Large-Scale Electromagnetic Characterization of Urban MIMO Communication Systems

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Multiple-input multiple-output (MIMO) wireless communication systems are of increased interest due to their high spectral efficiency and substantial diversity. Full characterization of the MIMO channel is very important, yet remains a challenge due to the complex electromagnetic interactions between the antenna elements and the environment. We use computational electromagnetics (CEM) to study the performance of MIMO links, and present large-scale simulation results in an outdoor urban environment. We examine the impact of the location of the antenna array in the environment, the average received power, and the angle spread on the average mutual information (AMI) of the MIMO channel. We find that locations closer to the base transceiver station (BTS) correspond to higher AMI, especially when these locations receive line-of-sight (LOS) rays. However, if perfect transmit power control is used, MIMO systems have higher capacity in non-line-of-sight (NLOS) regions due to increased spatial modes in the channel.

Our approach combines two different CEM techniques for the modeling of electromagnetic interactions: the Method of Moments (MoM) and Electromagnetic Ray Tracing (ERT). Combining both the near-field interaction of the array structures and the far-field propagation channel requires a hybrid approach of both ERT and MoM. MoM is used to model the near-field interaction among the array elements, while the far-field interaction between the antenna array and the environment is modeled by ERT. This is important because it allows us to isolate the influence of both near-field and far-field propagation parameters in AMI computations.

In Fig. 1(a) we plot the AMI for a 7 x 7 MIMO system making use of uniform circular antenna arrays in a center-excited urban microcell at 1.8 GHz as a function of position throughout the streets of a computer model corresponding to Austin, Texas. AMI is highest near the BTS and decays as a function of distance from the BTS. Locations close to the BTS have higher signal strength due to the limited path-loss, hence receive a larger capacity than positions further away from the BTS. In Fig. 1(b), we remove the effect of path-loss on AMI. Comparing with Fig. 1(a), we detect that there is an inverse trend with respect to LOS rays. Locations with NLOS rays seem to have AMI that is higher than those with LOS. In particular, there is a hotspot that appears in the upper area of Fig. 1(b) which corresponds to a group of tall buildings within the same proximity to the MTS. Our expectation is that this hub of tall buildings causes more diffractions, as well as a larger variation in the angle spread and therefore contributes to high AMI.

Figure 1 – AMI as a Function of Mobile Position for a Center Excited 7x7 MIMO System (A) With and (B) Without Path Loss Effects

Additional Information:

(1) Commission and Session Topic for Paper – C8-MIMO Antenna Systems

(2) New Knowledge Contributed by Paper – This paper makes a unique contribution by linking both near-field and far-field propagation effects to information theoretic measures of MIMO system capacity in a dense urban environment.

(3) Relationship of this Work to Previous Work – Previous work using computational electromagnetics for MIMO system study primarily only uses electromagnetic ray tracing to model far-field propagation effects. Near-field effects were not considered and primarily indoor environments were studied. Since there is the natural dependence in MIMO antenna systems on mutual coupling effects, this work considers method of moment modeling to additionally consider near-field phenomena. Further, since MIMO systems will be extensively deployed in outdoor environments, this work examines the important urban propagation environment where diffraction plays a significant role in coverage and capacity.