SMWD 2023, KTH Royal Institute of Technology, Stockholm, 23rd - 25th May 2023

Distributed MIMO Testbeds using 1-Bit Radio-over-Fiber Fronthaul

Lise Aabel(1)(2), Frida Olofsson(1), and Husileng Bao(1)
(1) Chalmers University of Technology, Sweden
(2) Ericsson AB, Gothenburg, Sweden

Summary

We present three testbed architectures for distributed MIMO communication with 1-bit radio-over-fiber fronthaul. For sub-6 GHz, we achieve time-division duplex multi-user communication with satisfactory EVM with a star topology, with the possibility to cascade several remote radio heads on a single optical fiber cable. For mmWave, we achieve in the downlink low EVM for a single remote radio head.

1 Introduction

Distributed MIMO promises to meet future network requirements for more uniform coverage, lower latency, and higher reliability. The theoretical field underpinning this statement is well studied, see, e.g., [1]. However, the hardware studies on distributed MIMO are few. The implementation concerns how to make a central unit (CU) support spatial multiplexing via distributed network access points. In the theoretical studies, perfectly synchronized remote access points are generally assumed, but the implementation is nontrivial. A practical solution is to let the CU be responsible for all signal processing, including frequency up- and down-conversion, and relay radio frequency (RF) signals over optical fiber cable between remote radio heads (RRHs) and the CU. Centralized digital processing of RF signals puts high requirements on the digital-to-analog and analog-to-digital converters and the linearity in the optical domain. To minimize the power consumption that comes with high speed sampling, and relax the linearity requirements on the optical components, we consider 1-bit quantization and binary optical transmission.

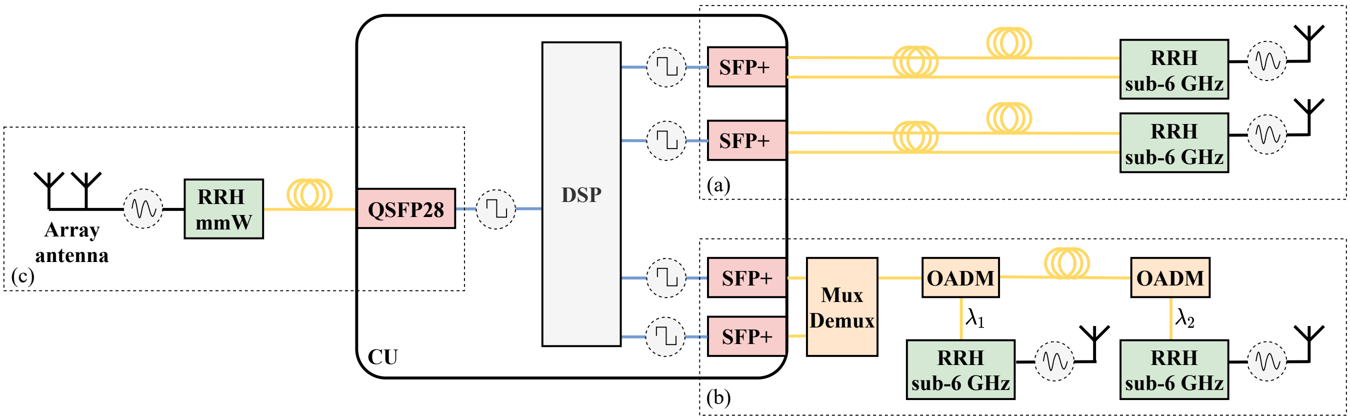

Figure 1. Illustration of three different distributed MIMO architectures, connected to one CU, which is responsible for all digital signal processing (DSP). We display in block (a) two parallel time-division duplex links for sub-6 GHz, in (b) two cascaded links for sub-6 GHz transmission, and in (c) a single link for mmWave transmission. Dashed circles indicates waveforms.

2 Time-division duplex architecture

We describe here the time-division duplex architecture for sub-6 GHz communication illustrated in Fig. 1, block (a). In the downlink, we use bandpass sigma-delta modulation of the RF signal at the CU, and transmit the signal to a RRH via a binary optical waveform. In the uplink, the RF signal is quantized into a binary waveform at the RRH via a comparator. Signal quality is maintained through non-subtractive dithering, which is supplied from the CU to the RRH via the optical fronthaul [3]. In our testbed, one small form-factor pluggable (SFP+) optical transceiver per channel at the CU connects via an uplink and a downlink optical fiber cable to the SFP+ at the RRHs. In the downlink, the electrical output interface of the SFP+ at the RRH is fed to a bandpass filter, followed by a power amplifier, which connects to the antenna port via a switch. In the uplink, the received RF signal at the RRH antenna is fed via the switch to a bandpass filter, followed by a low-noise amplifier, an automatic gain control loop, and passed to the positive differential input port of the SFP+. The dithering signal is fed to the negative differential input port of the SFP+, which quantize the input signals to a binary voltage that modulates the laser.

Our testbed operates at 10 GS/s sampling rate, 2.35 GHz carrier frequency, and supports up to 100 MHz bandwidth. We perform over-the-air reciprocity calibration according to the algorithm described in [2], to enable reciprocity based precoding. For three RRHs and two UEs, we achieve for 5 MHz bandwidth low EVM ($< 7\%$ in the uplink and $< 11\%$ in the downlink) per UE, despite the nonlinearities introduced by 1-bit quantization, due to high oversampling and noise-shaping [4].

3 Cascaded RRHs via wavelength division multiplexing

Distributed MIMO systems are expected to consist of a large number of antennas with widely spread out RRHs. The star topology, shown in Fig. 1, block (a), thus fast becomes impractical and does not promote scalability. We introduce the cascaded architecture for downlink transmission that is illustrated in Fig. 1, block (b). We use in this testbed one optical fiber cable to distribute binary RF signals to several RRHs in series, by using wavelength-division multiplexing (WDM).

At the CU, we use SFP+ optical transceivers of different wavelengths, and connect them to an optical multiplexer, which combines the optical signals into one output. Additionally, each RRH is equipped with an optical add-drop multiplexer (OADM) and an SFP+ dedicated to a single optical frequency. The OADM drops the desired wavelength at the intended RRH and pass on the others. This architecture can be extended to also include uplink communication, by using the same components, but instead use the OADMs to add optical signals and the demultiplexer to separate them. In order to use the cascaded system for distributed MIMO, it is important to minimize crosstalk between the channels in the optical domain.

4 mmWave application

The sub-6 GHz bands are crowded, hence, to increase the throughput, it is necessary to utilize also the mmWave bands (24–100 GHz). Two new problems arise when we increase the carrier frequency in our 1-bit radio-over-fiber architecture: we require higher sampling rates, and we face high pathloss. To reach higher data rate in the optical domain, we use a quad SFP (QSFP28), capable of supporting 100 Gbps by integrating 4×25 Gbps transceiver channels, see Fig. 1, block (c). We use intermediate frequency sigma-delta modulation to send data from the CU to the RRH. The four output signals from the QSFP28 at the RRH are each fed to a quadrature mixer through a $90°$ hybrid, to perform single-sideband frequency upconversion. One local oscillator feeds the four mixers, and the output signals connect to an array antenna.

This architecture enables digital beamforming, which is necessary to compensate for the high pathloss. At 2.2 m over-the-air transmission at 26.2 GHz, we achieve an EVM of 2% for a bandwidth of 130 MHz [5]. Furthermore, the spatial diversity that comes with distributed MIMO will partially relieve the problem of high pathloss, by physical nearness to the UEs. To use this architecture for distributed MIMO, the local oscillators in the RRHs must all be synchronized.

5 Acknowledgements

The work of L. Aabel is funded in part by the Swedish Foundation for Strategic Research under Grant ID19-0036. The work of F. Olofsson is funded by the Swedish Research Council under Grant VR-2019-05174. The work of H. Bao is funded by the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 860023.

References

[1] O. T. Demir, E. Björnson and L. Sanguinetti, *Foundations of user-centric cell-free massive MIMO*, Now Foundations and Trends, 2021.

[2] J. Vieira, F. Rusek, O. Edfors, S. Malkowsky, L. Liu, and F. Tufvesson, "Reciprocity calibration for massive MIMO: Proposal, modeling, and validation," *IEEE Trans. Wireless Commun.*, vol. 16, no. 5, pp. 3042–3056, May 2017.

[3] I. C. Sezgin, L. Aabel, S. Jacobsson, G. Durisi, Z. S. He, C. and C. Fager, "All-digital, radio-over-fiber, communication link architecture for time-division duplex distributed antenna systems," *J. Lightw. Technol.*, vol. 39, no. 9, pp. 2769–2779, May 2021.

[4] L. Aabel, S. Jacobsson, M. Coldrey, F. Olofsson, G. Durisi and C. Fager, "A TDD distributed MIMO testbed using a 1-bit radio-over-fiber fronthaul architecture", submitted to *IEEE Trans. Microw. Theory Technol.*, 2022.

[5] H. Bao, Z. S. He, F. Ponzini and C. Fager, "Demonstration of flexible mmWave digital beamforming transmitter using sigma-delta radio-over-fiber link," *52nd Eur. Microw. Conf. (EuMC)*, Milan, Italy, 2022.