Multi-Modal Sensing Aided RIS Communications

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Reconfigurable Intelligent Surfaces (RIS) have emerged as one of the key enabling technologies for beyond 5G and 6G networks due to their capability to create virtual line-of-sight (LOS) paths between transmitters and receivers in non-line-of-sight (NLOS) environments. However, to achieve narrow beams and significantly enhanced received power, RIS must incorporate a large number of elements. This, in turn, presents a challenge due to the substantial beam training overhead required for optimal beam selection, particularly when dealing with larger RIS arrays. In this work, we propose a novel approach that leverages multi-modal sensing data to guide the beam selection process in RIS, especially in mobile environments where frequent beam alignment is necessary. This approach is motivated by promising results from recent research (G. Charan, T. Osman, A. Hredzak, N. Thawdar and A. Alkhateeb, "Vision-Position Multi-Modal Beam Prediction Using Real Millimeter Wave Datasets," 2022 IEEE Wireless Communications and Networking Conference (WCNC), 2022, pp. 2727-2731; U. Demirhan and A. Alkhateeb, "Radar Aided 6G Beam Prediction: Deep Learning Algorithms and Real-World Demonstration," 2022 IEEE Wireless Communications and Networking Conference (WCNC), 2022, pp. 2655-2660), which demonstrated that multi-modal sensing, combined with machine learning, can effectively extract wireless channel information and map it to optimal mmWave beams in vehicle-to-infrastructure (V2I) communication scenarios. These findings suggest that sensing data from co-located sensors and mmWave systems can significantly reduce the beam training overhead in mmWave communication, with minimal impact on system performance.

We constructed a comprehensive dataset that includes both wireless data, such as the joint RIS-receiver power matrix, and multi-modal sensing data, including vision, position, LiDAR, and radar. The data collection system (the figure to the right) features a co-located RIS prototype with sensing units (360° camera, 3D LiDAR, and four FMCW radars) and mmWave (28 GHz) radios serving as transmitter and receiver. The stationary transmitter directs a fixed beam toward the RIS, while the mobile receiver, mounted on an AGV robot, moves within a grid monitored by a localization system. The RIS prototype is composed of four metasurface tiles, each containing 256 (16×16) independently tunable radiating elements, totaling 1,024 elements.

Data was collected in two scenarios: (i) with a clear LOS between the receiver's phased array and the RIS panel and (ii) with a mobile blockage obstructing the LOS. The camera, LiDAR, and radar sensors continuously streamed data, which was post-processed and synchronized with the joint power matrix. This research aims to use machine learning algorithms to extract features from these sensing modalities, map them to optimal RIS and receiver beams, and develop beam tracking algorithms to predict blockages and enhance beam alignment efficiency.