Investigation of Electromagnetic Wave Propagation for In-Body to On-Body Wireless Communications

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In recent years, in-body to on-body (IB2OB) wireless communication systems have become increasingly popular in biomedical and healthcare industries. Specifically, implanted and ingested sensors can collect real-time biological information, including glucose levels, heart activity, and tumor growth, and transmit to wearable on-body devices for monitoring purposes. Because human tissue properties cause high path losses and complicate electromagnetic (EM) wave propagation, designing power-efficient IB2OB communication systems first requires a comprehensive understanding of EM wave propagation inside and around the human body.

Previous studies have been focusing on either on-body or in-body wireless propagation channels. Alves *et al.* (Alves, et. al., IEEE Trans. On Antennas and Propagation, vol. 59, no. 4, pp. 1269-1274, April 2011) derive a simple path gain model for creeping waves excited by on-body transmitters. El-Saboni *et. al.* (El-Saboni, *et. al.*, IEEE 14th International Conference on Wearable and Implantable Body Sensor Networks (BSN), May 2017) characterize EM wave propagation inside and around the body by analyzing electric field distributions and path losses of in-body to in-body and on-body to on-body communication channels using three-layer cylindrical models. Floor *et. al.* (Floor, *et. al.*, IEEE Journal of Biomedical and Health Informatics, vol. 19, no. 3, May 2015) develop an IB2OB path loss model along a direct path using measured data from a living porcine subject. Their results indicate that the path loss inside the body has an overall inverse and linear relationship with antenna depth. Previous studies, however, do not compare propagation losses between in-body line-of-sight (LOS) paths and on-body non-line-of-sight (NLOS) paths. Furthermore, the dominant propagation path for IB2OB systems at ISM frequency bands remains to be identified.

In this study, we first use analytical models to determine theoretical rates of attenuation along direct and creeping wave IB2OB paths at 433MHz, 915MHz, and 2.45GHz. Next, half-wavelength dipoles and homogeneous cylindrical models are employed to simulate EM wave propagation and determine IB2OB path losses inside and around the body. The impact of antenna depth, antenna orientation, and insulation thickness on electric field strengths along IB2OB direct and creeping wave paths are carefully examined. Finally, we compare the results of these studies to full-wave, realistic human phantom simulations as well as experiments.