IoT-Aided Spatial Channel Prediction: Ray Analysis Perspective

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***Abstract*—In this paper, we aim to predict channels in unknown space using Multi-Layer Perceptron (MLP) based on ray tracing dataset. Our approach is compared to classical time-domain spectral analysis in two topologies: without and with obstacles.**

***Index Terms*—channel prediction, ray tracing, Multi-layer perceptron, ray attributes, multipath**

I. SYSTEM MODEL AND APPROACH

In this paper, we focus on performing spatial channel prediction by establishing spatial correlation using channel state information (CSI) obtained from the receivers (Rx). Assume the presence of a single transmitter (Tx) and multiple Rx within a 3D space. Spatial correlation between measured CSIs obtained at the Rx is given by ray tracing to design the channel behavior at unknown locations. **The wireless CSI** $h(t)$ measured at each Rx is a general mathematical description of a time-invariant system that captures the dynamic interaction of signals and can be expressed as $h(t) = \sum_k a_k \delta(t - t_0 - \tau_k)$, where a_k is the complex gain, t_0 is the initial start time of the signal and τ_k is the delay of path k [1], [2].

Our approach is to use MLP to predict ray attributes such as delay at an unknown location based on CSI measurements. Each input is sampled after replacing the $\delta(\cdot)$ with a sinc function to smooth. It contains a CSI value from the Rx and a corresponding delay. During training, the network identifies spatial correlations and dependencies between the input CSI data and delay. Fig. 1 visualizes our approach.

II. SIMULATION

Our focal is the interior setting of an open box-like cuboid that houses a Tx and multiple Rx. This controlled environment allows us to explore signal propagation dynamics through both line-of-sight (LOS) and non-line-of-sight (NLOS) paths. Among all possible paths from Tx to each Rx, we analyze solely the information from the top-3 paths in terms of amplitude. The simulation setup involves two distinct topologies. In the first topology, a Tx is positioned, and 10 × 10 Rxs are arranged, with a horizontal spacing of $2\mathrm{m}$ and a vertical spacing of $5\mathrm{m}$. The other topology, we introduce an additional complexity with a vertically long rectangular obstacle between the Tx and Rx. Then, we adopted conventional spectral analysis, which finds amplitude peaks in the time-domain, as a way to compare the performance of our approach.

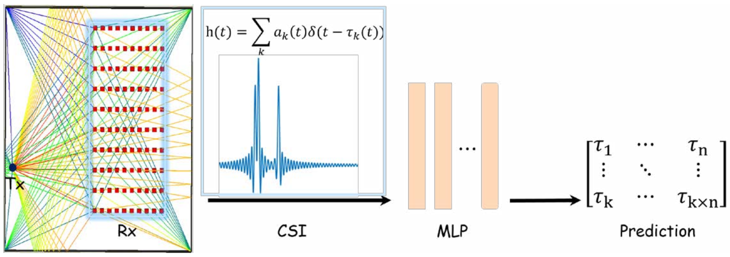
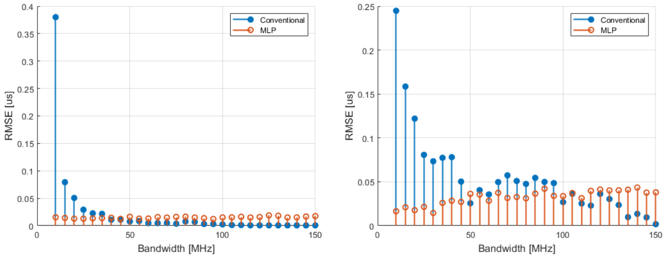


Fig. 1: System model overview: From ray tracing to MLP prediction.



(a) Unobstructed (Topology : 1) (b) Obstructed (Topology : 2)

Fig. 2: Performance metrics based on Bandwidth: MLP vs Conventional spectral analysis

Fig. 2 visually compares loss for two topologies. They show the prediction losses over a range of bandwidths. Fig. 2a shows that MLP outperforms by about 85.8% in the interval from $10\mathrm{MHz}$ to $35\mathrm{MHz}$. On the other hand, in the later bins, the conventional approach outperforms. This is due to the higher signal resolution in the high bandwidth band, which makes it straightforward to distinguish between signals. In a more complex environment, Fig. 2b shows that MLP is about 42.6% more favorable up to $85\mathrm{MHz}$. These results show that the MLP approach is more favorable in scenarios such as IoT where bandwidth is limited.

III. CONCLUSION REMARKS

In this paper, we used MLP to predict ray attributes of unknown spatial channels. We showcased that our approach outperforms a conventional spectral analysis method especially with a limited bandwidth. Due to the complexity of ray tracing, future work will investigate about predicting spatial properties without relying on ray tracing simulations.

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