From Physics-Based Propagation Modeling to Network Design for Train Communication Systems in Tunnels

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Communications-Based Train Control (CBTC) is a wireless technology aimed at replacing conventional rail signalling with train control enabled by wireless communication between the train and a network of access points.

Presently, the development of CBTC systems proceeds in several independent stages. First, extensive measurements are performed for the radio-frequency (RF) survey of the propagation channel, which is used to determine the placement of CBTC access points. In a second stage, after the placement of access points, another round of measurements is taken, this time evaluating the signal strengths of access points at each location. The purpose of the latter measurements is to evaluate if available handover algorithms (whereby a communication failure between the train and the CBTC access points is dealt with by identifying alternative communication paths through other co-existing wireless networks, such as LTE) meet the system requirements with regards to system availability and resilience to partial system failures.

This process suffers from multiple drawbacks: random fluctuations of wireless channel conditions, due to fading, interference, and network usage, are only accounted for in the second stage, that is, after the access points have been placed, and are not accounted for when placing access points. Vice versa, drastic state changes of the propagation environment, e.g., entering or leaving a tunnel, are not provided to the network-level handover algorithms, and must be re-discovered by online measurements of the received signal strength or other channel indicators.

In this paper, we overcome the virtual separation of network design and operation along disciplinary boundaries by bridging the gap between the output of current propagation models and channel characterizations that for network protocol design. We directly couple a network simulator with a ray-tracing based propagation modeling package, whose accuracy has been extensively validated against measurements in subway tunnel environments. Subsequently, instead of approximate or empirical channel models, the network simulator is directly informed by the ray-tracer about the node-to-node channel transfer functions. The positive impact of using high fidelity, physics-based propagation models at the network simulation level is evaluated through case studies of realistic CBTC network topologies.