A MMW Coordinate Multi-Point Transmission System for 5G Mobile Fronthaul Networks based on a Polarization-Tracking-Free PDM-RoF Mechanism

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Abstract: A PDM-RoF mechanism is firstly experimentally demonstrated for MMW coordinate multi-point transmission system with a polarization-track-free RAU design. Without additional latency for PDM demultiplexing, we evaluate various coordinate multi-point joint transmission scenarios.

1. Introduction

The coming 5G mobile communications has been expected to provide much faster and stable wireless communication services. One of the promising solutions is applying new radios in millimeter waves (MMW) regime to standalone from those extremely crowded 4G spectra. However, with such high carrier frequency, the MMW radios always suffer from much shorter wireless transmission distances than current wireless ones. Many proposed studies showed that much denser MMW base stations deployments, known as small cells, are inevitable for the wireless services based on these 5G standalone new radios. [1,2] By considering service handovers between base stations as the mobile users travel around various MMW small cells, there may be a spotty mobile service, even blind spots. It is critical that small cells should group up and collaborate with each other to enhance the overall wireless coverage and therefore the mobile service quality. A promising solution to this issue is coordinate multi-point (CoMP), where multiple MMW base stations belonging to the same central unit (CU) or distributed unit (DU) can work together to serve an individual mobile end user. [3,4]

To avoid long latency while still coordinating multiple MMW base stations and further enhancing the overall cost efficiency, radio-over-fiber (RoF) based mobile fronthaul can largely relieve the architecture complexities of the MMW base stations by centralizing all baseband units (BBUs) to mobile CU/DU, where mobile signal controls and managements become much more efficient than ever in such centralized manner. [5,6] In this paper, to further enhance cost efficiencies, we apply polarization division multiplexing (PDM) technology to MMW CoMP transmission system in 5G mobile fronthaul networks for the first time, where Fig. 1 shows the conceptual diagram. With our previous proposed polarization-tracking-free mechanism [7], the PDM demultiplexing can be achieved real-time without referring its counterpart's polarization or feedback tracking polarization manipulation, which implies highly flexible controlling and management for both regular point-to-point and CoMP wireless transmission scenarios. In the experimental demonstrations, we employ two 30-GHz MMW base stations coordinately serve a mobile end user at a 1.6-Gbps traffic capacity through the proposed PDM-RoF mechanism in both point-to-point and CoMP scenarios. The Alamouti space-time block coding (STBC) [8] can be applied without any modification for PDM technology, thus bringing no additional burden to communication latencies. We evaluate various end user spots in the wireless coverages, and the results show that the CoMP has the best and the smoothest mobile service quality even when we locate the end user at the edges between two MMW base stations.

2. A Polarization-tracking-free RAU Design for Alamouti STBC based MIMO Transmission

The proposed polarization-tracking-free radio access unit (RAU) can achieve PDM signal demultiplexing with simple optical filtering and photo-detection. In the CU/DU, various mobile service signals from the centralized BBUs are

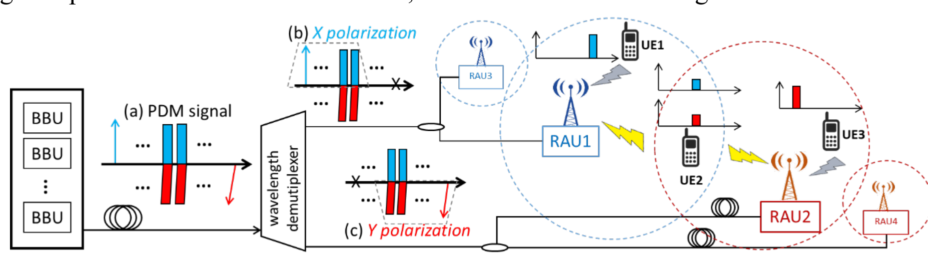

Fig 1. A conceptual diagram of the proposed CoMP MMW PDM-RoF for 5G mobile fronthaul system

assembled into an optical PDM-RoF signal. As shown in Fig. 1(a), two optical carriers are located on the opposite sides of the transmitted PDM-RoF signal bands, and respectively aligned the signals to two orthogonal polarization states, X and Y. During fiber transmission, a wavelength demultiplexer is applied prior to the designed RAUs. At each wavelength demultiplexer output, only the desired signal and its corresponding optical carrier on the same optical polarization pass the filtering. For example, as illustrated in Fig. 1(b), only the PDM-RoF signals and X-polarized optical carrier pass the demultiplexer's upper output, while the Y-polarized optical carrier is blocked. On the contrary, the X-polarized optical carrier is absent at the demultiplexer's lower output port. These filtered signals are then delivered to their destinating RAUs. In the photo-detections, without the supporting optical carrier, the RoF signal on the orthogonal polarization generates only self-beating noise in baseband without interfering the desired signal at RF band, therefore the PDM demultiplexing is accomplished here. It's worth to mention that no additional mechanism is applied to such self-beating noises.

Since the PDM demultiplexing can be accomplished real-time in photo-detections without extra mechanism or algorithm, the radio signal transmissions in this proposed PDM-RoF transmission system enjoy the same flexibility as most other CoMP systems, where the additional training signal or tedious processing latency in the traditional PDM systems never exists here. Each individual RAU is responsible for the close user equipment (UE), thus with higher received signal-to-noise ratio (SNR). However, for some end users at the edges of the RAU's wireless coverage like UE2, the wireless transmissions suffer from either strong inter-RAU interferences or insufficient signal power. One of the CoMP solutions is temperately turning down the emitting radio powers of some RAUs. This could be implemented with this proposed PDM-RoF transmission; however, the related software controlling is out of this paper's scope. The other CoMP solution is joint transmission, where RAU1 and RAU2 collaborate in serving UE2 at their coverage boundaries. We employ Alamouti STBC to the OFDM signal for this joint transmission scenario of the CoMP over the proposed PDM-RoF system, whose code rate is 1 without sacrifice any transmission capacity.

3. Experimental Demonstrations

We build a PDM-RoF transmission system with the proposed polarization-tracking-free design and two MMW small cells to demonstrate the CoMP joint transmission as depicted in Fig. 2. A binary sequence is encoded to 16QAM-OFDM signal offline. A 1024-FFT is applied, where 26 subcarriers are modulated with 16QAM format and the remaining subcarriers are zero-padded for oversampling. The OFDM signal is then coded with Alamouti STBC for the CoMP joint transmission over two RAUs. Then, by inserting a 1/4 cyclic-prefix and frequency up-conversion, both STBC coded OFDM signals occupy 400 MHz at its intermediate frequency (IF) of 5 GHz. Two individual digital-to-analog convertors (DACs) at a sampling rate of 12 GSa/s are applied to output these STBC encoded OFDM signals to the PDM-RoF system. These signals modulate the related optical carriers at 1550.025 and 1550.105 nm respectively, where we implement with two 10-GHz MZMs biasing at quadrature points. These two optical signals are polarization multiplexed with a polarization beam combiner (PBC), optically boosted with an EDFA, and then optical filtered to assemble the designed PDM-RoF signal, which optical spectrum is as shown in Fig. 2(a). Moreover, by suppressing the outer sidebands with the optical filter, the single side-banded PDM-RoF signal becomes spectrally compact and is immune from dispersion-induced power fading. At the transmitter output, the PDM-RoF signal launches to SMF transmission with its power of +3 dBm.

After 25-km SMF transmission, a 12.5/25-GHz optical interleaver is applied for optical filtering as the noted wavelength demultiplexer. The optical spectra of both outputs are shown in Fig. 2(b) and 2(c), where the Y and X

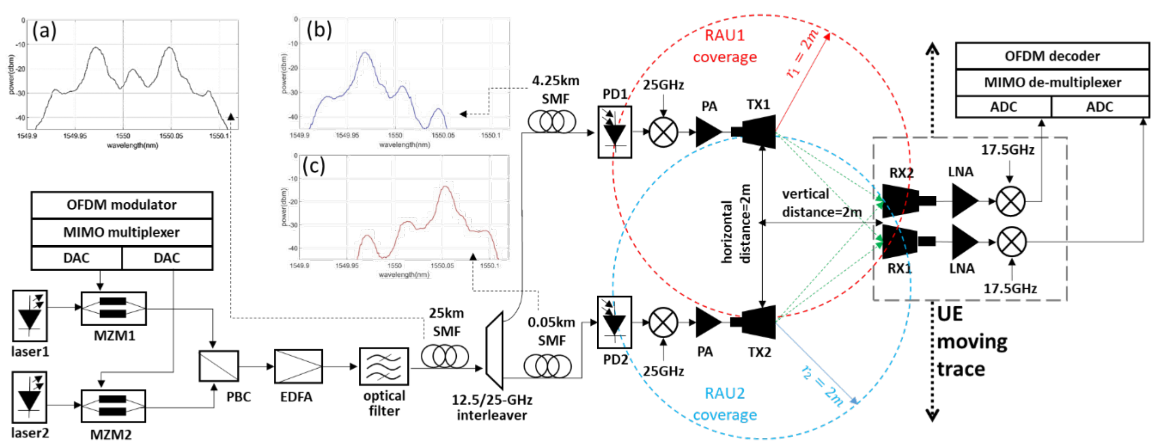

Fig. 2 The experimental setup with the optical spectra of (a) the PDM signal and (b-c) the optical filtered signals for PDM demultiplexing

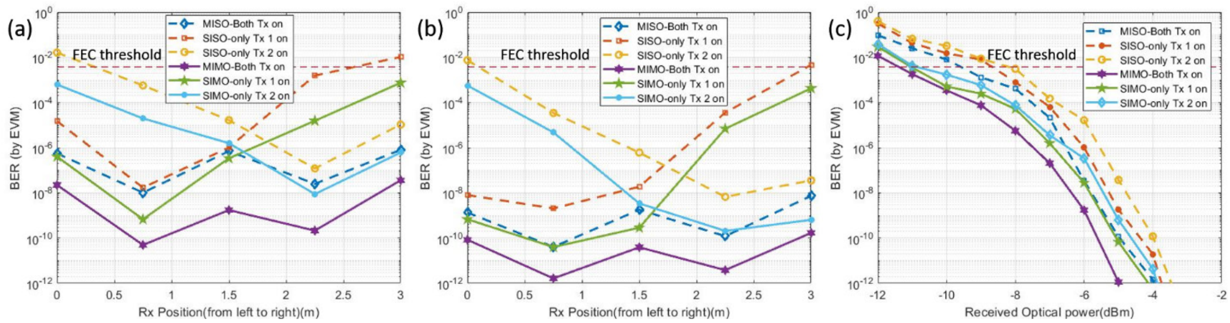

Fig. 3 (a-b) The BER performances of various wireless scenarios at (a) 2-meter and (b) 1-meter vertical distances; (c) The BER performances on received optical powers with 2-meter vertical distance.

polarization optical carriers are largely suppressed, respectively. To emulate the designed RAUs in a CoMP transmission environment, RAU1 dealing with X polarization attaches to the optical interleaver with an extra 4.2-km SMF, and RAU2 with Y polarization has an extra 50-m SMF. The distance between the two RAUs is 2 meters. In each RAU, a 10-GHz photo-detector (PD) is applied to receive the filtered PDM-RoF signal. As explained, the PDM demultiplexing is achieved in each PD, and the radio signal at 5-GHz IF outputs for the following MMW wireless transmission. The IF signals are then frequency up-converted to 30-GHz MMW with the aid of a 25-GHz clock installed in each RAU. With a power amplifier (PA), the boosted MMW radio emit through a 23-dBi horn antenna.

The UE detects the MMW signals simultaneously from both RAUs with two identical 23-dBi horn antennas. After a low noise amplifier (LNA), the received MMW signals are frequency down-converted to 12.5 GHz. Two individual analog-to-digital convertors (ADCs) are applied to bring the signals to offline signal processing, which mainly consists of a MIMO de-multiplexer, an OFDM decoder, and a one-tap zero-forcing linear equalizer.

The first experimental demonstration is evaluating the CoMP joint transmission with various UE locations. The received optical powers of RAUs are set at -5 dBm in this demonstration all the time. With a vertical wireless distance of 2 meters between transmitting and receiving antennas, the UE moves horizontally around the wireless coverage boundaries as shown in Fig. 2. Various wireless transmission scenarios are evaluated in this deployment as shown in Fig. 3(a). We firstly turn on only one RAU at a time and apply only one receiving antenna to the UE, namely the SISO wireless scenario. The BER performances, represented as the red and yellow curves, climb steeply as soon as the UE move away from the activated RAU. We then apply two antennas to the UE, namely the SIMO wireless scenario, and obtain similar results, represented in green and cyan curves, while the overall BER performances improved due to the received signal powers doubled. Then, we turn on both RAUs, and the BER performances are improved and smooth for all the UE locations for both 1-antenna UE and 2-antenna UE, which correspond to the MISO scenario in the blue curve and the MIMO scenario in the purple curve. These results strongly reinforce that the proposed polarization-tracking-free PDM-RoF system works perfectly for the CoMP joint transmission. It's worth to note that UE antenna deployment obviously less contributes to the received signal qualities. For a comprehensive evaluation, we reduce the vertical wireless distance between transmitting and receiving antennas to 1 meter and repeat the works. As shown in Fig. 3(b), all the BER performances improves mainly due to the enhanced received signal powers.

The second experimental demonstration is evaluating the received optical power sensitivities of RAUs. As shown in Fig. 3(c), by repeating the six wireless scenarios mentioned above, the RAU received optical power sensitivities defining at the applied FEC threshold BER=$3.8\text{x}10^{-3}$ are -8.5 dBm for the SISO scenarios, -9.5 dBm for the SIMO scenario, -11 dBm for the MISO scenarios, and -11.5 dBm for the MIMO scenario. A 3-dB improvement is obtained from SISO to MIMO principally due to the doubled received powers, where we merely observe any penalty from PDM and its polarization-tracking-free demultiplexing.

4. Conclusions

We propose a MMW CoMP transmission system for 5G mobile fronthaul based on our polarization-tracking-free RAU design. Two optical carriers are separately aligned to two orthogonal polarizations, and only one of them is sifted out to demultiplex the PDM-RoF signal real-time in photo-detection. The experimental demonstrations show CoMP joint transmission works perfectly with the PDM-RoF system without any observable penalty.

5. References

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