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Satellite Communication for the Adaptable Railway Communication System, Lab-Test Results and Field Test Preparation

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Extended abstract

This paper reports the activities of the X2Rail-5 WP3 work done on an adaptable communication system (ACS) in relation to satellite communication (SatCom). As illustrated in Figure 1, the ACS connects trackside applications with on-board side. Since coverage along the lines with a dedicated system (railway operator owned) is expensive, it can be supplemented using available public networks or other

technologies. The ACS can use several access networks such as 5G, LTE, SatCom, WIFI etc. so-called bearers. Thereby, the ACS provides connectivity via the bearers in a transparent way to the applications by providing session control functions, such as authentication, bearer selection, Quality of Service (QoS) control etc., and the necessary interfaces towards the bearers. Applications register at the ACS with a set of QoS parameters and the ACS aims to meet these by selecting a proper bearer and change it if network conditions require to. The ACS is by definition bearer agnostic and could be enhanced to any kind of bearer.

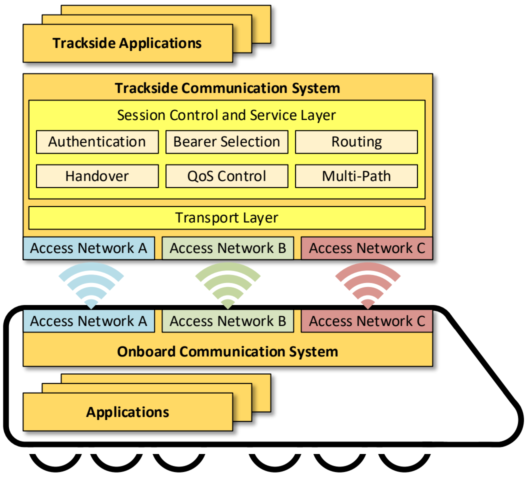

Figure 1: ACS general architecture

This approach decouples the application layer from transport as required by the Future Mobile Railway Communication System (FRMCS) user requirements [1]. The FRMCS is currently standardized as a successor to the GSM-R technology which will be obsolete in 2030.

During the project, three ACS demonstrators have been implemented by different companies each for different scenarios (Urban/Suburban, Mainline Highspeed, Regional and Freight) and tested in lab and in field.

In this context, considerations for SatCom as a bearer have been introduced in [2]. Accordingly, SatComs have the main advantage of covering large areas with low capital expenditure compared to the terrestrial infrastructure which makes it interesting for several use cases in the railway domain (by comparing SatCom capabilities and railway communication use cases from [3]):

- IoT connectivity, e.g. to connect smart way-side objects.
- Video connectivity such as for monitoring stations in remote areas and connecting cameras to a centralized control center.
- Virtual balises for assisting next generation signaling schemes
- Passenger communications, in combination with terrestrial technologies, especially in rural areas [4].
- A fallback solution for when terrestrial infrastructure is damaged.
- Reducing track side vandalism since there is a reduction in infrastructure [5].
- A compliment to terrestrial communication systems and act as a backup in case of missing coverage or during hand-over procedures.

In order to investigate if current SatComs can be used for FRMCS, a study was initiated by the European Union Agency for Railways (ERA) which revealed that none of the systems can fulfill all requirements [6]. It also stated the disadvantages that SatCom has for serving railways, which are: operational expenditure; availability; use of dedicated handheld devices; latency due to the round-trip time of the signal in case of

Geostationary Earth Orbit (GEO) and Medium Earth Orbit (MEO) systems, which especially impacts voice communications. The SatCom systems analyzed in the study differ in setup and technologies used such that each system has specific characteristics that cannot be generalized. The best solution found was a theoretical MEO system (C-band, constellation of 10-15 satellites) which only lacked a suitable security mechanism in order to fulfill the requirements. All this implies that either SatCom systems can only be used for applications with less strict requirements, or consideration should be given to relaxing the requirements if circumstances allow, e.g. in less congested conditions on the track in regional scenarios.

In line with this, in another study funded by ESA [7], it was found that additionally in a GEO solution the capacity requirements are demanding especially considering autonomous driving and video transmission and need further investigations. A LEO constellation would be able to fully achieve all requirements. Given this, we decided to focus with our developments on signaling (i.e. ETCS) since here SatCom can fulfill the requirements.

In order to demonstrate the applicability of SatComs to the railway sector and perform investigations in a lab, a prototype based on Software Defined Radio (SDR) has been implemented which offers flexibility and may be adapted to many different telecommunication systems [8]. In order to demonstrate its applicability to the railway sector, we are integrating this SatCom prototype as bearer for the ACS in lab.

The prototype could in principle be used for every scenario of the project. However, especially for the urban area, it is expected that the requirements can be addressed entirely by terrestrial technologies since they are highly available and the coverage of SatCom suffers due to shadowing caused by buildings [6]. The biggest advantage of SatCom is the coverage area which can save a lot of costs, especially in rural areas where additional terrestrial infrastructure would be needed. Hence, SatCom is considered for the regional/freight line and for the mainline/highspeed line demonstrators, also during the field test. In the following we (I) present some details of the ACS as background; (II) given a brief overview of the SatCom prototype lab setup and results; (III) Illustrate the field test setup which used a commercial SatCom system.

The Adaptable Communication System

Figure 2 present the ACS Layers connecting the application domain with the Network Domain [9]. The ACS layer consists of the ACS control Plane, the ACS Tunnel Management and the ACS user plane which provides connectivity via an ACS Onboard Gateway to an ACS Network Gateway.

The Application Domain interfaces via an ACS Client. The Network Domain performs the transport layer communication via one or more transport network(s), such as SatCom. The connection of the Network Domain/Transport Layer is established by IP service connections.

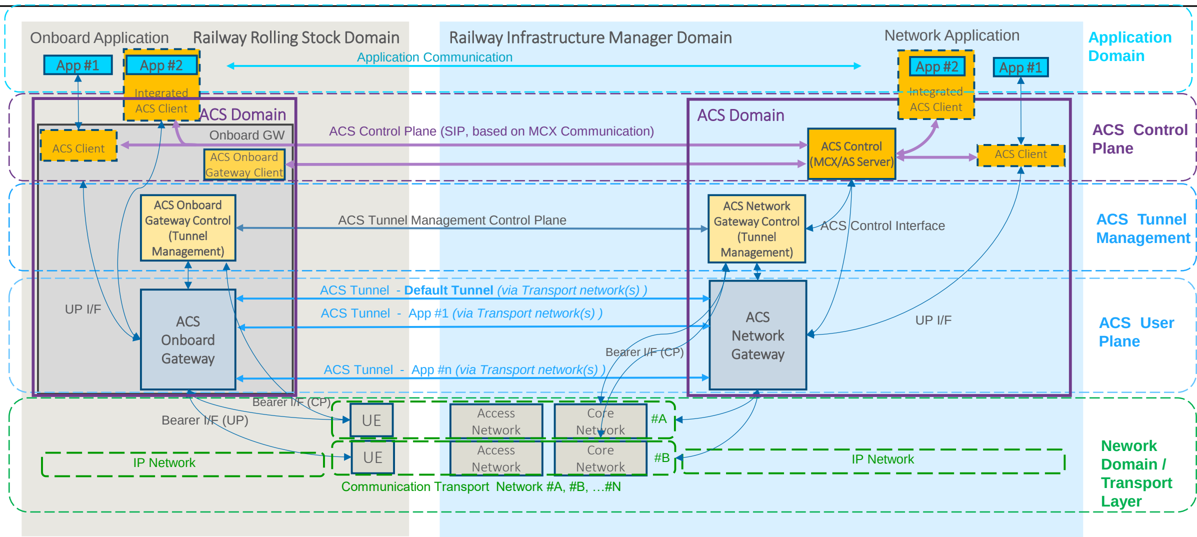

Figure 2: The ACS Layers [9]

The ACS provides a common application interface for any interaction between the ACS itself and the railway applications. The following functional scope is provided for applications using the ACS in order to provide a transparent connection:

- Registration
- Identification
- Authentication
- Authorization
- Session Management
- Session setup
- Addressing
- Communication characteristics (QoS)
- Session negotiation
- Session termination
- Service management:
- Location
- Communication characteristics
- Coverage (hotspots geolocation information)

The applications request towards the ACS Control Plane their requirements for communication needs – both on onboard-side and network-side. The ACS Control Plane then controls and grants the communication via the ACS Tunnel Management and ACS User Plane by providing an interface for applications domain for: Identity Management; Addressing; Session Management and Service Management. The ACS Tunnel Management acts as subcomponent of the control plane to steer the network domain functions for the Session Management. Note that MCX has been selected as ACS Control plane (also in line with FRMCS), but in principle also other options can be used. The ACS User Plane then performs the bearer selection (incl. default bearer); routing, handover, multipath (redundancy/ aggregation), QoS control and security.

SatCom Prototype

We develop a SatCom Prototype based on SDR which has been introduced in [8]. The prototype consists of a gateway side which is connected to the track-side of the ACS and a user terminal connecting the onboard-side as illustrated in Figure 3. User terminal and gateway are connected by a satellite return link (from user to gateway via satellite), and forward link (from gateway via satellite to user).

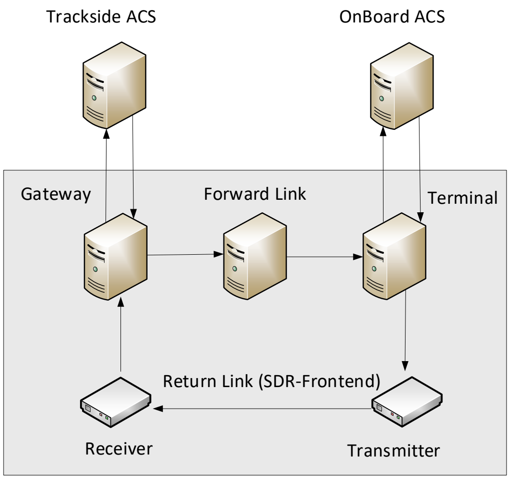

Figure 3: SatCom SDR prototype setup

We provide a MAC and a PHY layer implemented in C/C++ for each the gateway and the user terminal running on dedicated PC. Two USRP N210 are used as radio-frequency frontend to convert the data into the desired radio waveform. The USRPs are connected by a coaxial cable equipped with a 35dB attenuator in order to protect the RF component from high currents. An Octoclock is used for time reference. A satellite channel emulator adds a fixed delay (200ms) and a certain packet drop rate.

We assume a wide-band system for the forward link which is not limited by resources and simply forward the messages on this link. For the return link, the situation is different where multiple users transmit in an uncoordinated way with short signaling messages, as it is the case for ETCS. Furthermore, in order to provide a cost-efficient solution enabling equipment for a large number of trains, the terminal complexity must be kept low. Random Access (RA) schemes are a suitable solution for such characteristics and fit better than typical applied TDMA schemes. We implemented Contention Resolution ALOHA (CRA) [10]. CRA belongs to a family of modern RA schemes for data transmission and uses proactive replications of packets and successive interference cancellation for achieving a high spectral efficiency. No channel sensing or any advanced handshake procedure to grant resources are necessary. In order to resolve possible channel contention when multiple users (trains) access the same resource at the same time, advanced signal processing, error correction and interference cancellation are exploited. All these advanced techniques entail additional complexity that is confined to the receiver side. The prototype is the first in the railway sector to implement a frame- and slot-asynchronous uncoordinated RA protocol.

Lab-Tests

The SatCom SDR prototype was integrated as bearer next to 4G in lab within the regional line demonstrator. The integration was done via VPN connecting the SatCom prototype at DLR premises in Germany with the demonstrator at Hitachi’s premises in Italy. As application an ETCS traffic emulator was used. The SatCom prototype adds delay which is characteristically for a SatCom channel in geostationary orbit and is expected to be much higher than the delay caused by the remote integration. Therefore, no negative effects are expected by the remote integration for the integration tests. For performance tests it is recommended to have a local integration.

Several integration tests have been performed using pings: Bidirectional connectivity initiated at the wayside ACS and Bidirectional connectivity initiated at the on-board ACS. On Average 440ms was needed per transmission which matches the set delay for a GEO satellite plus some additional delay for the remote integration via VPN. Furthermore, packet inspection tests have been performed. The test was passed and the expected packets where received with the set channel impairments. Figure 4 presents the achieved bitrate on forward and return link path. For ETCS a minimum of 4kbit/s is required which was constantly achieved.

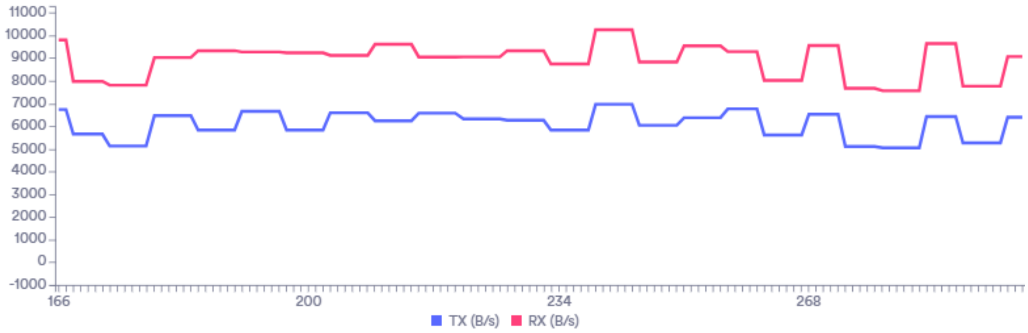

Figure 4: SDR SatCom Prototype results network chart [2]

The test results attest a successful integration of the SDR SatCom prototype. By the use of a traffic emulator, it could be verified that the SatCom prototype can be used for ETCS traffic. The network chart showed a smaller transmission rate at the return link which is expected since here the SDR link is used. The data rate still is above the limit defined in the user requirements, hence we could verify that the system can be used for ETCS traffic.

Regional and Freight Demonstrator Field Test Set-up

These results in lab using the SDR prototype motivated further tests in field using operational commercial SatCom systems. Figure 5 depicts the logical network architecture used for the Regional and Freight demonstrator field test, specifying the actual number and types of the network connections at disposal on the ACS gateway and the three key applications that have been chosen for the field test campaign (Channel Characterization Tool (CCT) for testing and monitoring, ETCS/ERTMS and VoIP for wayside communication).

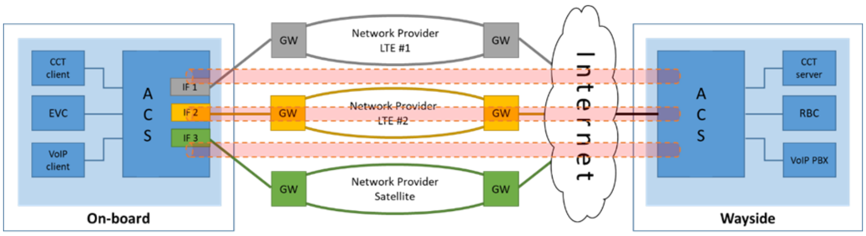

Figure 5: ACS regional line field test setup

On the train, two embedded LTE modems and one external satellite modem are available; each client application device has been configured with a static private IPv4 address. The on-board ACS gateway and the wayside site are logically connected through three network tunnels, that are build and manages by the ACS platform. Both on-board and wayside ACS gateway will have an assigned public static IP address to be reachable during the tests. A test train will be used on which's rooftop two combined antennas (2G/3G/4G/GSM-R/GNSS) and a HUGHES SatCom antenna mod. C11 connecting to BGAN service from Inmarsat will be installed for the trackside/on-board data exchange. LTE1 service provider is TIM, LTE2 Vodafone. Figure 6 shows the mechanical solution adopted by the ACS onboard GW.

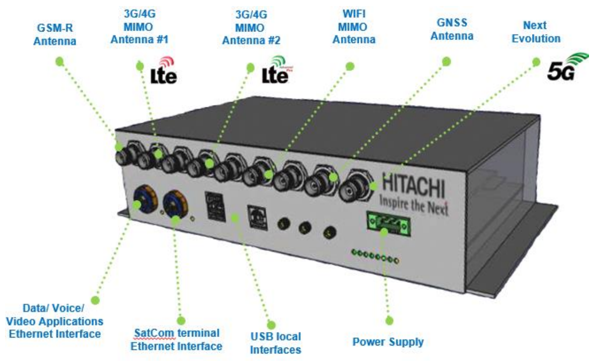

Figure 6: ACS onboard GW hardware schematic

The trial will be performed in the track between Novara and Rho, Lombardy, in the North of Italy. Its integrated in the double track Railways line 153km long connecting Torino and Milano and managed by RFI. The Novara-Rho Pilot-Line has been selected by RFI for being the first application of an ERTMS Level 2 system based on GNSS localization.

Preliminary radio surveys on the test track route were conducted within the scope of the SAT4TRAIN project (see Figure 7). The train runs were based on a double-journey measurement campaign during which the performances of an ETCS emulator were logged to register the status of bearers along the path and the functionality of signaling protocols implemented by the ETCS emulator.

Figure 7: Connectivity Journey 1: Novara – Milano-Lambrate (Green: no criticality, Yellow: some criticality, Red: criticality)

The ETCS emulator registered ‘critical conditions’ in three sections of the path. All these events are linked to situations when the train were close to or went under motorway overpasses or was approaching arrival station passing in a zone surrounded by buildings. In this situation, all bearers experienced quality degradation, which resulted in packet loss/corruption; these impairments did not cause faults in the Euroradio protocols due to retransmissions occurred at either TCP or applicative layer. The second measurements varied and seem to confirm the time variant nature of retail LTE network quality of service.

Additional field test will soon be performed providing more results on the performance using SatCom for the ACS.

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References

[1] FRMCS Functional Working Group, UIC, "Future Railway Mobile Communication System User Requirements Specification", 15th of January 2019, V4.0.0

[2] B. Allen et al., "Next-Generation Connectivity in a Heterogenous Railway World," in IEEE Communications Magazine, doi: 10.1109/MCOM.001.2200130.

[3] Report ITU-R M.2418-0

[4] A. Gonzalez-Plaza et al., "5G communications in high speed and metropolitan railways," 2017 11th European Conference on Antennas and Propagation (EUCAP), Paris, 2017, pp. 658-660, doi: 10.23919/EuCAP.2017.7928756.

[5] Alessia Miglietta et al., "Iris4Rail - Iris for Railway Communications", available at: https://space4rail.esa.int/projects/iris4rail-iris-for-railway-communications

[6] ERA 2016 01 SC, "Study on feasibility of SATCOM for railway communication", Final Report, Version 1/1, 16/02/2017

[7] C. Iacurto et al., "Capacity Study for a 5G Satellite System to support Railway FRMCS Critical service over Europe," 2022 IEEE 95th Vehicular Technology Conference: (VTC2022-Spring), Helsinki, Finland, 2022, pp. 1-5, doi: 10.1109/VTC2022-Spring54318.2022.9860366.

[8] Benjamin Barth, Federico Clazzer, Marcel Grec, Sandro Scalise, "Satellite Communication Prototype Based on SDR". First Scientific Workshop SmartRaCon, 25.06.2019, Lille, Frankreich.

[9] X2Rail-5 Deliverable D3.1: "Specification of the Communication System and Guideline for Choice of Technology", V3.0,2023

[10] F. Clazzer, C. Kissling, M. Marchese, "Enhancing Contention Resolution ALOHA Using Combining Techniques", IEEE Trans. Comm., Vol. 66, No. 6, pp.2576-2587, Jun. 2018.