Theoretical Impact of Continuous MIMO Antenna Arrays on Degrees of Freedom

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Abstract—Electromagnetic information technology (EMIT) is a novel communication technology that exploits electromagnetic waves, large multiple-antenna systems, network architectures, and higher frequency bands to achieve high data rates, reliability, coverage, and traffic demands in future wireless communication networks. One of the key challenges in EMIT is to analyze the degrees of freedom (DoF) in multiple-input multiple-output (MIMO) systems, which measure the number of independent data streams that can be transmitted or received. With the push towards mathematically continuous antenna arrays such as continuous aperture MIMO (CAP-MIMO), the theory behind creating higher DoF in a single beam must be examined. This work creates a theoretical model for a near-field EMIT system that uses both discrete and continuous MIMO to observe DoF in the sub-terahertz (sub-THz) frequency range, a promising spectrum for future wireless communications. To further understand DoF, both analytical expressions and the correlation between spatial regions are visualized. Through numerical simulations, the significant impact of electromagnetic fields (EMFs) on hybrid MIMO (HMIMO) systems is observed, affecting both the DoF and signal-to-noise ratio (SNR). The results show that communication performance in line-of-sight (LoS) MIMO systems can be improved by exploiting EMFs. These findings have important implications for the design and optimization of future wireless communication systems.

Keywords— electromagnetic information technology, MIMO, degrees of freedom, sub-terahertz communication, 6G

A hybrid approach that integrates classical and modern mathematical methods, namely Green's functions and channel theory are used to model and analyze the EMIT system. First, Green's function for Maxwell's equations in free space is calculated, using Fourier theory to obtain both the spatial and wavenumber domains solutions for EMIT analysis. Expressing the EM field at all points in space and time as a superposition of the contributions from all possible point sources simplifies the computations in both traditionally complex geometries and boundary conditions. Next, the interaction of the electromagnetic waves with the antenna surface is calculated, using the boundary conditions and the impedance matrix to determine the surface currents and fields. Third, both the wavenumber domain and the spatial domain solutions are combined, using the method of moments (MoM) and Galerkin's method to solve the integral equations for the overall channel equation. The MoM is a numerical method that discretizes the continuous problem into a finite number of unknowns and matches the moments of the true solution with those of the approximate solution. Galerkin's method is useful, because it is a general and flexible method that can handle non-linear and non-homogeneous problems. It also ensures that the approximate solution satisfies the boundary conditions exactly and minimizes the error in least-squares scenarios. Lastly, Green's functions are applied to the EM wave equation, to obtain the EM field distribution in the near-field region and the far-field radiation pattern of the MIMO arrays. Channel theory is also applied to the EM field, to evaluate the channel capacity and SNR of the EMIT system under different scenarios and configurations. These results include the radiation pattern, channel capacity, SNR, and their implications for performance improvement are discussed, showing promise for future design and optimization.

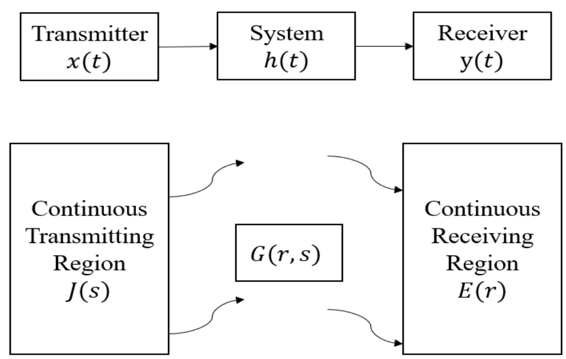

Figure 1: Modeling Channel Capacity and EM Theory in Spatial and Wavenumber Domains

Acknowledgment

This work was supported by the IITP grant funded by the Korea government (MSIT) (2021-0-02208).

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