

Measurement and Analysis of ITS-G5 in Railway Environments

Abstract. In this paper we present first measurement results of a novel approach in Train-to-Train (T2T) communications. For this measurement campaign an Intelligent Transport System (ITS-G5) communication link was used to investigate the influences of a railway environment on a Car-to-Car (C2C) communication standard based system. The measurements cover a wide range of scenarios from urban to rural environments, forest to open field as well as tunnels and crossings under bridges. The investigated measurement categories are channel characteristics, system performance and environmental aspects. The results should clarify, if a technology transfer from road to railway traffic communications would be expedient.

Keywords: railway, train-to-train, Next Generation Train, dynamic coupling, virtual coupling, ITS-G5, IEEE802.11

1 Introduction

Most of the publications about vehicular communications focus on car communication issues and the related propagation aspects. With good reasons, the individual transport has been increasing tremendously in the last decades. Even though C2C is the biggest market and automotive manufacturer and IT companies are investing billions of dollars, these technologies are also interesting for all other types of vehicles. For railway traffic and management Vehicle-to-Infrastructure (V2I) was the most common communication scenario till now. The last years, a lot of investigations were done on Global System for Mobile Communications-Railway (GSM-R), potential successors like a transfer of Long Term Evolution (LTE) to railway [8] and the availability of those systems for high speed trains in different scenarios [4]. For future applications on railway tracks like dynamic coupling or platooning and with it a more efficient and safe usage, also T2T communications are going to be very important.

T2T communications, like in the Railway Collision Avoidance System (RCAS) are designed for very specific tasks, offering a large coverage but small bandwidth. ITS-G5 would supplement such a system with a higher data rate at short range. Hence, why not using the existing ITS-G5 standard from C2C applications and transfer the technology to railway traffic. To evaluate this possible application and to identify differences on the propagation channel for road and railway environment this measurement campaign was executed.

2 Measurement Campaign

In the same way as it was performed for the RCAS measurement campaign as presented in [2], the purpose of these measurements was to investigate the performance of an existing commercial system in a different environment, as it was designed for. We used Cohda Mobility MK5 On Board Unit (OBU) Enclosure modules [5] as transmitter and receiver. The Cohda MK5 module provides an automotive qualified IEEE 802.11p dual-antenna radio and a Global Navigation Satellite System (GNSS) [6]. With the use of an automotive system in a railway environment several questions were raised: How does a train influence the link in comparison to a car? What are the influences of a railway track environment on the propagation channel? If there are differences between car and train as well as street and track in case of the channel, can the C2C system handle those different circumstances and how is the performance influenced?

To answer these questions a measurement campaign was performed. In Order to investigate different environmental and topological aspects, this campaign was organized similar as the campaign in [2]. Our partner, the "Bayrische Oberlandbahn" (BOB) provided one diesel-hydraulic train-set for the time of the measurements.

2.1 Railway Network

BOB operates with 20 trains on a total network of 120 km with 27 stations and transports around 15,000 people per day within urban, suburban and rural environment. As shown in Figure 1, the railway network consists of one main line from Munich to Holzkirchen and 3 branches, to Lenggries, Tegernsee and Bayrischzell. The main line is electrified, offers two tracks and is used by the Munich commuter railway system as well. Going on the branches south from Holzkirchen, the network is single track and not electrified. On each run, a combined set of 3 consists departs from Munich central station. In Holzkirchen, one consist splits up to Bayrischzell, two continue to Schaftlach, where they split again and are heading to Lenggries and Tegernsee. On the way back, the consists couple again on the mentioned stations and arrive as one train back at Munich central station. Due to this procedure and the hourly train schedule, only at one place north of Holzkirchen, two trains pass each other. This mentioned single event with two trains and the coupling of the train sets in the stations won't reflect a sufficient distribution of measurement environments. Hence, to cover all kind of different environments and scenarios in T2T communications, the transmitter (Tx) was installed on a BOB train and the receiver (Rx) on the German Aerospace Center (DLR) Safety of Life Communications (SoL) measurement car.

2.2 Environment and Scenarios

The environment along the track varies from urban and suburban in the metropolitan area of Munich to rural areas in the south of Bavaria. The trains passes one tunnel, under several bridges, villages, stations, forests, open field, lakes and



Fig. 1: BOB route network [3]

mountains. The travel speed of the train goes from 35 km/h near level crossings up to 140 km/h between Holzkirchen and the suburbs of Munich. The variety of scenarios even increases with the possible relative movements of the car to the train. The different measurements can be divided in dynamic and static scenarios as shown in Table 1. Dynamic measurements were done on roads directly next to the railway track; in this way the car emulates a second moving train. Static measurements supplement the scenarios, either the car parks at interesting positions where the train pass by (e.g. on a bridge or next to a level crossing) or both vehicle velocities are zero (e.g. in a railway station).

Table 1: Traffic scenarios in T2T

Traffic scenario	Description	
Dynamic	Follow	Train and car driving the same speed in same direction
	Opposing	Train and car driving in opposing direction
	Overtaking	Train overtakes the car or vice versa
	Approach	Train close the gap to the car or vice versa
Static	Pass	Train pass the parked car
	Station	Train and car stop in station

The different scenarios were combined with different environmental aspects as mentioned before. Under consideration of local restrictions and private property

along the railway track, 18 different measurement scenarios were investigated in 20 measurement runs.

2.3 Measurement Setup



Fig. 2: T2T measurement setup: Rx on the car in the foreground and Tx on the train in the background

The measurement setup included two T2T links, ITS-G5 and RCAS and a spectrum analyzer on the receiver side in the car. For all measurements and both T2T links, the train was set as transmitter and the car as receiver as shown in Figure 2. In detail, we set up one Cohda box as transmitter in the train with a multi-band antenna, including a GNSS antenna and two 5.9 GHz antennas. This antenna was mounted outside of the train on the highest possible point which ensured horizontal transmission. A second Cohda box and antenna were installed in the car as receiver. The Cohda MK5 enclosure offers two independent integrated radios, which were used for different settings as mentioned in Table 2. The transmit power at the Cohda box met the lower bound of the ITS-G5 standard Equivalent Isotropically Radiated Power (EIRP) requirements. Both modules logged the transmitted and received packets. At the train side the Cohda box logged the information of each sent package with a sequential number. The packet information included the GNSS position and time stamp of the train, packet size, modulation and data rate information. At the receiver side in the car, each received packet was analyzed and logged. Next to the received information a time stamp and the GNSS information of the Rx module, the speed of the car, the received power and the sensitivity of both radios were logged.

The spectrum analyzer was realized with a software defined radio in the car. The transmitted ITS-G5 signal was received with a separate 5.9 GHz antenna and feed to an Ettus USRP N210 [1]. The spectrum was analyzed at 5.9 GHz with 25 MHz bandwidth for the signal transmitted in channel 180.

The RCAS units and the corresponding antennas and power supply were installed in the train and the car. This system provided detailed information

Table 2: Cohda MK5 radio settings

Radio	A	B
Channel	180	176
Carrier frequency	5.9 GHz	5.88 GHz
Bandwidth	10 MHz	10 MHz
Transmit power	21 dBm, 24 dBm	21 dBm, 24 dBm
Data rate	6 Mbit/s	3 Mbit/s
Modulation	QPSK	BPSK
Coding rate	1/2	1/2
Packet length	150, 400 Byte	150, 400 Byte
Repetition time	100 Hz	100 Hz

about the train and car position, direction and speed. This was necessary for precise coordination and timing of the measurement campaign. The RCAS system operates with Terrestrial Trunked Radio (TETRA) at 470 MHz with 25 kHz bandwidth and 10 W EIRP.

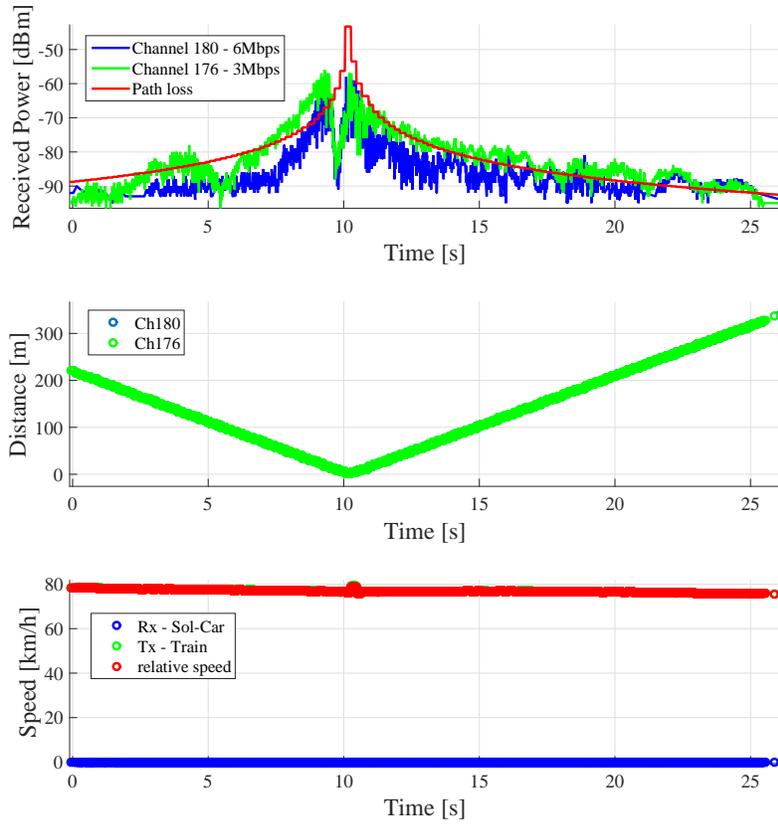
3 Data Analysis

The following analysis is based on the data of the Rx Cohda box. As mentioned before, all required information was logged on the box in the car.

3.1 Scenarios

Out of the different measured scenarios as described in Section 2.2, three of them are pointed out and the recorded data and evaluated characteristics over time are shown. In Figure 3a, 4a, 5a the first chart shows the measured received power and the path loss in Line of Sight (LOS) condition calculated with Equation 1, the second chart shows the distance between Tx and Rx and the last one the speed of the train and the car, as well as the relative speed over the measurement time. Figure 3b, 4b, 5b show a snapshot during each measurement. All three measurements were done with an output power $P_{Tx} = 21$ dBm.

The first scenario represents a train passing a stopped vehicle with a certain speed. Therefore, the car was parked on a cross bridge as shown in 3b (on the picture the train is approaching) and the train passed by with 80 km/h (see 3a bottom chart). The different power level of arrival and departure is caused by the trees marked with a yellow circle. The dense tree marked with a red circle causes

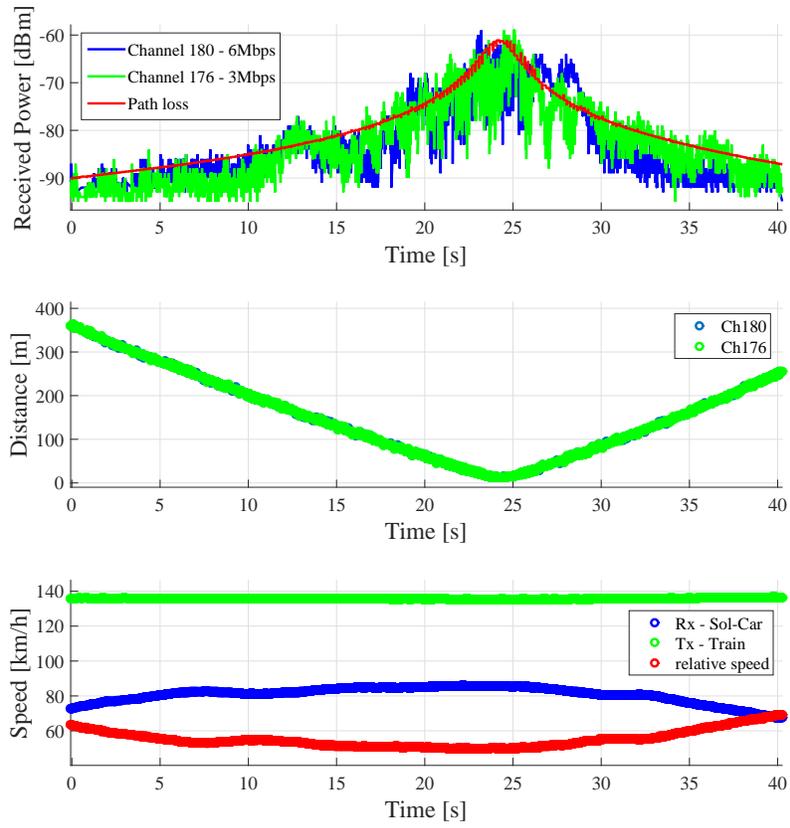


(a) Data



(b) Train passing the car parked on a bridge

Fig. 3: Measurement of a passing train

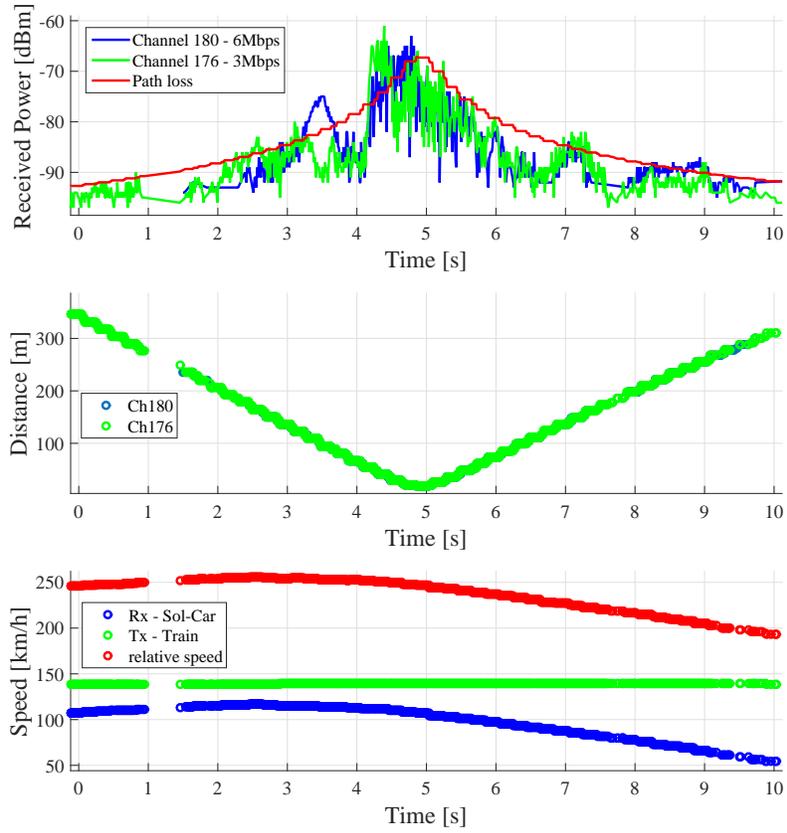


(a) Data



(b) Overtaking maneuver in a forest

Fig. 4: Overtaking measurement



(a) Data



(b) Car and train opposing each other in a village environment

Fig. 5: Opposing measurement

the fading between 5 and 6 seconds. The fading at around $t = 10$ s is caused by the bridge itself when the transmitter is passing under the bridge and car. For the departure ($t > 10$ s) the maximum coverage reaches around 350 m.

The second measurement setup shown in Figure 4 evaluates a train overtaking another one. The car is driving with approximately 80 km/h and was overtaken by the train with 140 km/h. On Picture 4b the 470 MHz TETRA antenna, the 5.9 GHz dipole antenna and the white radome including both 5.9 GHz antennas and the GNSS antenna are visible. Left and right of the track was dense forest. The observed fading is caused by the forest environment. The different height of the used vehicles causes variations in antenna gain depending on the position of the vehicles to each other.

A train opposing the car is the last setup shown in Figure 5. The relative speed of around 250 km/h results from approximately 108 km/h of the car and 142 km/h of the train. The small tree on the left, between the road and the track causes several not negligible fades at 1, 4, 6.5 and 7.5 seconds. By accident, this tree marked with a red circle in Figure 5b was several times in the LOS because of the opposing movement. Out of all scenarios coverage can be achieved for different settings as mentioned in the next section.

3.2 Coverage

Due to the way of today's train operation, the distances between trains and with it the related distance between two or more mobile users in a T2T network is usually several kilometers. In Figure 6, the received power and theoretical path loss over the distance are shown. In detail, the average power per distance for radio A (Ch 180) and radio B (Ch 176) is shown for each channel and also separated for 150 byte and 400 byte long packets. Equation 1 describes the power in dB at the receiver entrance (P_{Rx}) resulting from the transmitter power plus the antenna gain (G_{Tx}, G_{Rx}), minus all losses including the cable losses (L_{cable}), the connector losses ($L_{connectors}$) and free space loss.

For an output power of $P_{Tx} = 21$ dBm the maximum coverage is around 400 m as shown in Figure 6a. In Figure 6b, the cut-off distance for $P_{Tx} = 24$ dBm is clearly visible at 600 m. The maximum allowed EIRP for ITS-G5 is 33 dBm. Hence, by an increase of 9 dB at the transmitter output power and path loss exponents for LOS equals to 2 and for non-LOS equals to 4 as used in [2] the theoretical coverage quadruple for LOS and double for non-LOS. This leads to an estimated coverage up to 2400 m for LOS and 1200 m for non-LOS conditions. Comparing the two different radios, radio B is showing a better performance. This results from the lower data rate and with it a more robust connection. Differences between 400 and 150 byte long packets are negligible for coverage.

$$\begin{aligned}
 P_{Rx} = & P_{Tx} - L_{cable} - L_{connectors} + G_{Tx} \\
 & - 20 \cdot \log_{10}\left(\frac{4\pi r \cdot f}{c}\right) \\
 & + G_{Rx} - L_{cable} - L_{connectors}
 \end{aligned} \tag{1}$$

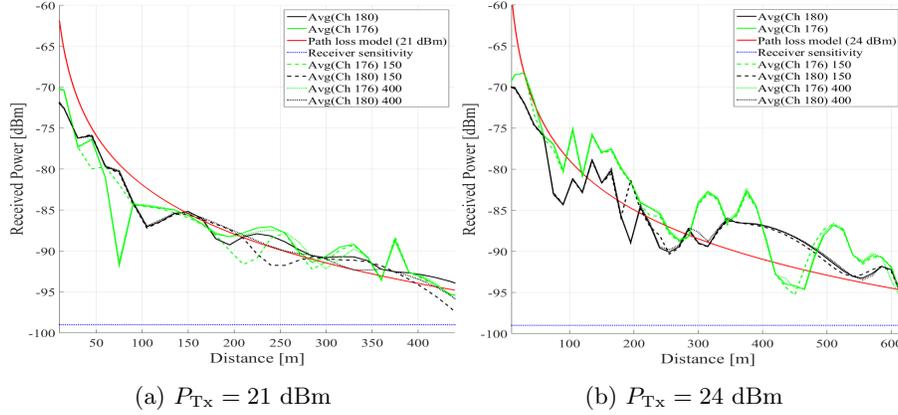


Fig. 6: Received Power over distance

3.3 Line of Sight

The design of a railway track is setup for a desired travel speed of the train. Formerly, tracks in rural areas were influenced by the surroundings like rivers, mountains and villages. Nevertheless, the track design and especially the curve radius is setting the maximum speed. In case of propagation aspects, the curve radius and the track width are setting up a minimum given LOS distance. In Table 3, key values of the track are listed. The recorded GNSS data gives the minimum and maximum values for the curve radius R , the track width d_T and the train speed v in these sections. Out of the measured data the average values were calculated.

The LOS distance (d_{LOS}) can be calculated with Equation 2. This calculation describes the worst case scenario: a curved track with obstacles next to the track e.g. buildings or trees. The maximum available coverage could be assumed as a combination of the LOS and the non-LOS component.

The braking distance of a vehicle d_B can be calculated from the measured speed, the maximum allowed acceleration for trains ($a_{max} = 1.5 \text{ m s}^{-2}$). One part counting in the system delay τ_{sys} is added to Equation 3. One possible application of ITS-G5 in railways could be the communication within a platoon of virtual coupled trains. For a stable drive of the platoon, the coverage of the communication can be less than the braking distance of one consist but large enough to cover the whole platoon including the system delays.

$$d_{LOS} = 2 \cdot \sqrt{R^2 - \left(R - \frac{d_T}{2}\right)^2} \quad (2)$$

$$d_B = \frac{v^2}{2 \cdot a_{max}} + \tau_{sys} \cdot v \quad (3)$$

Table 3: Track analysis

	R [m]	d_T [m]	v [km/h]	d_B [m]	d_{LOS} [m]
min	124	8	35	31	63
avg	400	12	73	137	138
max	2000	20	140	504	400

3.4 Update Delay

For most communication applications the throughput is a key indicator, for safety relevant systems the delay between two consecutive received messages from Tx at Rx is more significant. This value is defined as the update delay of a system as presented in [7]. In T2T communications the update delay represents a quality measure for up to date traffic information e.g. position, velocity, acceleration or heading. Figure 7 shows the investigated Complementary Cumulative

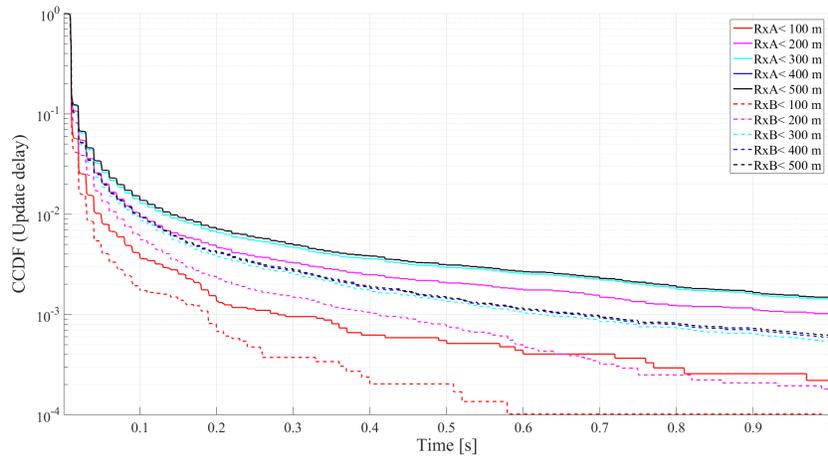


Fig. 7: Update delay for all received packets

Distribution Function (CCDF) of the update delays; the solid series of curves represents radio A, the dashed curves radio B. For both radios, the CCDF of the update delay is investigated for packages received within different coverages from 100 m to 500 m. In general, the update delay probability lowers for shorter communication ranges due to the higher received power. For example take a delay of 0.5 s for radio B, the CCDF for 200 m is $3 \cdot 10^{-3}$ and for 100 m Figure 7 shows $9 \cdot 10^{-3}$. An increase of the transmit power would have the same effect and would shift the curves down to the left. For this investigation, radio B with

a data rate of 3 Mbit/s shows a better performance within all distances. These results reflect power performances of radio A and radio B as shown in Figure 6.

4 Conclusion

In this paper the measurement results of a novel approach in T2T communications were presented. The performance of ITS-G5 under railway environment was investigated. One train and one car were equipped with ITS-G5 Cohda units and additional measurement equipment and ran on 20 measurements in 3 days. A wide range of different scenarios from urban, sub-urban and rural were investigated. An extract of these measurements was presented in this paper and the performance of ITS-G5 in railway environments investigated.

With these measurements a proper usage of ITS-G5 in a railway environment is proven. For certain applications within a coverage of up to 1200 m this communication standard is able to handle the diverse environments along a rail track. This measurement data will help to investigate new possibilities in T2T communications for non-high-speed trains. Future channel models out of this data will provide a basement for a development of suitable T2T applications in railway environments.

Acknowledgement

The authors are thankful for the cooperation and support of "Bayerische Oberlandbahn" for these measurements. This cooperation lead to a novel collection of data in T2T communications.

References

1. *Ettus USRP N200/N210 Networked Series*, 2014.
2. Andreas Lehner, Cristina Rico Garca, and Thomas Strang. On the Performance of TETRA DMO Short Data Service in Railway VANETs. *Wireless Personal Communication*, 2012.
3. Bayerische-Oberlandbahn GmbH, October 2015.
4. Binghao Chen, Zhangdui Zhong, Bo Ai, De Guan, Ruisi He, and David G. Michelson. Channel characteristics in high-speed railway. *IEEE Vehicular Technology Magazine*, June 2015.
5. David de Haaij. *Cohda Mobility MK5 OBU Enclosure Design Description*, 2014.
6. David de Haaij and Mike Sloman. *Cohda Mobility MK5 Module Datasheet*, 2014.
7. Bernhard Kloiber, CR Garcia, Jérôme Härri, and Thomas Strang. Update delay: A new information-centric metric for a combined communication and application level reliability evaluation of cam based safety applications. *ITS World Congress*, (October):1–9, 2012.
8. Aleksander Sniady and Jose Soler. LTE for Railways - Impact on Performance of ETCS Railway Signaling. *IEEE Vehicular Technology Magazine*, June 2014.