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Support of Multi-antenna and Multi-user Systems Using Radio Over Fiber

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Abstract: Analog radio-over-fiber can efficiently support multi-antenna and multi-user techniques for future mobile communications. Experimental results demonstrate that the wider antenna separation that can be provided enhances multi-antenna scheme performance.
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1. Introduction

Next-generation mobile communication systems (5th generation, 5G and beyond) are to offer ultra-high data rates to users, in what is referred to as the enhanced mobile broadband (eMBB) aspect of the service [1]. In order to provide for the several Gb/s data rates per user, and tens of Gb/s data rates per cell envisaged, different technical solutions are required. The first is the use of wider bands of spectrum: while new spectrum is being made available at sub-6GHz frequencies, for advanced 5G and beyond, it is the use of the relatively uncongested millimeter-wave (mmW) spectrum that will be important. Frequency bands around 28 GHz and 60 GHz, in particular, have been identified [2]. A second solution to achieving higher data rates is the use of smaller cells. With the use of mmW frequencies, smaller cells become necessary anyway for improving received signal-to-noise ratios and obtaining higher bit-rates, due to the increased wireless path loss. Increased path loss can also permit greater cell isolation (reduced co-channel interference) allowing greater system capacity through increased frequency reuse factors. A third solution is the use of multi-antenna techniques, or multiple-input multiple-output (MIMO) schemes. These have already been used in 4th generation long-term evolution (4G-LTE) mobile systems and wireless local area networks (WLANs), providing higher bit-rates through spatial multiplexing or improved and more consistent bit-rates to particular users by using spatial diversity. In advanced 5G systems, massive MIMO is envisaged, where the number of antennas at cell sites exceeds the number of users, allowing numerous "pencil beams" to users, greatly enhancing system capacity through spatial multiplexing [3]. The smaller size of mmW antennas and components is thought to make massive MIMO more technologically feasible at these higher frequencies. Thus, advanced 5G for eMBB is expected to feature aspects of all three solutions.

The use of smaller cells can be adopted in two ways. Traditional small cells would see very large numbers of micro-/pico- base stations being deployed together with numerous backhaul links and inter-base station interfaces (denoted X2 in LTE parlance). Alternatively, radio heads can be deployed and connected back to centralized baseband base station units through a fronthaul [4]. Up to now fronthaul has been based on sending sampled radio signals, using industry standards such as the Common Public Radio Interface (CPRI), but it has been realized that 5G bandwidths will make this approach infeasible, especially for MIMO systems [5]. New functional splits between central unit and radio heads which create interfaces transporting digital data rather than sampled waveforms have been defined [6]. However, there has also been renewed interest in the use of analog radio-over fiber (RoF) for the fronthaul, a technology which is bandwidth efficient, but has been generally confined to (mainly indoor) distributed antenna systems up to now [7].

In this paper, we examine the use of analog RoF to support wideband mmW multi-channel and/or MIMO communication systems. We review the potential for bandwidth efficiency. In particular, as RoF enables distributed MIMO, a form of what is also referred to as joint transmission/reception Coordinated Multipoint (CoMP) through the distribution of the jointly processed wireless signals to/from geographically separated antenna units, we examine how such schemes perform at mmW frequencies, where line-of-sight links with little multipath exist. Experimental measurements for both spatial multiplexing and spatial diversity schemes are presented.

2. System scenarios

Figure 1 shows a system scenario for an advanced 5G eMBB-type service, where remote radio units are able to provide high-data rate carrying mmW pencil beams directed towards users while legacy systems provide more general geographic coverage. The mmW beams may be created by completely steerable array techniques or by beam-switched systems in which active beam(s) is/are selected from a number of possible fixed beams. In general, this requires the transport to the remote radio unit of individual signals for each beam or for each antenna element.

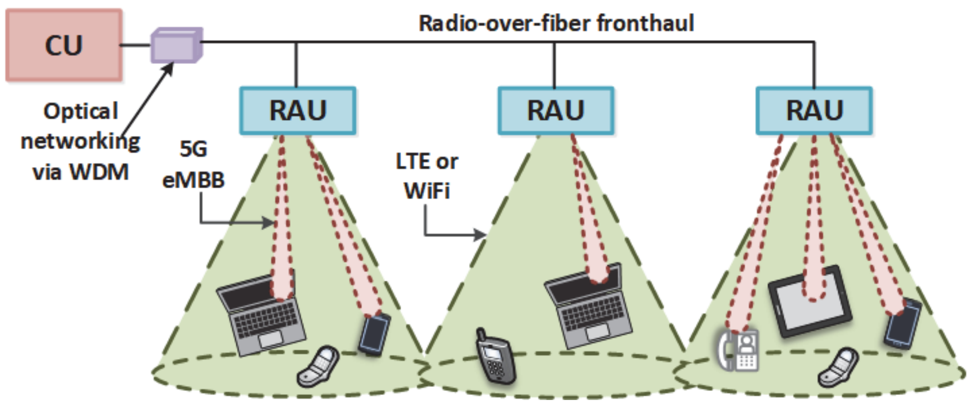

Fig.1 Scenario for advanced 5G eMBB heterogeneous wireless system. CU: Central Unit; RAU: Remote Antenna Unit; WDM: Wavelength Division Multiplexing.

Projecting from the current CPRI line rates, if 40 100 MHz-wide MIMO signals were being transported to/from a radio head, a bit rate of 202.752 Gb/s would be required in each direction on the fronthaul link. On the other hand, if the analog transport of the radio signals is used, and the multiplexing on the fiber links can be carried out with significant bandwidth efficiency, analog links with just over 4 GHz bandwidth would suffice. Analog subcarrier multiplexing techniques have previously been proposed [7], but are limited by the performance of analog RF/microwave filters. Recent work on digital multiplexing for analog RoF has demonstrated excellent bandwidth efficiency [8], at the same time taking advantage of MIMO processing at the receiver to counteract the effects of low sampling rates.

3. Distributed MIMO/CoMP for mmW systems

Figure 2 shows an experimental arrangement used to demonstrate distributed MIMO (CoMP joint transmission/reception) at 60 GHz using RoF distribution, in this case at intermediate frequency to separate transmitter antenna units [9]. The different antenna symbols refer to the use of horn and slot-waveguide antennas, although other antenna arrangements have also been used. The offline processing enables the frequency offset/phase correction necessary with the different transmitter and receiver local oscillators. The results for example measurements are shown in Fig.3 [9]. The results on the left show the reduced post-processing EVM with spatial diversity, and overall user data-rates of 1 Gb/s for both SISO and MIMO cases. On the right, the MIMO EVM results are comparable to those for SISO, but are for spatially multiplexed transmission with 1 Gb/s data rate compared to 0.5 Gb/s in the SISO case. For the spatial diversity, Alamouti Space-Time Block Coding (STBC) was used, while Zero-Forcing (ZF) was used for the spatial multiplexing. In Fig. 3, the 12.5% EVM line corresponds to the LTE limit for 16-QAM, and the legend reference to 20 cm, 30 cm and 40 cm, refers to different spacings for the transmitter antennnas (the receiver antennas were adjacent to each other). For the results presented, which were for a wireless path of 1.5 m, it can be seen that the best results were obtained with a separation of 30 cm. Further results, to be published, have confirmed that the separation generally increases with increasing wireless path distance (we have found this to be 60 cm for 6 m distance, and 120 cm for 8 m distance). Generally, the increased channel decorrelation with increased antenna separation improves performance, but many MIMO algorithms also rely on similar receive power levels for the signals, so this poses opposing limitations unless the system can switch to antenna selection instead of joint processing. Further work is needed to understand the opposing limitations and to test systems which can be switched between transmitter/receiver combining and selection.

In [9], we also demonstrated that while the spatial decorrelation of the mmW channels in the 2 x 2 MIMO was enhanced and sufficient for the joint-processing algorithms to show significant performance improvements, this decorrelation was relatively static. Individual 1 x 1 transmitter-receiver antenna pair measurements were taken and these channel measurements were used to compute the channel and precoding coefficients. The emulated MIMO results were then found to be very similar to those obtained in the real 2 x 2 measurements. This technique would have advantages in research and development of future massive MIMO systems where the full number of antennas was not initially available.

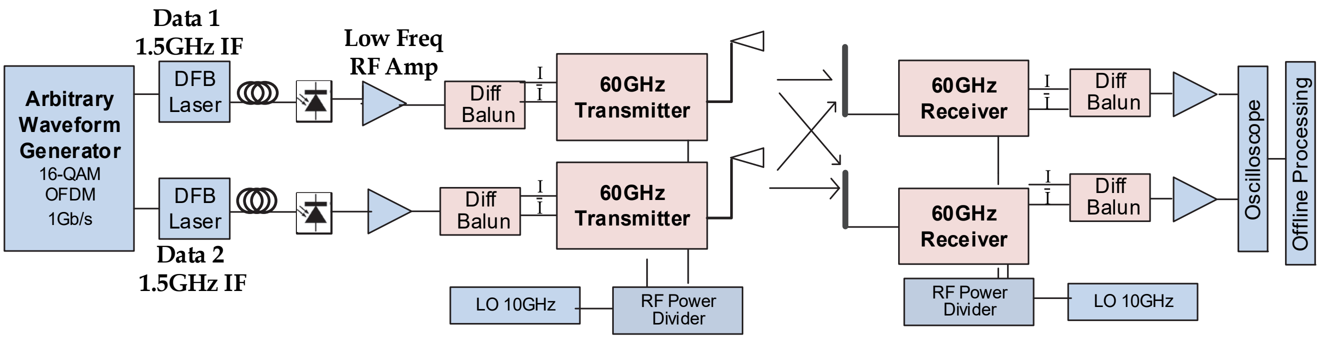

Fig.2 Experimental set up for mmW RoF distributed MIMO

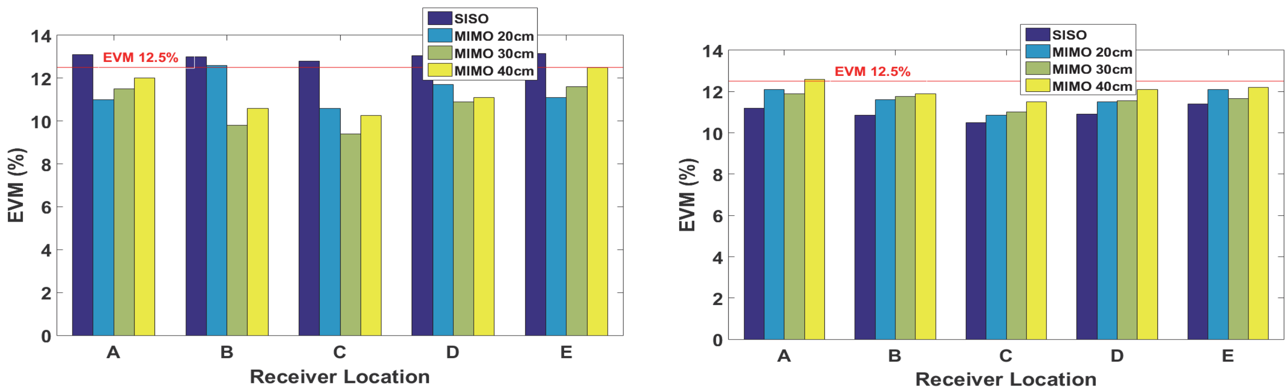

Fig.3 Experimental results for STBC-Alamouti versus SISO (left), and ZF-beamforming versus SISO (right), at different receiver locations.

4. Summary

Analog RoF offers a promising, spectrally efficient solution for the fronthaul of 5G mobile communication systems considering the larger bandwidths and MIMO techniques that must be supported. With RoF distribution, the channel decorrelation in distributed MIMO/CoMP techniques for mmW frequencies is increased, and both spatial diversity and spatial multiplexing have been demonstrated to offer enhanced performance.

5. Acknowledgment

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