A Hybrid Propagation Modeling Technique for Complex Railway Environments

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A prerequisite for the deployment of a rail signaling system is the existence of a suitable propagation model that can guide the distribution of signaling transponders. Despite the long history of tunnel propagation modeling, the established practice for the development of such models is the exhaustive radio survey of the railway line. With the rapid expansion of high-speed rail and its ever increasing incorporation into urban transportation networks, radio surveys along tens to hundreds of kilometers become necessary, consuming a substantial amount of resources. More importantly, since any new rail signaling technology needs to undergo thorough radio survey prior to deployment (with no guarantee of success), its development becomes a high cost and high-risk endeavor for service providers, effectively discouraging the application of emerging wireless technologies, such as cognitive radio, to rail signaling.

The apparent contradiction between the fact that tunnel propagation is well understood, yet its models are not practically used, can be explained by realizing the safety critical character of rail signaling in conjunction with the nature of tunnel propagation research that has been conducted so far. In particular, waveguide tunnel models (D. G. Dudley et al., IEEE Antennas and Propagat. Mag., vol. 49, no. 2, Apr. 2007) can nicely illustrate the qualitative characteristics of wave propagation in tunnels. Yet, they are hardly applicable to the actual geometries, which typically include features that cannot be easily embedded in the simplistic framework of a waveguide model.

Since waveguide mode solvers attain unparalleled efficiency, as they are analytical in nature, this work is aimed at enhancing their accuracy in realistic tunnel propagation scenarios. To that end, we propose to combine the accuracy of a 2.5-D high-order finite-difference analysis of guided-wave modes in realistic tunnel cross-sections, with the efficiency of waveguide mode analysis based on *numerically* extracted modes. This analysis can be performed for both straight and curved tunnels through a coordinate transformation. Statistically variable geometric features will be accounted for via an adaptive stochastic collocation technique. Hence, a new stochastic guided-mode FDTD solver will be formulated, aimed at the determination of the propagation constant as a random variable, due to the uncertainty in parameters such as wall dielectric constant, conductivity and roughness. Subsequently, these modes can be used to efficiently determine path loss over long distances in uniform, yet complex tunnel geometries.