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Characterization of C-Band Train-to-Train Communication for Virtual Train Coupling

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Abstract

In this paper we give an overview of existing vehicle-to-vehicle channel models for the road and railway sector. Published models for the special application of train-to-train (T2T) communications are evaluated. Advantages and disadvantages of different modelling techniques are discussed to create a basis for a future T2T model. Based on the literature research the architecture for a broadband T2T channel model is presented. The model architecture is applied to different environments and the most important objects along the railway lines. A first examination of measurement data collected in the Roll2Rail project is discussed. The focus is on the received signal power, the latency and the influence of the different environments on those two measures. The measured scenarios include the environments station, open terrain, cuttings, walls, and tunnels.

Keywords: virtual coupling, channel model, train-to-train, characteristics, C-Band, communications.

1 Introduction

Virtual coupling of trains is an innovative concept which can significantly increase the capacity of railway networks. It enables coordinated driving of trains at short distances and adds new flexibility in operations. Virtually coupled trains are not being connected via mechanical couplers. Instead, they can move very close to each other in relative breaking distance. In this way trains drastically reduce their headways and increase line capacity. Moreover, the operational practice of coupling two or more passenger trains together over common sections of their respective routes, known as portion working, can be realized very effectively, because coupling times are omitted. In this way, todays heavily occupied routes can be further exploited and the usage of railcars can be optimized, because their operation can be adapted more easily to the changing demand on different sections and at different times.

The distance between the virtually coupled trains shall be controlled through reliable ranging sensors and wireless train-to-train (T2T) communications as illustrated in Figure 1, which provides low latency exchange of position, velocity, braking characteristics and other parameters among the trains. Certainly, this concept requires that potential hazards due to closer distances of trains are mitigated. For the T2T link this means, that requirements will be set on the tolerated latency depending on the situation, i.e. on the margins in distance and braking abilities, in order to guarantee safe operations. The performance of a T2T link varies according to the changing environment, distance, relative speed, channel load or e.g. possible unwanted interference. For developing reliable solutions for this safety critical application, it is therefore essential to understand and appropriately model the propagation conditions.

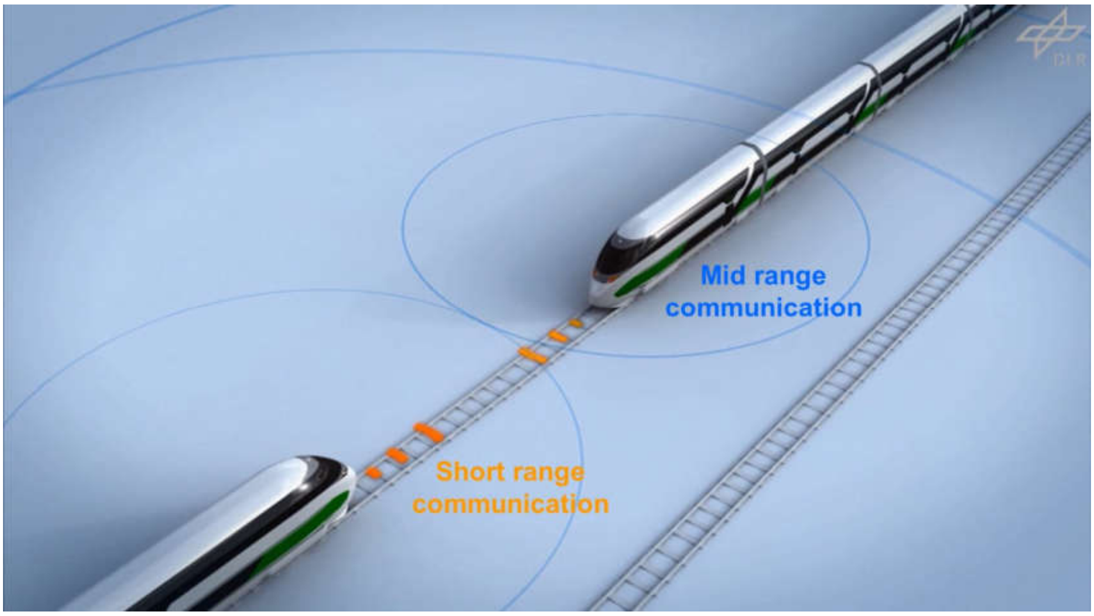

Figure 1: Digitalization of train control enables virtually coupled trains

Wireless communication standards have been gradually evolved with support for new applications, e.g. by introducing direct communication among fast moving nodes. Especially car-to-car (C2C) communication has been investigated in detail over the last years. In comparison, T2T has only been used for a few innovative cases and is hardly examined. However, for T2T communication several existing standards can be applied and new standards are in preparation. Terrestrial Trunked Radio (TETRA) based T2T communication is used for the Railway Collision Avoidance System (RCAS) [1] and investigations on IEEE 802.11p have been conducted in railway environments [2]. Similar, the applicability of the direct mode of LTE-V2X for T2T was investigated in [3]. In the future IEEE 802.11bd and 5G New Radio (5G NR) shall further support T2T applications.

2 Methods

The propagation conditions have a major influence on the performance of any communication system. A profound knowledge of the radio channel is the foundation for further development of existing and for the design of new systems. In the literature we find numerous channel models for C2C communication, but there are specific differences to T2T, e.g. the motion, environment, vehicle size, and antenna position. In road transport, vehicles may freely move between lanes and make sharp turns on intersections, while the movement of trains on the rail is limited and curvatures are usually larger than 100 m. The acceleration is lower, but the absolute speed can be higher for trains than for cars. In both areas the channel models are usually divided into urban, suburban and rural environments. Similar objects such as buildings, noise barriers, masts, signs, bridges, hills, trees or vegetation occur. However, the composition of a particular environment with different objects varies greatly depending on the means of transport.

Deterministic channel models, like e.g. ray-tracing, are based on the solution of the Maxwell equations. Ray-tracing is highly computationally intensive and requires a very high degree of detailed descriptions of the geometry and surroundings. On the other hand, stochastic models describe the propagation properties based on stochastics, not taking geometry into account, thus requiring many different models for different scenarios. Therefore, a suitable T2T channel modelling approach for applications like virtual coupling is a combination of stochastic model and the representation of geometric aspects, which can be realized by a geometry-based stochastic model (GSCM). These models introduced by [4] are suitable for the modelling of spatially and temporally variable channel states with consideration of different environments, geometries and movements. Not only long-lasting statistical properties but also non-stationary effects can be modelled.

GSCMs based on channel measurements are presented in [5] for C2C communication in the motorway environment and in [6] for intersections in the urban environment. In [7] a comprehensive T2G GSCM is presented, taking catenary masts as periodically occurring objects into account, and in [8] forests, hills and buildings as scatterers are added. Compared to the investigations on channel models summarized in [9] and [10] for C2C communication, there are significant gaps in the existing models for T2T communication. As concluded in [11], it was therefore necessary to perform measurements in order to develop adequate C-band channel models for T2T communication.

3 Results

The railway infrastructure and its surroundings must be considered in the T2T model. Therefore, we analysed measurement data collected in the Roll2Rail project on the high-speed line between Naples and Rome. The power delay profile (PDP) was used for initial analyses of the direct or line of sight (LOS) signal and the multipath components (MPCs) coming from surrounding objects. In combination with track maps, satellite images and our measurement data, we could separate four different environments and identify several objects important for wave propagation. The environments included stations, open terrain, cuttings, walls, and tunnels. The different objects occur with varying frequency in the environments mentioned. The result of the analysis is summarized in Table 1.

Environments	Urban
	Sub-urban
	Rural
	Tunnel
Objects	Rails
	Overhead system
	Signaling system
	Walls
	Cross bridge
	Cutting
	Buildings
	Trees

Table 1: Railway environments and surrounding objects.

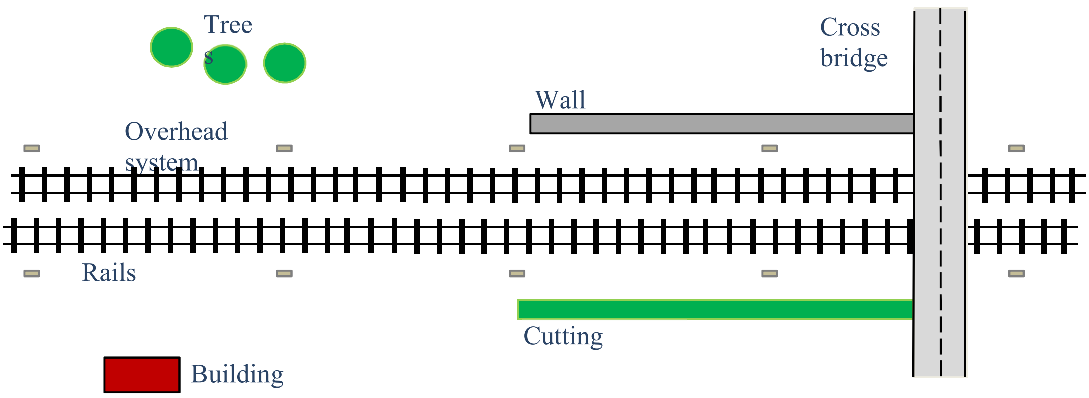

Figure 2: Geometric architecture of the railway environment in rural areas.

The geometric architecture of the railway environment in rural areas is shown in Figure 2. The most common and nearest objects are overhead line masts and signaling equipment. For high-speed lines such as the line between Naples and Rome, the minimum distance between the masts is 60 m. Cuttings in hills, slopes or steep concrete walls may occur close to the line. Further distinctive objects are transverse bridges for road traffic or other railways. Buildings of the infrastructure company are often built a few meters away from the track. Private buildings are often separated from the track system by noise barriers or embankments, or are spatial far from it.

Along the railway lines there is also vegetation; the greatest influence is exerted by large trees or dense forests near the route. The possible influence of the environment on the communication between trains is shown in Figure 3. MPCs can occur due to the objects in the immediate vicinity of the trains. The MPCs arriving at the receiver are superimposed on the direct or LOS signal. Depending on the phase difference of the direct signal or LOS and of the MPCs, different variations of the summed received signal may occur. This directly influences the further processing of the received signal.

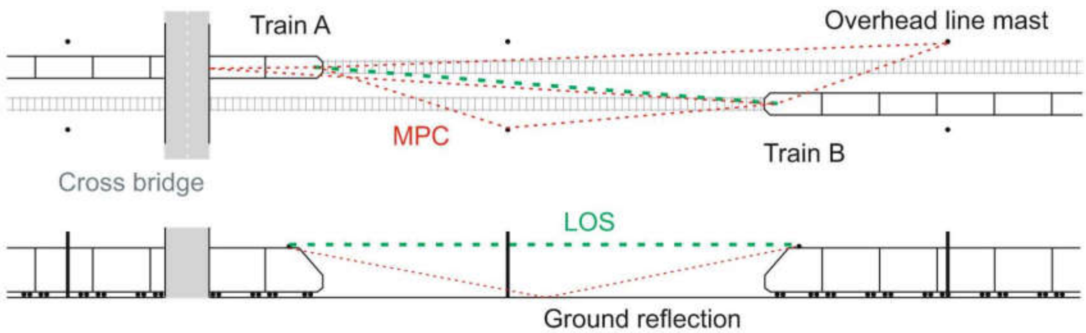

Figure 3: Wave propagation of the LOS and possible MPCs between trains in rural areas.

If the objects responsible for multipath paths are considered in the architecture of the channel model, future communication systems can also be developed, tested and trained on the basis of this model. This means that the resulting communication systems can be developed even more robustly, taking MPCs into account.

4 Conclusions and Contributions

For this paper, a literature search for existing channel models for the road and rail sector was conducted. The evaluation of the published models showed that none of the existing models are suitable for train-to-train (T2T) communication and specifically T2T models for frequencies above 1 GHz are not available. Advantages and disadvantages of different modelling methods were presented and the decision for a geometry-based stochastic model was worked out. Based on the literature research and on measurement data an architecture for a broadband T2T channel model was presented. With this architecture four different environments and the most important objects along railway lines are taken into account.

As a first step towards a channel model, channel sounder measurements were performed in the framework of the Roll2Rail project. For the development of the model within the scope of this paper, the measurement data from the Roll2Rail measurement campaign were processed and analyzed.

Preliminary analysis of the data was carried out. The Power Delay Profile (PDP) can be used to determine received power and latency analysis. Furthermore, the different environments can be clearly identified and reflected signals linked to objects along the railway line. The proposed environments include railway station, open terrain, cuttings, walls and tunnels.

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