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Sub-6GHz MIMO channel sounders for Railway environments

Ali Sabra¹, Marion Berbineau^{1,3}, Patrice Pajusco², Jamal Eddine Amghar², Ahmed Abdelghany², Caroline Maye³

¹*Institut de Recherche Technologique Railenium, F-59300 Famars, France*

²*IMT Atlantique, Lab-STICC, UMR CNRS 6285, F-29238 Brest, France³*

³*Université Gustave Eiffel, COSYS-LEOST, F-59650 Villeneuve d'Ascq*

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Due to the very soon obsolescence of the current train-to-ground communication system used in Europe, 2G-based GSM-R (Global System for Mobile Communication - Railway) will be replaced by a 5G-based communication system called FRMCS (Future Railway Communication System). The system will be IP based, and in order to be bearer independent, some solutions in development proposed to consider parallel use of several radio bearers, based on different radio access techniques, namely Wi-Fi, LTE (Long Term Evolution), Satcom and 5G [1]. The deployment of FRMCS along the different types of railway environments will require the development of new radio planning models. Trends on channel models for 5G are presented in [2]. A survey of channel models for high-speed lines is given in [3] and a very complete state of the art on existing railway channel models and environments is also provided in [4], which highlights the crucial lack of usable existing MIMO (Multiple Input Multiple Output) radio channel models for 5G particularly in the Railway Frequency Bands. The ambition of 5G-RACOM and 5G-REMORA projects is to fill this gap. In order to develop complete 3D channel models for FRMCS, wideband dual-polarization MIMO measurements will be carried out to extract measurements based statistical MIMO channel models. A MIMO channel sounder will measure the different coefficients of the channel matrix. They are differentiated by the excitation signal and processing methods at reception (switching between antennas or parallel processing [5]). There are main types of sub 6 GHz sounders: MIMOSA [6], RUSK [7], Propsound [8], Keeyesight [11] and sounders constructed from Software Defined Radio (SDR) cards considering LTE signals [9], [10]. Two complementary SDR-based MIMO channel sounders are under development specifically for these measurements in the railway frequency bands.

The MIMO 4x4 channel SDR-based channel sounder developed at Université Gustave Eiffel with Railenium is based on [13] and [18]. It considers 4 RIO-2954 MIMO USRP (Universal Radio Peripheral) cards with 2 antennas on each board. The excitation signal is an Orthogonal Frequency Division Multiplexing (OFDM) waveform derived from an LTE TDD signal (Nation Instrument, 2017). A specific software integrates all the processing steps of a standard LTE communication system (modulation, channel estimation, equalization...) applied to the MIMO. Fig. 1 gives a photography of the channel sounder installed in the laboratory. Each transmitting USRP card is connected to a synchronization module used to transmit the clock signal from a GPS antenna. The cards are controlled using a PC directly connected to them by an MXI cable. In reception, the two SDR boards are connected to a second clock module and a support chassis of the various modules (see Fig. 1) via a PXI interface card. The general control of the system is done by a controller under Windows. Two 2.9 TB hard disks were added to record the channel transfer functions during measurements. A specific FPGA is used for signal processing at reception. One hour of measurement can be recorded.

The frame of the LTE-TDD signal is defined by 10 subframes of 1 ms each composed of 2 time slots of 0.5 ms. Each interval comprises 7 OFDM symbols [14]. The center frequency of the sounding signal is between 0.05 and 6 GHz with a bandwidth of 18 MHz. The signal sampling frequency is hardware dependent and is equal to 30.72 MHz. The LTE signal is composed of radio resource blocks that include data symbols and pilot symbols whom position scheme corresponds to a fragmented in time and frequency positioning scheme [15]. Channel estimation is performed on each Cell Reference Symbol (CRS) distributed periodically every 0.5 ms and in all 6 frequency subcarriers with interpolation both in frequency and time to identify channel variations outside CRS symbols. The maximum Doppler shift measurable is 7 kHz. The maximal measurable delay is equal to 66.6 μ s and the minimal one is 55.5 ns. The maximal output power is -9 dBm and the sensitivity is equal to -65 dBm. Consequently, Signal amplifiers and pre-amplifiers on each Tx and Rx will be used to extend radio coverage. The statistical parameters extracted are the Power Delay Profile, the maximum excess delay, the average delay, the RMS (Root Mean Square) delay spread and the Doppler Spread Function.

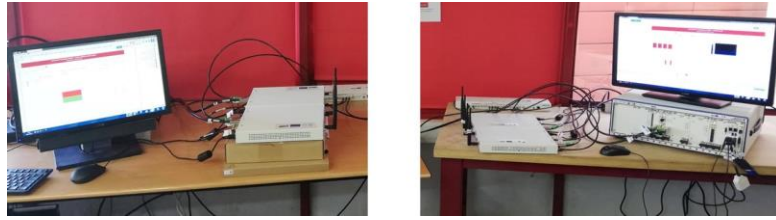


Fig. 1. The equipment in the laboratory

To avoid the use of a dedicated transmitter, IMT Atlantique proposes using the existing signals from mobile network operators to estimate the propagation channel. The LTE standard, widely deployed in France, is a suitable candidate. LTE frequency bands are close to the FRMCS bands, and the LTE downlink signal contains Cell Reference Signals (CRS) for computing Channel State Information (CSI). These reference signals are consistently transmitted, irrespective of user traffic. This approach offers several advantages, including realistic and various configurations, no need of dedicated transmitter deployment... Consequently, this method enables the collection of a substantial amount of propagation data in diverse scenarios, which is crucial for generating relevant propagation channel models.

For this purpose, IMT Atlantique has developed a Software-Defined Radio (SDR)-based channel sounder. The system comprises two USRP X310 devices (4 RX channels) equipped with a GPS Disciplined Oscillator (GPSDO) to ensure precise synchronization in both time and frequency. The host computer operates C++ software responsible for transferring raw data and managing Realtime Automatic Gain Control (AGC). Post-processing is conducted offline using Python and open-source libraries. To obtain representative measurements of the railway environment, the propagation trial was conducted onboard the TGV IRIS 320. The channel sounder is depicted in figure 2 (right). This train is dedicated to the control of the rail track. Thus, it travels on the whole commercial high-speed tracks. This propagation measurements took place Calais and Lille. Several runs were done. About 500 km and 2.5 To.

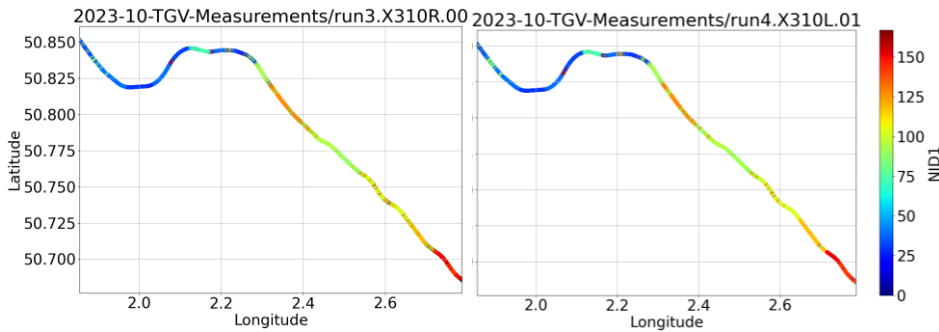


Fig. 2. PCI detection with 2 runs (left), Channel sondeur onbaord IRIS 320 (right)



PSS and SSS were searched in the raw data to synchronize the LTE frame and to identify the PCI of each received base station. The results from two different runs are depicted in Figure 2 (left). Similar results were obtained, confirming the accurate identification. Characteristics of the base stations are important for comparing measurements and models. ANFR data provide this information (height, location, sector direction, etc.) but the PCI is missing in the database. Thus, the link between base station and PCI has to be done. A simple way is to select the closest base station when the timing advance of a PCI is minimal. However, this approach leads to ambiguities. To improve this naive approach, the timing advance profile along the run is used and compared to simulate profile. Much better results are obtained and illustrated in Figure 3.

In conclusion, two complementary Channel Sounders (CS) based on LTE signals and utilizing Software-Defined Radio (SDR) technology are currently in development. The UGE/Railenium CS requires a dedicated base station positioned along the track. Channel sounding is achieved through channel estimation using known LTE pilots instead of random data. The IMT Atlantique channel sounder utilizes signals from Mobile Network Operators, providing a convenient method for acquiring propagation data in various scenarios. An initial trial was conducted on board IRIS 320. An algorithm designed to detect characteristics of the received base station has been proposed and validated using measurement data. New propagation measurements onboard trains are expected in the first quarter of 2024.

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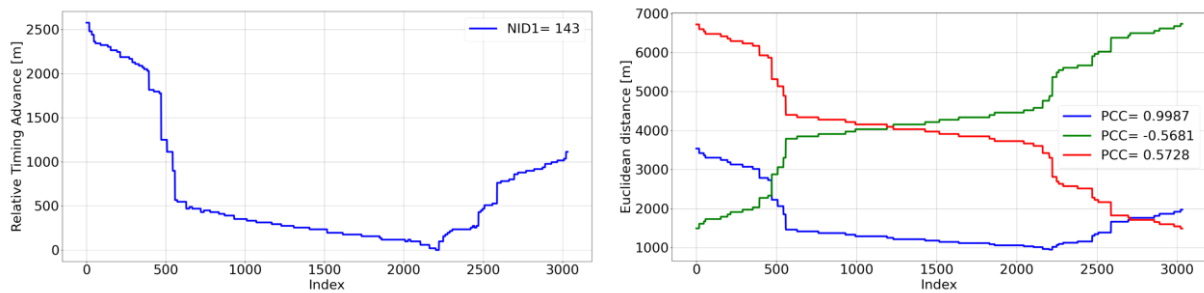


Fig. 3. Timing advance profil of measurement (left) and possible candidates

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