Distributed MIMO Antenna Architecture for Wireless-over-Fiber Backhaul with Multicarrier Optical Phase Modulation

Antonio Caballero[1], Shing-Wa Wong[2], Darko Zibar[1], Leonid G. Kazovsky[2], Idelfonso Tafur Monroy[1]
1. DTU Fotonik, Department of Photonics Engineering, Technical University of Denmark, Ørsteds Plads, B. 343, DK 2800 Kgs. Lyngby
email:acaj@fotonik.dtu.dk
2. Department of Electrical Engineering, Stanford University, Stanford, CA 94305, USA

Abstract: A novel optical phase-modulated wireless-over-fiber backhaul architecture for next generation cellular network is presented and experimentally demonstrated for high capacity wireless multicarrier uplink transmission on a single wavelength.
OCIS codes: (060.1660) Coherent communications; (120.5060) Phase modulation; (060.5625) Radio frequency photonics

1. Introduction

The exponential growth on the demand of high speed wireless data communications has put significant pressure on the cellular operators to improve their cellular access network capacity. Multiple-input and multiple output (MIMO) distributed antenna system (DAS) is a promising technology that can improve system capacity by mitigating inter-cell interferences [1]. In a MIMO-DAS, as shown in figure 1, RF signals are transported to a baseband processing unit (radio equipment controller, REC) from multiple cell sites (radio equipment, RE), through a RF transport interface, thus allowing communication between neighboring cells. Standards such as common public radio interface (CPRI) or open base-station initiatives (OBSAI) uses digital formats to represent the demodulated but not-yet decoded RF samples. However, they demand large backhaul bandwidth compared to their actual RF bandwidth, due to the high resolution bits needed for the digitalization process of the RF samples [2].

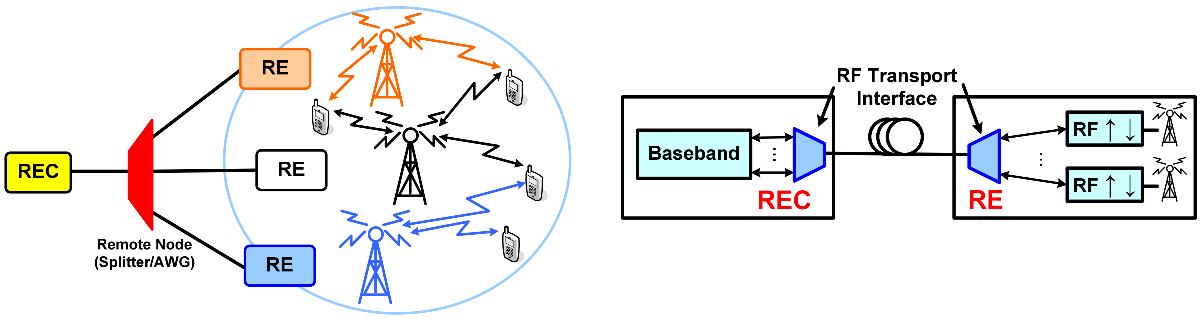

Figure 1(a): Point-to-multi-point backhaul architecture for multi-cell sites MIMO-DAS. Figure 1(b): MIMO-DAS system separates baseband unit from RF units. They are connected by RF transport interface to exchange RF IQ samples

The use of radio-over-fiber (RoF), where the analog signals are transported transparently through the optical fiber link, is an alternative to digitalized radio systems. In order to multiplex the different wireless channels, the use of a multicarrier intermediate frequency (IF) has been proposed for efficient bandwidth utilization [3]. RoF link with optical intensity modulation and direct detection (IM-DD) of radio signals is a commonly used option for downlink. However, for uplink transmission (antenna to REC), where the requirements on linearity are more stringent, the performance of IM-DD is suboptimal due to the high optical power required and limited linearity, especially for high capacity wireless links. Recently, optical phase-modulated RoF (PM-RoF) links has been proposed and demonstrated to offer both high linearity and high sensitivity for high speed wireless signals [4,5]. By using linear demodulation on the digital domain, it is possible to recover the phase of the optical field and compensate for link impairments. However, they require a second laser source as a local oscillator (LO) and a 90° optical hybrid receiver. The centralization of both components in the REC in the proposed point-to-multipoint architecture allows the system to become cost-effective for high capacity cellular backhaul.

This paper investigates the use of PM-RoF for the MIMO-DAS uplink. The architecture uses multicarrier IF to multiplex up to 12 high capacity wireless channels (100 Mbaud and 200 Mbaud). We have analyzed the requirements of the PM-RoF link in terms of laser linewidth and optical phase modulation index. Experimental demonstration of an emulated multicarrier system is reported as a proof of concept, including the transport on a single optical carrier of an emulated high capacity cell group and successful demodulation with an overall bit-rate of 4.8 Gbit/s.

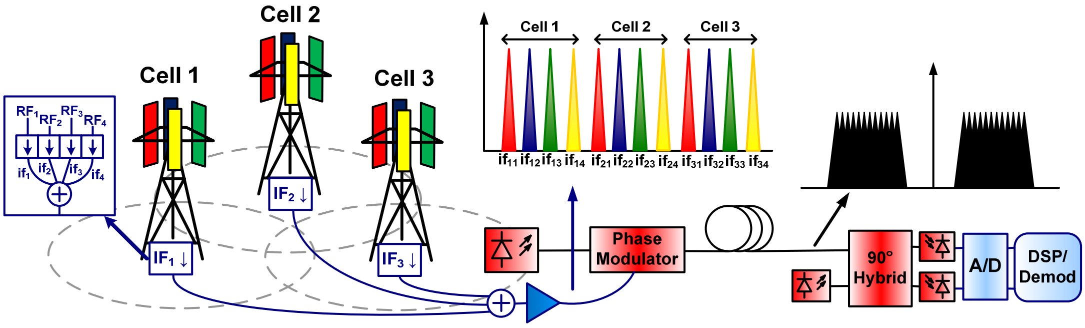

Figure 2: Proposed scenario where 3 cells of 4 antennas each are connected to a central station using an IF-ROF link. The 12 channels are electrically multiplexed in frequency in the electrical domain and transparently transported through the fiber.

2. Proposed architecture

As in MIMO-DAS uplink, received signals for all the cellular antennas occupy the same frequency range; the data from the different antennas are subcarrier multiplexed in a narrow grid, thus decreasing the total bandwidth of the electro-optical system. Figure 2 shows the proposed architecture, where the multiplexed antenna channels are then optically modulated using a phase modulator and transported over fiber backhaul to the REC. The phase of the optical carrier is recovered there using coherent detection. Transmission impairments from electrical and optical components can be compensated by digital signal processing. The required receiver sensitivity is significantly improved, making the use of optical amplification or high power laser sources unnecessary. The architecture can be easily scaled to a wavelength division multiplexed (WDM) system, using different wavelength for different groups of cells. Figure 2 also shows a possible scenario for next generation long-term evolution (LTE) interface, where 3 cells are connected to a REC using a single fiber link. Each RE has four antennas, giving a total of 12 independent channels of about 200 MHz each. The required bandwidth for the multiplexed signals in the proposed architecture is decreased below 4 GHz.

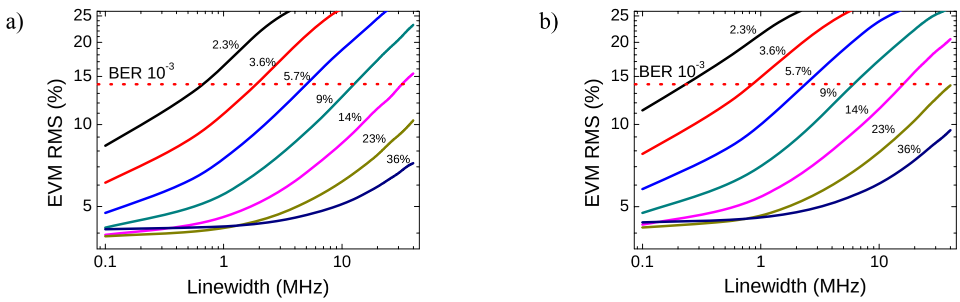

Figure 3: Error vector magnitude (EVM) at different modulation index as a function of lasers linewidth (transmitter and local oscillator equal linewidth). Transmitted single carrier 100 Mbaud (left) and 200 Mbaud (right) 16QAM RF signal over the phase-modulated optical link with 20 km SMF and coherent detection.

3. System performance requirements

The main limitations for a PM-RoF systems are the modulation index of the electrical signal and the induced phase noise due to the linewidth of the transmitter and local oscillator lasers. The received power is not the main limiting factor due to the short length of the link and the use of optical coherent detection. The use of high modulation index decrease the noise influence induced from the lasers and photodetectors, therefore its value is recommended to be as high as possible, within the ($-V_\pi$, V_π) range, to avoid phase uncertainty.

The proposed architecture has been simulated using Matlab and VPI Transmission Maker software, emulating a single carrier at 2 GHz with 100 or 200 Mbaud 16QAM over a 20 km optical phase modulated fiber link, with coherent detection. The root-mean-square error vector magnitude (RMS EVM) has been calculated, to show the induced distortion of the link for a high order modulation format. In the system, a BER of 10^{-3} is obtained with EVM of 14%. A laser linewidth value of less than 2 MHz is requested to assure low signal distortion in the link, which can be easily achievable with a standard DFB laser; as well as a modulation index over 10% per subcarrier. Therefore, low V_π voltage modulators are necessary in order to achieve high modulation index with low driving RF power.

4. Experimental results

The experimental setup is also described in figure 2. A multicarrier electrical signal was emulated using an arbitrary waveform generator (Tektronix AWG7122B) at 24GSa/s. This signal was created adding up 6 (3 cells of 2 antennas) or 12 (3 cells of 4 antennas) independent 16QAM modulated signals, emulating the different antennas. Then, this signal was amplified with a maximum RF output power of 10 dBm, driving a PM with a V_π of 7 V. A 1 MHz linewidth laser with +3 dBm output power was used at the transmitter. The optical signal was detected using a 90^o optical hybrid with integrated photodiodes (7.5 GHz bandwidth) after transmission over 22.8 km of SMF. As a LO, a low linewidth (~200 kHz) external cavity laser was used, with 0 dBm output power. The received optical power was set to -9 dBm in order to avoid saturation of the photodetectors. The two resultant photocurrents (I&Q) were sampled using a high speed digital sampling scope (DSO) at 40 GSa/s. Offline processing was used to demodulate the detected signal, consisting on frequency offset compensation between the transmitter laser and LO, and common digital demodulation of the desired channel [5]. BER results were obtained by averaging over all the subcarriers, as due to different electrical responses of the amplifier and modulator, each subcarrier had slightly different power.

Figure 4 shows the results for two considered cases: 12 subcarriers with 100 Mbaud 16QAM in 150 MHz grid spacing and 6 subcarriers at 200 Mbaud 16QAM, 300 MHz grid spacing (4.8 Gbit/s total bit-rate transmitted). The performance was evaluated for different modulation indexes per subcarrier. BER below 10^{-3}, corresponding to an RMS EVM <14%, were obtained for both cases being the maximum modulation index plotted the one corresponding to 10 dBm total input power to the PM. The frequency response of the amplification stage was not totally flat at high RF power levels, creating distortion on some subcarriers. A low V_π PM will improve substantially the performance, by decreasing the amplification needed to drive the PM.

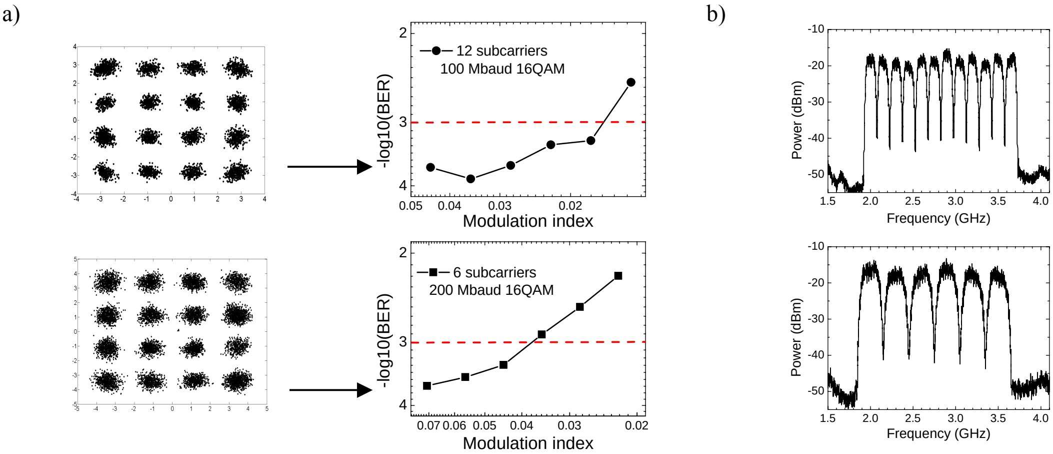

Figure 4: a) BER results as a function of the individual modulation index for 12 x 100 Mbaud 16QAM (top) and 6 x 200 Mbaud 16QAM (bottom) including constellation of the received symbols. b) Electrical spectrum of the transmitted subcarrier systems.

5. Conclusion

We have proposed and experimentally demonstrated a novel architecture for transparent transport of multiple wireless channels over a single laser source for MIMO-DAS. This architecture is highly linear and capable to support multiple users with high individual bandwidth requirements. We have reported experimental demonstration of a cellular coverage of 12x400 Mbit/s (3 cells x 4 antennas, 100 Mbaud 16QAM) and 6x800 Mbit/s (3 cells x 2 antennas, 200 Mbaud 16QAM) on a single optical carrier, showing the potential integration of the proposed architecture into the next generation cellular networks.

References

[1] M. K. Karakayali, G. J. Foschini, and R. A. Valenzuela, "Network coordination for spectraly efficient communications in cellular systems," IEEE Wireless Communications, vol. 13, pp. 56-61, August 2006.

[2] C. Hoymann, L. Falconetti, and R. Gupta, "Distributed Uplink Signal Processing of Cooperating Base Stations based on IQ Sample Exchange," in Proc. ICC, pp. 5, June 2009.

[3] D. Wake, A. Nkansah, and N. J. Gomes, "A Comparison of Radio Over Fiber Link Types for the Support of Wideband Radio Channels," J. Lightwave Technol., vol 28, n. 16, August 2010

[4] T. R. Clark and M. L. Dennis, "Coherent Optical Phase-Modultion Link," Photon. Techhnol. Lett., vol. 19, no. 6, August 2007.

[5] A. Caballero, D. Zibar and I. Tafur Monroy, "Digital coherent detection of multi-gigabit 40 GHz carrier frequency radio-over-fibre signals using photonic downconversion," El. Letters, vol. 46, issue 1, pp. 58-59, 2010.