Stochastic Characterization of Wave Propagation in Mine Environments

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Wireless communication systems are key to ensuring mine safety as they have the potential to continue operating during catastrophic events when wired communication systems fail (Miner Act 2006). The design of wireless communication systems for mine environments requires simulation tools capable of analyzing electromagnetic wave propagation through electrically large mine tunnels and galleries. Ideally, these tools should account for the presence of miners, mining equipment, trolleys, and rails, as well as the roughness on the walls. Furthermore, they must yield statistical information of certain observables (e.g., probability distribution function (pdf) of received power) required for wireless channel design, given uncertainty in mine geometry and the position and shape of obstacles, material and wall roughness properties, and transmitter and receiver locations.

In this work, an efficient stochastic electromagnetic simulation framework that addresses the above challenge is proposed. The proposed framework hybridizes (i) a deterministic electromagnetic simulator for modeling wave propagation in mine environments (Bakır et al., USNC/URSI National Radio Sci. Meet., 2009) with (ii) a stochastic collocation (SC) method (Yücel et al., USNC/URSI National Radio Sci. Meet., 2009) to extract pertinent statistical data. The SC method approximates the observable using a generalized polynomial chaos expansion (gPC) (D. Xiu, *Commun. Comput. Phys.*, 2(2), 2007, pp. 293-309) (viz. orthogonal polynomials spanning the entire random domain). The coefficients of the gPC expansion are determined by computing inner products on a sparse grid constructed using the Smolyak algorithm. At integration (collocation) points, the deterministic electromagnetic simulator is executed to compute the exact value of the observable. Therefore, this method is non-intrusive and straightforward to implement. The approximate observable values obtained from the resulting gPC expansions are then used to replace the actual observable evaluations (i.e. the costly deterministic simulations) when extracting observable pdfs via Monte Carlo methods.

The scheme's applicability will be demonstrated through the simulation of some wireless communication links working at 900 MHz (IEEE 802.15.4 standard) and 2.4 GHz (IEEE 802.11 standard) located inside electrically long mine tunnels and galleries. In these simulations path loss in the mine environment will be studied to find the best statistical distribution (e.g. Rice, Rayleigh and lognormal) to model fading in the communication channel. Statistical studies of coverage and range of wireless access points will also be presented.