Realization of Multi-Point Coordinated Beamforming Over Millimeter-Wave Channels with Random Blockage

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SUMMARY Although 5G millimeter-wave (mmWave) communication systems enable high-speed and large-capacity communication [1], [2], the deterioration of communication quality due to path blockage is one of the challenges that should be addressed [3]. This work studies the realization of multipoint coordinated robust beamforming on an experimental platform composed of off-the-shelf computing devices and developed prototypes of hybrid beamformers to overcome inherent instability due to random blockage and verify its performance. Robust beamforming algorithms are implemented on open-source software, OpenAirInterface, which is compliant with 3GPP. The details of the implementation and architecture are presented. Through our experiments, we confirm that user equipment can achieve high throughput stably, even in environments with random blockages.

Keywords: *5G, OpenAirInterface, FPGA, beamforming, mmWave, nano-area*

1. Introduction

Although 5G millimeter-wave (mmWave) communication systems are capable of high-speed communication [1], [2], they are susceptible to obstacles and cause deterioration in communication quality due to path blockage [3]. Therefore, technologies that avoid throughput degradation owing to blockage while maintaining high-speed and large-capacity communication are required [4],[5]. Beamforming plays a key role in compensating for the high path attenuation of mmWaves. Arranging multiple base stations linked to each other, dubbed as coordinated multi-point (CoMP), is also considered as a candidate solution for maintaining high throughput [6]. In this study, we implemented a multi-point coordinated robust beamforming method [7], [8] on a mmWave hybrid beamforming testbed to mitigate the effect of path blockages and evaluated its performance to determine whether user equipment (UE) achieved the required throughput.

2. Experiment

As shown in Fig. 1, our testbed was composed of multiple radio units (RUs) and a common distributed unit (DU) and communicated over mmWave bands to form a “nano-area” that was several tens of meters in diameter [3], [5]. The RUs performed beamforming, while the DU coordinately controlled the beams of all the RUs. In references [7] and [8], beamforming techniques were proposed to minimize the probability that each UE's throughput is below the target rate owing to random blockage. We implemented these beamforming algorithms on our testbed to measure and evaluate their performance.

More specifically, we used a desktop (Intel Core i9-9900K at 3.6 GHz, 64 GB RAM) with an NVIDIA GeForce GTX1660Ti GPU to deploy the DU. An open-source software, *OpenAirInterface* (OAI), was chosen to realize a 5G software stack compliant with 3GPP [11]. Multiple RU-PCs were connected to a common DU via 10 gigabit Ethernet as fronthaul links. Each RU consisted of an off-the-shelf computing device with an Intel Core i5-11400 at 2.6 GHz and 16 GB RAM (RU-PC), an FPGA board of HTG-ZRF8 connected to the RU-PC by an 8-lane PCI Express as a baseband processing unit (BPU), and a 28-GHz hybrid beamformer (HBF) equipped with a planar antenna array as a radio frequency unit (RFU) developed jointly with Tamagawa Electronics Co., Ltd. The BPU inputs an 8-channel intermediate frequency (3.8 GHz) signal to the subsequent RFU as a digital beamforming vector. Each HBF adopts a partially connected hybrid beamforming architecture [9], [10] and radiates vertically polarized waves from a 4 × 8 = 32-element planar antenna array, as shown in Fig. 2. Each UE consists of an off-the-shelf computing device (Intel Core i7-9700K at 3.0 GHz, 16 GB RAM) with OAI installed, a software-defined radio device (USRP N310), an up/down converter, and an omni-antenna.

To realize the robust beamforming in each RU [7], [8], UEs must send 3GPP compliant frequency range 2 (FR2) uplink signals using OAI to RUs. The RUs then send the received 8-channel uplink signals to the DU. In this work, multiple RUs share a local oscillator (LO) and are synchronized by a 1 pps pulse derived from the GPS. The DU performs channel estimation for 3 RUs × 2 UEs × 8 channels using a sounding reference signal (SRS) or demodulation reference signal (DMRS), received from multiple RUs. To allow a DU to process UL signals sent from multiple RUs and perform channel estimation, we extended OAI to handle multiple RUs simultaneously. We also developed a hardware driver that control interfaces between RUs and a DU. The DU calculates the optimum beams via an empirical risk minimization algorithm based on the channel estimation results and shares them with the

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RUs by fronthaul links.

As shown in Fig. 3, we performed signal transmission experiments using two RUs and one UE in an anechoic chamber. In these experiments, OFDM QPSK signals transmitted from RUs were successfully received and demodulated on UE-side using MATLAB software as shown in Fig. 4.

3. Conclusion and Future Works

We presented the implementation of mmWave robust hybrid beamforming algorithms on the open-source 5G software stack, OAI, in our testbed. We performed over-the-air testing using our testbed to evaluate the performance of the robust beamforming. The experimental results proved the feasibility of the robust beamforming and it can achieve stable communications with multiple UEs, even in the mmWave nano-area environment with random blockages. In our presentation, we will demonstrate the detailed architecture of the test bed and further discuss the experimental conditions and results.

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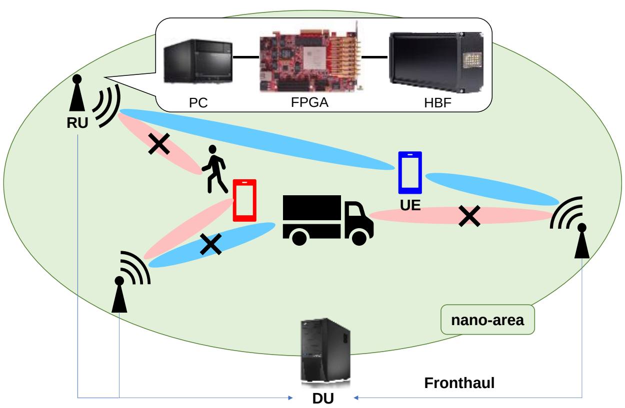

Fig. 1 System model showing two UEs, three RUs, and one DU in a "nano-area". The RUs are connected to the common DU via fronthaul links. Cross marks denote path blockage by obstacles, such as human bodies and vehicles.

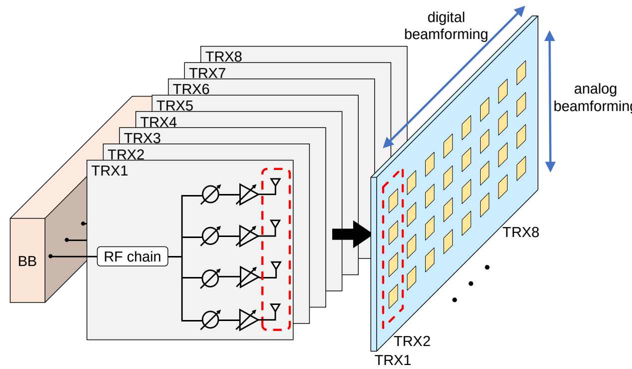

Fig. 2 Configuration of partially-connected hybrid beamforming. The input signal branched into four antennas by an analog circuit is radiated from 32 elements of the planar array antenna with vertically polarized waves. BB denotes baseband processing.

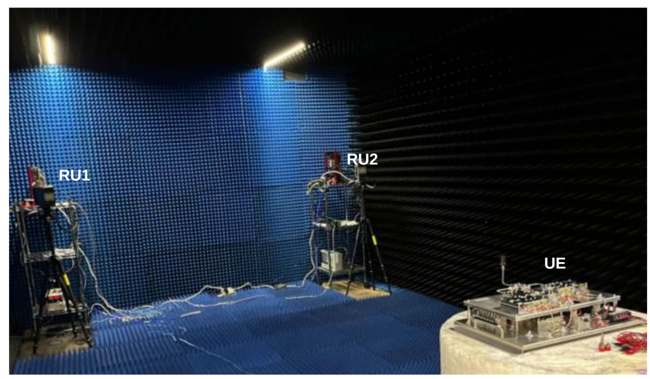

Fig. 3 Experiment using two RUs and one UE in an anechoic chamber.

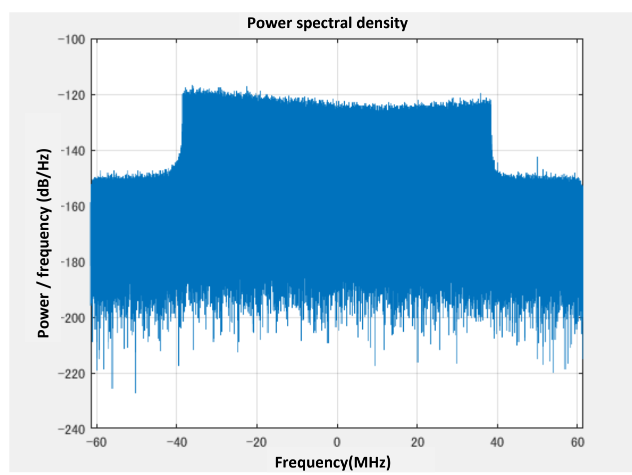

Fig. 4 Experimental result of OFDM signal transmission.

References

[1] T. S. Rappaport *et al.*, "Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!," in IEEE Access, vol. 1, pp. 335-349, 2013, doi: 10.1109/ACCESS.2013.2260813.

[2] W. Roh *et al.*, "Millimeter-wave beamforming as an enabling technology for 5G cellular communications: theoretical feasibility

and prototype results," in IEEE Communications Magazine, vol. 52, no. 2, pp. 106-113, February 2014, doi: 10.1109/MCOM.2014.6736750.

[3] T. Murakami *et al*., "Research Project to Realize Various High-reliability Communications in Advanced 5G Network," 2020 IEEE Wireless Communications and Networking Conference (WCNC), 2020, pp. 1-8, doi: 10.1109/WCNC45663.2020.9120477.

[4] K. Ishibashi, *et al*., "User-Centric Design of Millimeter Wave Communications for Beyond 5G and 6G," in IEICE Transactions on Communications, vol. E105-B, no. 10, Oct. 2022.

[5] Y. Fujii, T. Iye, K. Tsuda and A. Tanibayashi, "A 28 GHz Beamforming Technique for 5G Advanced Communication Systems," 2021 23rd International Conference on Advanced Communication Technology (ICACT), 2021, pp. 96-99, doi: 10.23919/ICACT51234.2021.9370919.

[6] T. Okuyama, N. Nonaka, S. Suyama, Y. Okumura, T. Asai, "Base Station Cooperation Technologies Using 28 GHz-Band Digital Beamforming in High-Mobility Environments," in IEICE Transactions on Communications, vol. E104-B, no. 9, pp. 1009-1016, 2021, doi: 10.1587/transcom.2020FGP0013.

[7] H. Iimori, G. T. F. de Abreu, O. Taghizadeh, R. -A. Stoica, T. Hara and K. Ishibashi, "Stochastic Learning Robust Beamforming for Millimeter-Wave Systems With Path Blockage," in IEEE Wireless Communications Letters, vol. 9, no. 9, pp. 1557-1561, Sept. 2020, doi: 10.1109/LWC.2020.2997366.

[8] H. Iimori, G. T. F. De Abreu, O. Taghizadeh, R. -A. Stoica, T. Hara and K. Ishibashi, "A Stochastic Gradient Descent Approach for Hybrid mmWave Beamforming With Blockage and CSI-Error Robustness," in IEEE Access, vol. 9, pp. 74471-74487, 2021, doi: 10.1109/ACCESS.2021.3079508.

[9] M. Majidzadeh, A. Moilanen, N. Tervo, H. Pennanen, A. Tolli and M. Latva-aho, "Partially connected hybrid beamforming for large antenna arrays in multi-user MISO systems," 2017 IEEE 28th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC), 2017, pp. 1-6, doi: 10.1109/PIMRC.2017.8292390.

[10] X. Song, T. Kühne and G. Caire, "Fully-/Partially-Connected Hybrid Beamforming Architectures for mmWave MU-MIMO," in IEEE Transactions on Wireless Communications, vol. 19, no. 3, pp. 1754-1769, March 2020, doi: 10.1109/TWC.2019.2957227.

[11] OpenAirInterface Software Alliance "OpenAirInterface 5G software alliance for democratising wireless innovation," https://www.openairinterface.org, (accessed July, 2022).