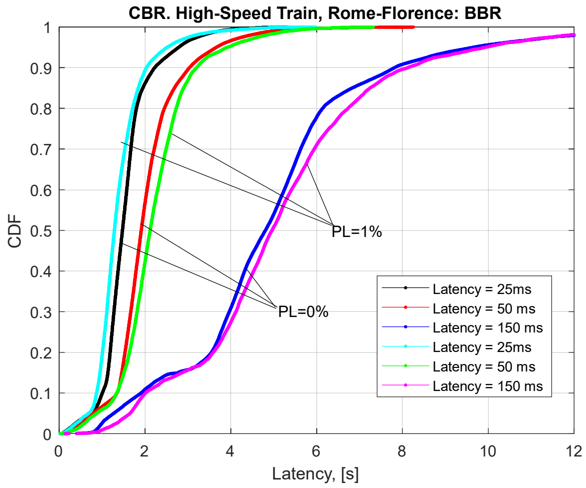
Distance between elements	Value
d_eNB – Urban	3.36 km
d_eNB – Suburban	9.12 km
d_eNB – Rural	9.6 km

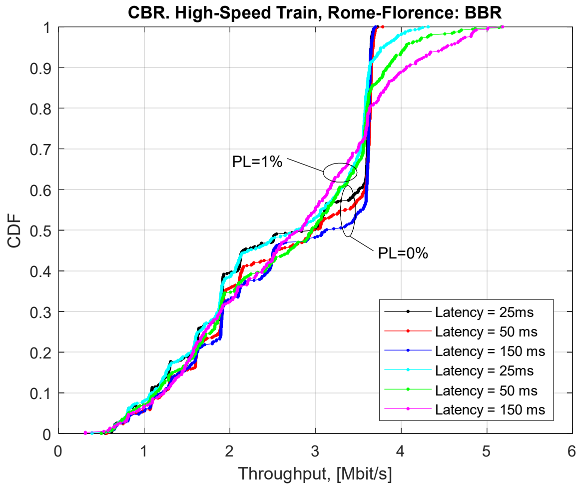
LTE/5G with 1.25 MHz in the GSM-R band

Results: CBR for cubic and BBR, high speed line









WP3: some conclusions and remarks

- No significant dependence of protocol performance on the selected scenario (mainline, regional, metro/urban)
  - All the considered transport protocols can track and adapt to variable transmission channel capacity
- Packet loss is the most influencing channel parameter for performance
  - For PL=0%, TCP cubic and TCP BBR are able to track the available transmission channel capacity in all the considered scenarios at the expense of increased packet latency
  - For PL = 1%, TCP BBR is able to track the available transmission channel capacity. In fact, BBR experienced similar TH for PL=0% and PL=1%, in every scenario
- SCTP (single stream) tries to save latency
  - SCTP particularly interesting for signaling services characterized by low data rates but requirements on latency.
- Similar behavior of TCP cubic, TCP BBR and SCTP passing from CBR to VBR, for high bit rates traffic sources
- Coexistence issues have been also analyzed: **BBR vs TCP cubic and BBR vs SCTP**
  - Similar behavior (channel TH partition) when PL=0%
  - BBR acquires more bandwidth for PL=1% and tends to starve TCP Cubic

Next AB4Rail activities (1/2)

- **WP2 activities (Workstream 1)**
- Experimental assessment of most promising ABs
  - Emulation/Simulation approaches for assessment of ABs will be (forcibly) considered due to:
    - Market un-availability of FSO technologies able to operate in (even very low) mobility scenarios – only FSO technologies for static communications are available on the market
    - OneWeb and SpaceX HTS LEO systems will be (probably) made available for commercial services not before the end of 2022
    - HAPS: no communication networks based on HAPS have been deployed yet; up to now several experiments have been carried out in the last few years and others are ongoing. Very interesting and promising results have been obtained from experiments.

- **WP3 activities (Workstream 2)**
  - Performance evaluation of application and transport protocols
  - Performance evaluation of secure application and transport protocols

Next AB4Rail activities (2/2)

- Final deliverables
  - WP2: Release of Deliverable 2.4 (expected 31 May 2022) - Experimental assessment of the most promising ABs
  - WP3: Release of Deliverable 3.5 (expected 30 June 2022) - Analysis of options for transport and application protocols and of their secure versions
- Report on Dissemination and Exploitation activities (D4.3) – 31/12/2022
- Future dissemination activities
  - TRA2022 conference (https://traconference.eu/) : 14-17 novembre 2022, Lisbona (we have submitted one presentation entitled: "*'Future Communication Systems for Railway: the AB4Rail project in H2020 Shift2Rail Programme*'"
  - Automotive 2022 (à for exploitation of AB4Rail results toward other communities, such as automotive)
  - 2nd IEEE Future Network Security: Challenges & Opportunities Workshop (19-21 April 2022, Virtual). We will send one presentation in the next edition of 2022 (https://futurenetworks.ieee.org/conferences)
  - Our presentation at Convegno internazionale AEIT-FITCE, "61st Fitce International Congress "Future telecommunications: infrastructure and sustainability" Rome Italy), 29-30 settembre 2022 (link: https://convegni.aeit.it/misw7/struttura/pagedin.php?web=fitce2022&page_cod=conf_intro&page_mod=open)

Pubblications

- AB4Rail webpage: https://www.ab4rail.eu
- R. Giuliano, F. Mazzenga, A. V. Vegni, A. Vizzarri, "*Adaptable Communication System (ACS) for Flexible Communications in the Transport Sector: the AB4Rail project experience*", 2021 AEIT International Conference on Electrical and Electronic Technologies for Automotive (2021 AEIT AUTOMOTIVE), Virtual Conference, Nov. 2021.
- A. Calderone, R. Giuliano, "*Emulation of Rail and Automotive Applications based on Adaptable Communication System*", 2021 AEIT International Conference on Electrical and Electronic Technologies for Automotive (2021 AEIT AUTOMOTIVE), Virtual Conference, Nov. 2021.
- E. Innocenti, R. Giuliano, "*CNN-based Passenger Detector for Public Transport Vehicles*", 2021 AEIT International Conference on Electrical and Electronic Technologies for Automotive (2021 AEIT AUTOMOTIVE), Virtual Conference, Nov. 2021.
- L. Cotugno, F. Mazzenga, A. Vizzarri, R. Giuliano, "*The major opportunities of Blockchain for Automotive Industry: a Review*", 2021 AEIT International Conference on Electrical and Electronic Technologies for Automotive (2021 AEIT AUTOMOTIVE), Virtual Conference, Nov. 2021.
- Participation at:
- IEEE, Future Network Security: Challenges & Opportunities Workshop, Presentation: "*Future Railway Communication Systems: the FRMCS and the ACS Two Contrasting Approaches*"

Horizon 2020
European Union Funding
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Thank you for your attention!

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This project has received funding from the Shift2Rail Joint Undertaking (JU) under grant agreement No. 101014517. The JU receives support from the European Union's Horizon 2020 research and innovation programme and the Shift2Rail JU members other than the Union.

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