URSI GASS 2021, Rome, Italy, 28 August - 4 September 2021

Analysis of the Susceptibility of the LoRa Communication Protocol in the Railway Electromagnetic Environment

Virginie Deniau(1), Thomas Vantroys(2), Norbert Becuwe(3), Christophe Gransart(1), Artur Nogueira de Sao José(2), Alexandre Boe(2), Eric Pierre Simon (2), Olivier Vlamynck(3), Florent Valenti (3), Jonathan Villain(1) and Quentin Rivette (3)
(1) COSYS-LEOST, Univ Gustave Eiffel, IFSTTAR, Univ Lille, F-59650 Villeneuve d'Ascq, France
(2) Univ. Lille, CNRS, USR 3380 - IRCICA - Institut de Recherche sur les Composants logiciels et matériels pour l'Information et la Communication Avancée, F-59000 Lille, France
(3) SNCF VOYAGEURS–Direction du matériel-Ingenierie du matériel-574 Industriel, Hellemmes, France

Abstract

In the context of the digital transformation of railway transportation systems, railway operators investigate the potentialities of the IoT (Internet of Things) in order to optimize the maintenance operations on the vehicles and the infrastructures. One of the interest is to use IoT communication solutions in order to centralize the data measured by the different sensors distributed everywhere along the railway infrastructures and on board the trains. In this perspective, different communication protocols could be employed. This paper deals specifically with the LoRa communication protocol and analyses its susceptibility in the presence of railway electromagnetic interferences. This paper presents a susceptibility analysis of the LoRa communications in the presence of transient EM interferences representative of the electromagnetic interferences produced by the sliding catenary-pantograph contact.

1 Introduction

As part of its digital transformation, the French railway operator SNCF uses the LoRa communication protocol in order to transmit measured information by sensors located on board the trains to the maintenance centers [1]. The centralisation of the sensor data allows optimising the maintenance operations schedule. However, the LoRa communications can be affected by the presence of EM disturbances on board trains. The presence of electromagnetic disturbances can induce losses of communication and therefore requires re-transmission of LoRa messages [2]. Knowing that too many re-transmissions lead to a reduction in battery life, it is essential to optimize the robustness of communications face to the electromagnetic interferences [3]. In this context, the LoRa-R project was involved in order to analyse the susceptibility of the LoRa communication protocol face to the different railway constraints: speed, integration and electromagnetic (EM) disturbances. The term LoRa means Long Range. It is a technology that allows connected objects to exchange with relatively low symbol rates. This technology allows reducing the energy consumption of the devices, giving them several years of autonomy. This technology can use the free 868 MHz radio frequency band. On board SNCF trains, various sensors are installed in order to follow the state of different railway components. The collection of the data measured by the sensors requires railway agent interventions. In consequence, to optimize the collection of the sensor data, SNCF developed a LoRa interface which can be connected to the different sensors in order to send the measured data. Two different solutions can be employed to centralise all the data on the IoT platform. The LoRa interface can transmit the data via the ground LoRa network or the data can be transmitted via a LoRa-4G gateway located on board the train. The first solution is only available when the speed train is low. Then, the second solution is often the only one adapted. Nevertheless, the signal received by the on board gateway can be disturbed by the on board EM interferences. This paper studies the susceptibility of the on board LoRa communications face to the transient EM interference which is produced by the catenary-pantograph electrostatic discharges. Knowing that several LoRa communication parameters can be configured, the aim of this study is to identify the parameter values which provide the most robust LoRa communication solution in the presence of such interference. The next section of this paper presents the LoRa physical layers and the characteristics of the applied EM interference. The third section of the paper describes the test bench which was developed, the different devices and the experimental process. Finally, the last section presents and analyses the results.

2 The LoRa protocol and the considered EM interference

2.1 The LoRa physical layer

The LoRa modulation method is a Direct Sequence Spread Spectrum (DSSS) method, called Chirp Spread Spectrum (CSS). Each symbol is spread by a chirping factor, called the spreading factor (SF). The SF can vary between 7 and 12, and when the SF is increased the data rate is reduced. On the other side, the SF increase enlarges the LoRa communication coverage. Moreover, the LoRa communications can be configured with different channel bandwidths: 125 kHz, 250 kHz and 500 kHz, located in the free 868 MHz radio frequency band.

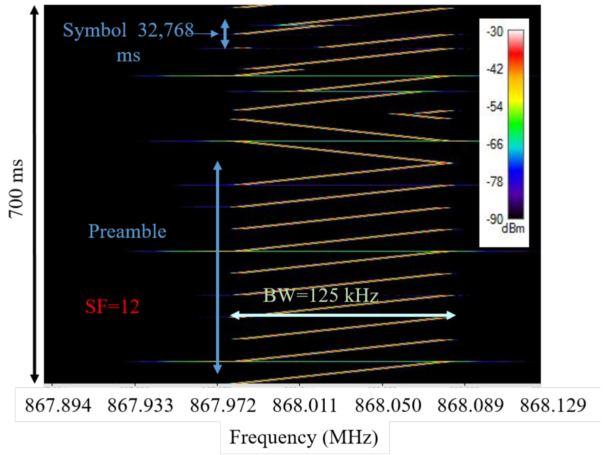

Figure 1. Illustration of a LoRa signal in time-frequency representation

2.2 The railway electromagnetic disturbances

The railway EM environment is rich in electromagnetic emissions. Indeed, the railway is an electrical transport means involving very important power levels. However, the major part of the emissions are in the lower frequencies. Nevertheless, the trains collect their electrical energy through the pantograph sliding along the catenary. Unfortunately, this sliding contact is imperfect and characterized by brief and frequent contact losses, which induce numerous electrostatic discharges. In previous projects, on board measurement campaigns were performed to characterize the electromagnetic emissions produced by these electrostatic discharges. The EM interferences considered in this paper are the transient EM interferences which are provocked by the losses of contact catenary-pantograph [4]. In the past, these transient EM interferences were measured and characterized in order to analyse their potential impact on the GSM-R communication system [6]. It was then observed that they are very broadband interferences, reaching the frequency bands of the GSM-R (876-880 MHz and 921-925 MHz). Knowing that the frequencies employed by the LoRa communication solution (863-873 MHz) are adjacent to the GSM-R frequencies, they can also be affected by these transient EM interferences. This previous study allowed us to define an interference model, which can be used for laboratory tests and expressed by equation (1). The envelope of the signal $Vtrans(t)$ is a double exponential function in which t_{rise} is the rise time between 10% and 90% of the peak value and t_{hold} is the hold time at 50% of the peak value.

$$Vtrans(t) = A \cdot \left(e^{\frac{-t}{t_{rise}}} - e^{\frac{-t}{t_{hold}}} \right) \cdot \sin(2\pi f_C t) \cdot u(t) \qquad (1)$$

A is the signal amplitude and $u(t)$ is the step unit function. The term $sin(2\pi f_C t)$ focuses the model over the frequency band of interest: f_C is the center frequency of the studied communication channel.

The previous studies also demonstrated that the impact of such interferences on a communication system highly depends on the repetition rate of these transient signals [5]. However, the repetition rate can significantly vary according to the railway operation conditions : state of the catenary, quality of the tracks, one or two pantographes on the train and train speed. Figure 2, which presents two measurements performed on board train with an oscilloscope, illustrates this variability of occurence.

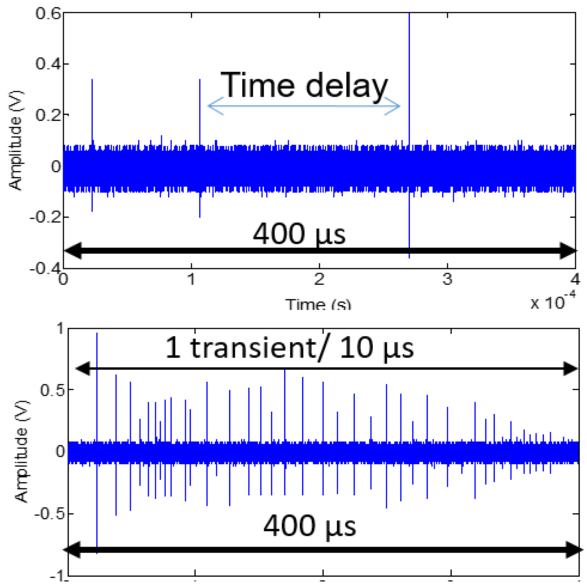

Figure 2. Transient electromagnetic interferences collected by an oscilloscope connected to an antenna on a train roof

Due to the repetition rate being an impacting parameter, we study the susceptibility of the LoRa communication according to the time interval between the successive transient interferences.

3 The LoRa susceptibility test bench

The loRa experimental test bench was preliminary developed to perform tests in a conducted mode. Indeed, the conducted mode avoid to introduce variations in the test configuration due to possible inaccuracies in the position of the antennas. In general, tests in conducted mode present a good repeatability, which allows analyzing the impact of the different communication and interference parameters. The employed test bench is presented in figure 3. In order to establish LoRa communications, the test bench is composed of an ARM CORTEX M4 board as a LoRa client and a Kerlink LoRa-Ethernet gateway. The Kerlink gateway is connected through an ethernet cable to a raspberry PI4. The PI4 contains the network server and application server to manage and record all the LoRa trafic (LoRaWAN layer).

The application on the cortex boardembedded on the microcontroller periodically generates a LoRa frame and the LoRaWAN server sends back an acknowledgment. We have tested several configurations of the LoRa protocol: bandwidth 125 KHz, spreading factors 7 and 12, coding rate of 4/5 and 4/8. The Adaptative Data Rate (ADR) has been desactivated.

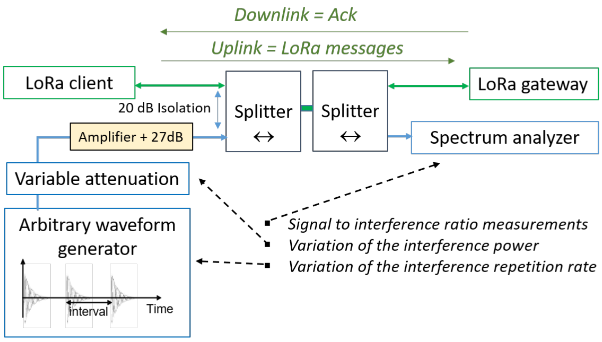

Figure 3. Schematic diagram of the test bench used to evaluate the susceptibility of LoRa communications in the presence of interference.

In order to apply transient EM interferences, we employed an arbitrary waveform generator in which the transient interference model was preliminary loaded. By employing the internal generator trigger, we generated the interference in a repeated mode and with a fixed time interval. In order to increase progressively the power level of the transient EM interference, a variable attenuator was connected at the generator ouput. By reducing the attenuation, the power of the interference was progressively increased up to reach the breakdown of the communication. However, We did not indefinitely increase the power of the interfering signal but we increased it until we obtained a signal to interference ratio (SIR) of about -3 dB. Thus, certain repetition intervals of the transient interference did not produce a communication cut-off due to the fact that we limited the maximum power of the interference. The SIR measurements were carried out with a spectrum analyzer as presented in figure 3.

Figure 4 illustrates the succession of the uplink and downlink LoRa messages, observed with the spectrum analyzer centered on the 868,3 MHz channel and configured in zero span, i.e. in time domain.

We observe the uplink message sent to the gateway and the aknowledment (ACK) message which is the answer of the gateway when the LoRa message is correctly received. In our experiment, we adopted as susceptibility criteria the absence of ACK message.

4 Experimental results

Figure 5 presents the SIR at the communication breakdown instant for two different values of the spreading factor: 7 and SF 12. The figure reports the minimum ratio between the LoRa signal and the interference signal to maintain

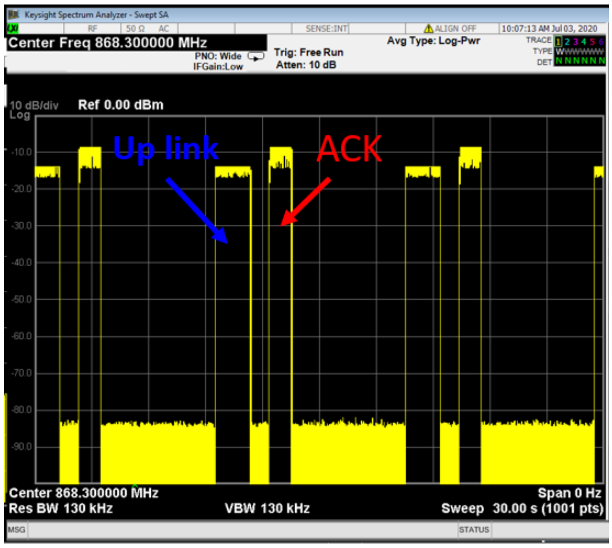

Figure 4. Observation of the downlink and uplink LoRa signals with the spectrum analyzer in zero span.

a correct communication. In our experiments, a "correct communication" means that the LoRa Gateway sends back an ACK message. Then, this figure reports the SIR reached when the acknowledgement signal disappears, corresponding to a bad quality reception of the message by the gateway. The critical SIR is presented according to the repetition rate of the transient interference. Both results are obtained with a Coding Rate equal to 4-8.

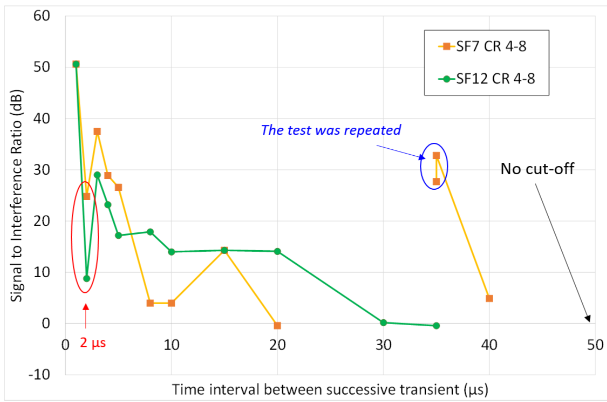

Figure 5. Signal to interference ratio required to breakdown the LoRa communication, according to the repetition rate of the transient EM interference.

These experiments were carried out with fixed transient interference time intervals ranging from 50 µs to 1 µs. On the one hand, looking at the results with the spreading factor 12, the SIR corresponding to the susceptibility limit generally increases when the successive interferences are closer in time, except for the 2 µs time interval. This result seems fairly consistent. On the other hand, we cannot make the same observation for a SF of 7. Indeed, certain time intervals relatively high, as 35 and 40 µs, induced a breakdown of the communication with a significant SIR value. With the 35 µs time interval, the experiments was repeated to check the repeatability. In reality, for the tests with SF = 7, we noticed that the results can be sensitive to the test procedure. When the interference power level is increased slowly and progressively, the communication can support a relatively low SIR. However, if a significant interference power level is suddenly applied, an immediate breakdown of the communication can occur. We therefore need to further study the LoRa protocol to identify possible adaptation mechanisms. On the other hand, we note that for time intervals inferior to 10 µs, the results obtained with both SFs follow the same trends. In particular, it appears that the 2 µs interval leads to a lower susceptibility. Moreover, this result shows that the communication system appears to be robust to this transient interference for both SFs when the repetition interval is greater than 40 µs.

5 Conclusion

We have proposed an experimental approach to analyze the susceptibility of the LoRa communication face to the railway transient EM interferences. Overall, the results show that the communication system appears to be robust to this transient interference when the repetition interval is greater than 40 µs. However, it should be highlighted that the SIR was measured by taking the interference-induced power on the communication channel using a spectrum analyser. This method of power estimation does not take into account the particular time distribution of the transient interference and the variation of the interference power on the channel over time. More generally, this study provides preliminary results, but the analysis needs to be strengthened by carrying out an in-depth study of the protocol due to the initial results being difficult to interpret. It will then be possible to improve the test process by applying transient interference scenarios with variable intervals in order to be representative of the reality of interference on board the trains.

6 Acknowledgements

This work was performed in the framework the LoRa-R project which is co-financed by the European Union with the European Regional Development Fund, the Hauts de France Region Council and the SNCF railway company.

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