A Fast-Multipole Domain Decomposition Integral Equation Solver for Characterizing Electromagnetic Wave Propagation in Mine Environments

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Reliable and effective wireless communication and tracking systems in mine environments are key to ensure miners' productivity and safety during routine operations and catastrophic events. The design of such systems greatly benefits from simulation tools capable of analyzing electromagnetic (EM) wave propagation in long mine tunnels and large mine galleries. Existing simulation tools for analyzing EM wave propagation in such environments employ modal decompositions (Emslie et. al., *IEEE Trans. Antennas Propag.*, 23, 192-205, 1975), ray-tracing techniques (Zhang, *IEEE Tran. Vehic. Tech.*, 5, 1308-1314, 2003), and full wave methods. Modal approaches and ray-tracing techniques cannot accurately account for the presence of miners and their equipments, as well as wall roughness (especially when the latter is comparable to the wavelength). Full-wave methods do not suffer from such restrictions but require prohibitively large computational resources. To partially alleviate this computational burden, a 2D integral equation-based domain decomposition technique has recently been proposed (Bakir et. al., in *Proc. IEEE Int. Symp. AP-S*, 1-2, 8-14 July 2012).

In this work, the above-referenced 2D solver is extended to 3D, resulting in the first-ever full wave solver capable of analyzing large-scale and realistically loaded mine environments. Just like its 2D counterpart, the scheme divides long mine tunnels into short sections (subdomains) and separately characterizes EM wave propagation in each of them. To accommodate the characterization of tunnel sections tens to hundreds of wavelengths long, the 3D scheme uses a parallel surface integral equation solver accelerated by both fast multipole and fast Fourier transform methods (Taboada et. al., *IEEE Antennas Propag. Mag.*, 51(6), 20-28, 2009). To obtain a global inter-domain solution, the scheme introduces equivalent surface currents on the air interfaces between subdomains; these currents derive from modal solutions for an unperturbed waveguide and constitute a reduced basis sets for characterizing EM wave propagation throughout the long tunnel. The method's efficiency and applicability will be demonstrated via the simulation of communication links inside realistic mine tunnels.