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Title: Full-Wave Electromagnetic Simulator for Statistical Characterization, Optimal Deployment, and On-the-Fly Reconfiguration of Wireless and Through-the-Earth Communication and Tracking Systems

Organization: University of Michigan

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Partnerships: Office of Mine Safety and Health Research (OMSHR), National Institute for Occupational Safety and Health (NIOSH)

Focus Area: Mine Escape, Rescue, and Training
Topical Area: Communications and Tracking

Problem Statement and Justification: Reliable wireless communication, sensing, and tracking systems for underground mine tunnels/galleries play a vital role in ensuring miners' safety and operational effectiveness during daily routine and catastrophic events. The 2006 MINER Act requires operators to implement wireless communication systems capable of surviving disasters and supporting two-way post-event communication and tracking functions. The design, deployment, and post-event reconfiguration of such systems would greatly benefit from electromagnetic (EM) simulators for characterizing wave propagation in mine tunnels and galleries occupied by miners and equipment and possibly obstructed by debris from a cave-in. Unfortunately, present EM simulation techniques are not up to this task as they fail to capture the complexity of wave propagation in such real-world mine environments. Moreover, they do not provide statistics/uncertainty quantification (UQ) of key observables (e.g., the probability density function (PDF) of received signals). Current simulators cannot produce site-specific quantitative data that aids in the design of these systems and/or their on-the-fly reconfiguration when disaster strikes, forcing system designers to rely on expensive experimental deployment procedures and to overdesign systems.

Impact of the Research: The objective of the proposed research is to develop a new computational framework that leverages a novel full wave EM simulator in concert with modern UQ techniques to produce qualitative insights and actionable quantitative data to aid in the design, deployment, and post-event reconfiguration of wireless and Through the Earth (TTE) communication and tracking systems customized to specific mine environments. The proposed framework will aid mine operators and designers of wireless and TTE communication and tracking systems to: (i) determine survivability thresholds and assessment metrics for communication and tracking systems; (ii) evaluate signal path transmission loss and noise interference in communication technologies, including through-the-earth communication devices; and (iii) assess the coverage capability, quality of service and accuracy of current communication and tracking technologies.

Objectives and Research Approach: The above stated objective will be attained via a four-pronged approach: (i) Development of a fast multipole method - fast Fourier transform based EM simulation + UQ framework that incorporates domain/Tucker decompositions, impedance and resistive boundary conditions and Karhunen-Loeve expansions to deal with the most general mine layouts and configurations; (ii) Extensive verification and validation of the framework by comparison with measurements obtained from our OMSHR partners and other entities, as well as published data; (iii) Application of the EM+UQ framework to statistically characterize numerous systems, ranging from leaky feeder networks (VHF - UHF) replete with amplifiers and repeaters, TTE systems composed of surface or buried loops (VLF), medium frequency (MF) radio systems, various wireless mesh network (WMN) systems utilizing IEEE 802.11b (2.4 GHz) and 802.15.4 (900 MHz) protocols, as well as ultra-wide band (UWB) radios (during normal mine operations as well as post-event); and (iv) Evaluation of the framework's promise in lowering the cost of deploying wireless systems and enhancing mine safety through optimal system design and reconfiguration.