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5G Realistic Radio Channel Models for FRMCS Deployment in Railway Environments

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Abstract. The Future Railway Mobile Communication systems (FRMCS) is the new system under development, based on 5G-NR, that will replace the GSM-R standard. Its deployment will require the design of new radio engineering tools, which in particular rely on new 3D radio channel models to validate the performance of proposed networking technologies under high-speed conditions, and to perform future radio-planning tasks. The 5GREMORA projects aims at developing new measurement-based 3D radio channel models for railways, and demonstrating how new scheduling algorithms can be assessed with those models. The paper outlines the main ambitions of the project; and presents the preliminary results obtained so far.

Keywords: 5G, FRMCS, Safe communications, Channel models, Channel sounding, Railways.

1 Introduction

The Future Railway Mobile Communication System (FRMCS) is designed at European level to answer the increasing needs of Railway in wireless communications. It will be IP based, multi-bearer and resilient to technology evolution and interference. This new system will offer the railway industry a full migration towards 5G as GSM-R becomes obsolete in 2030. Currently, to the best of our knowledge, there is no model of 5G radio channel in the railway frequency bands (RFB) harmonized at European level. 5G railway radio channels in 900 and 1900 MHz bands are not yet characterized and it requires further study. The 5G REMORA project is set up to develop realistic new 5G railway radio channel models enabling FRMCS evaluation and deployment in the railway frequency bands not covered in other 5G related projects. The rest of the

paper is organized as follows. Section 2 presents the channel sounder systems (CSS) considered. Section 3 details the modelling approach with Ray Tracing. Section 4 highlights the work related to the development of an advanced scheduling technique. Then we conclude.

2 Radio channel characterization in the railway environments

2.1 Introduction

Railway environments are very complex and harsh from a radio point of view. Various obstacles or scatterers such as the pylons supporting the catenary, as well as the rapid transitions between different scenarios (cutting/tunnel, cutting/viaduct) can create severe radio impairments. Due to speed, the train can rapidly go through diverse scenarios and a single-environment radio channel model is unable to accurately capture the channel variations. Thus, environment transition must be considered in the railway channel models. Doppler effects and possible interferences due to the proximity of high voltage in the vicinity of the antennas are additional factors that make the railway environments very specific compared to the urban or suburban environments generally considered in standardization groups (3GPP). In addition, to the challenges related to the nature of railway environments, it is important to insist on the fact that the organization of measurements in railway environments is a very challenging task.

In [1], the authors have classified several existing papers dealing with radio channel characterization mainly in HSL environments. The measurements are generally performed over 20 MHz in the LTE band. The measurement-based models proposed are mainly simple TDL (Tapped Delay Line) or CDL (Cluster Delay Line) models generally with no geometric information on angle of arrival or departure of the rays. The ambition of the 5GREMORA project is to build measurement-based 3D stochastic channel models inspired from 3GPP ones complemented by Ray tracing models. Three complementary channel sounders (CS) are considered in the project.

The CEA-LETI owns a unique 4x4 MIMO Channel Sounder System (CSS) [2] operating in the frequency band from 10 MHz to 40 GHz with a bandwidth up to 1 GHz and capable of measuring a mobility up to 300 km/h. The CEA CSS is composed of two subsystems, the receiver (Rx) part and the transmitter (Tx) part, each one synchronized with rubidium clocks. Comparing to VNA (Vectorial Network Analyser) method, the Tx and Rx subsystems can be separated at very large distance for propagation measurements and retrieve channel variations to address mobility (Doppler, stationarity, *etc.*). CSS maximum range variates with frequency, e.g. up to 3 km at 800 MHz and 500 m in the Ka band. To realize MIMO measurement, a switching array is implemented on the Tx side while on the Rx side, each antenna has its own RF chain allowing faster capture than switching arrays techniques (Switching @ Tx & Rx sides) and free of inter-symbol interference like in real arrays techniques (parallel @ Tx & Rx sides) [3].

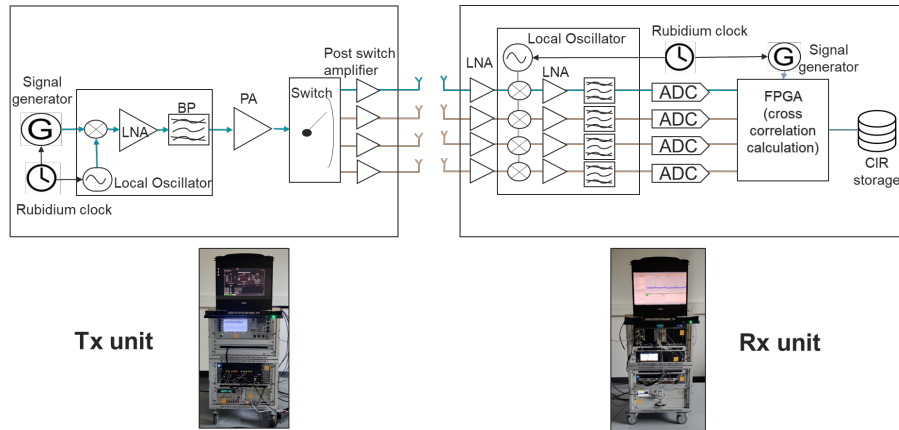


Fig.1. CEA's channel sounder

Université Gustave Eiffel has recently developed a flexible sub-6 GHz 4x4 MIMO reconfigurable channel sounder based on SDR (Software Defined Radio) boards (USRP 2954R) and TDD LTE signal with 1200 pilots on 20 MHz (see Fig.2). The system includes a base station and a mobile station that should be synchronized using clock distribution via GPS. The complex frequency response of the channel (CFR) is extracted continuously from the LTE signal at the estimation stage. The sampling rate is equal to 30.72 MS/s. The sounder can record data during 1 hour and it is designed to operate at high speed [4]. Amplifiers and pre-amplifiers are used both at transmitter and receiver sides. Specific railways antennas are used both on the ground and on the train roof..



Fig.2. Sounding signal transmitter (left side) and receiver (right side)

IMT Atlantique has been developing a versatile measurement equipment to study wireless propagation channels [5]. In this project, this equipment is extended to perform passive propagation channel estimation using existing LTE signals. Many base stations from public operators are available along rail tracks, and their frequency bands are close to the FRMCS bands. For that, B8 and B20 LTE Band (10 MHz bandwidth) will be used to explore FRMCS 900 channel. B3 LTE (20 MHz bandwidth) band will be used for FRMCS 1900 band investigation. Main characteristics of these base stations (location, height, antenna orientation, etc.) are available in the public government database. This approach will provide a large amount of data in various and realistic

scenarios without a complex setup (no need to deploy transmitters and request frequency allocation). Moreover, MIMO channel estimation will be performed with Cell-Specific Reference Signals, transmitted continuously regardless of the traffic load. The main drawback will be possible interference between base stations. The proposed channel sounder is composed of two USRPs (X310) with UBX daughterboard (Fc 0.01-6 GHz, BW 160 MHz), a rubidium clock to ensure temporal and frequency synchronization, Huber and Suhner shark antennas located on train rooftop. To validate our system, test measurements have been performed with a car and an antenna array as shown in the figure below.



Fig.3. IMT-Atlantique's Sounding system

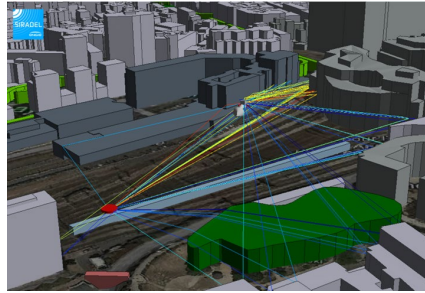


Fig. 4. Ray-tracing applied on an urban railway scenario.

3 Radio Channel modeling for 5G-based FRMCS

The development of radio channel models is an active field of research for 5G NR standard. The models generally give an analytical or stochastic expression of the channel impulse or frequency response obtained thanks to measurements, or may rely on deterministic ray tracing (RT) tools [6]. A complete state of the art on railway channel models is proposed in [7]. The lack of operational 5G MIMO (Multiple Input Multiple Output) radio channel models in RFB bands is highlighted. The ambition of 5G REMORA project is to fill this gap. That is why the wideband dual-polarization MIMO measurements presented in section 2 will be exploited for the construction of new FRMCS statistical MIMO channel models.

Ray-tracing (RT) will complement the statistical modelling approach by emulating the train mobility and spatially-consistent MIMO radio channel variations in real environments. Several works over the last ten years have demonstrated the interest and applicability of RT for railway scenarios, either at sub-6GHz or in the millimeter-wave band. RT gives the possibility for fast deterministic multi-path-predictions in diverse scenarios, including the urban, cutting and viaduct situations [8]. However, there are still several key challenges, which includes: validation from channel measurements; consideration of dual-polar MIMO; scalability; and capability to combine long-range propagation and strong interactions (by metallic objects) nearby the antenna. An enhanced version of the Volcano ray-tracer is developed to address those challenges.

The initial Volcano solution [9] covers rural environments, urban areas, indoors and tunnel scenarios, in sub-6 GHz and millimeter-wave bands; multi-paths and polarized fields are computed to estimate realistic MIMO channels. In the 5G-Remora project, the tool is planned to be qualified and tuned by comparison to the measurements collected in real HST scenarios. Particular attention is brought to the modelling of scattered components e.g., due to poles or catenaries located close to the train antenna. The ultimate ambition is to predict accurate train-to-infrastructure time-variant spatially-consistent MIMO channel traces, with fine time resolution (possibly 1 ms), based on the tuned RT model. That will be demonstrated in various complex scenarios, e.g., in urban areas (Fig. 4). Preliminary results will be presented at the conference (but without the tuning aspect) that shows the emulated channel variations when the train is travelling in the centre of a large city (Paris).

4 Advanced scheduling technique

As aforementioned in the introduction, the 5G REMORA project envisions enabling FRMCS evaluation in the railway frequency bands. When deploying FRMCS, it is crucial to pay attention to the requirements of the services to be proposed through FRMCS, e.g., the train virtual coupling or the control of automated train. These requirements are described according to several time-related metrics [10], one of which is the survival time defined as “the time that an application or service consuming a communication service may continue without an anticipated message”. The management of multiple nearby trains that compete for the radio resources access is a major challenge to comply with the survival time requirements. Therefore, a scheduler responsible for allocating resources to the trains is essential in the evaluation. The 5G-REMORA project published in [11] a first version of a family of schedulers built on the survival time in a multi-train scenario based on the reinforcement learning approach. The current evaluation assumes a simple model of the radio propagation channel. As the results are promising, as observed in Fig.5, it is planned to use the radio channel modeling for 5G-based FRMCS, see Section 3.

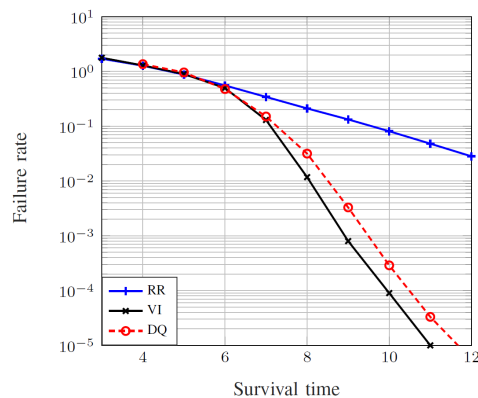


Fig.5. Performance of the scheduling process.

In Fig.5, the x-axis is the survival time in number of time slots, the y-axis is the number of survival time excesses per time unit. The Round-Robin (RR) is the baseline that allocates the resource to the trains following a buffer of all the trains index. The Value Iteration (VI) and Deep Q-learning (DQ) stem from a reinforcement learning approach.

5 Conclusion and future works

The efficient deployment of 5G-Based FRMCS along railway lines in the Railway frequency bands, will require the development of new 5G radio channel models. The paper has presented the main objectives and preliminary results of the French project 5GREMORA supported by ANR under Grant n° ANR-22-CE22-0015. The presentation will highlight the measurements results as the first trials is planned in October 2023.

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