Natural wave propagation in subway tunnels at mobile communications frequencies

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Abstract— A measurement campaign has been carried out in the Berlin subway to characterize EM-wave propagation in underground railroad tunnels. The received power levels at 945MHz and 1853.4MHz are used to evaluate the attenuation and the fading characteristics in a curved, arched-shaped tunnel. The measurements are compared to ray-optical modelling results. It is shown that the geometry of a tunnel, especially the cross-sectional shape and the course, is of major impact on the propagation behaviour and thus on the accuracy of the modelling.

I. Introduction

In order to characterize wave propagation in underground railroad tunnels in the GSM900 and GSM1800 frequency bands, a measurement campaign was carried out in the Berlin subway. Three tunnels of different shape, length, and building materials are investigated. Furthermore, different transmitting antenna positions are analysed. The received power levels at 945MHz and 1853.4MHz are used to evaluate the attenuation and the fading characteristics of the different constellations and environments.

For the simulations, a ray-optical modelling approach, based on stochastic ray launching with ray density normalization (RDN) is used [1]. This method allows simulating wave propagation of high frequency EM-waves in arbitrarily shaped tunnels. The geometry of the tunnel cross-sections, the course of the tunnels, building materials, as well as the positions, velocities and directional patterns of the transmitting and receiving antennas are taken into account by the simulation approach.

II. Measurement setup and procedure

A. Measurement equipment

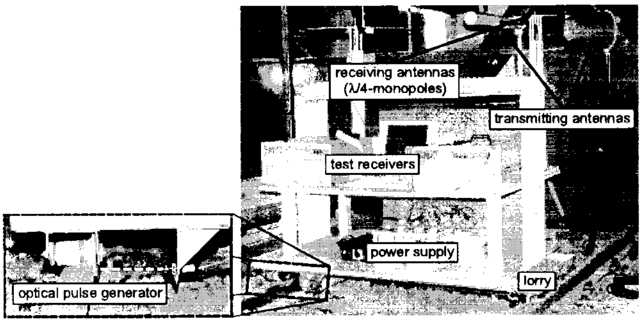

Fig. 1. Measurement setup with transmitting antennas and receiving equipment mounted on a lorry with an optical pulse generator

The measurements were performed using a Ballmann STX-GSM 2 GSM900 test transmitter, a Rhode&Schwarz SME 23 GSM1800 test transmitter, and two Rhode&Schwarz extended test receivers ESVD for digital mobile radio networks. The transmitters generated two harmonic signals at $f_{GSM} = 945$MHz and $f_{DCS} = 1853.4$MHz, respectively. The intermediate frequency (IF) measurement bandwidth was 10kHz. For the GSM900 band, a log-periodic (LogPer), vertically polarized transmitting antenna with 12dBi gain was used (Kathrein K73226), whereas for the GSM1800 band, a wide-band Yagi antenna with 17dBi gain (Jaybeam J7360) was employed. Both are standard antennas for the deployment in tunnel environments. As receiving antennas, two $\lambda/4$-monopoles were chosen due to their omnidirectional antenna patterns. The battery-driven receivers were mounted on a lorry which was manually pulled through the tunnels at an average speed of 1.5m/s. The measurements were recorded approximately every 30cm, where each measured value corresponds to the averaged received signal during a 10ms time interval. The actual measurement location was retrieved with a pulse-generator coupled to the wheels of the lorry (cf. Fig. 1). Each measurement was run and recorded twice in order to determine the time variance of the transmission channel. Furthermore, the two corresponding measurements were compared and aligned to each other to ensure a reasonable precision in the absolute location of the measured values. This was necessary due to the imprecise performance of the pulse generator, which provided an impulse approximately every 17.9cm with a precision of ± 0.5cm. The positions of the transmitting antennas were varied for each measurement. The receiving monopoles were fixed on the lorry at a height of $h_R = 1.47$m above the rails.

The measured path loss has been deduced from the ratio of the measured received power to the input power of the transmitting antennas, including the antennas characteristics. The attenuation of the connecting cables was taken into account, and an additional 1.5dB loss was assumed for any kind of mismatch in both the receiving and transmitting branches. The simulated path loss also includes the antenna characteristics.

B. Measurement environment

For the following exemplary analyses, a curved arched, single-lane tunnel is used (subway U8 between "Karl-Bonhoeffer-Nervenlinik" and "Rathaus Rein-