MIMO System Capacity Improvements Using Radio-over-Fibre Distributed Antenna System Technology

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Abstract: The effect of antenna separation in a 3×3 MIMO system using RoF DAS technology is investigated. Larger antenna separation is found to improve the throughput due to reduced channel correlation and improved SNR.

OCIS codes: (060.2330) Fiber optics communications; (060.5625) Radio frequency photonics; (060.2360) Fiber optics links and subsystems;.

1. Introduction

As the demand for high-quality and high-speed wireless communication systems grows, multiple-input-multiple-output (MIMO) technology has been shown to both increase data capacity through spatial multiplexing and improve system reliability through antenna diversity without occupying additional spectrum [1]. However, the capacity which can be achieved through spatial multiplexing is dependent on the degree of correlation between the channels between each of the base station antennas and the mobile terminal. Typically for the usual small antenna separations, the correlation is high, thus limiting the system capacity. A solution to this problem is to combine radio-over-fibre (RoF) distributed antenna systems (DAS) with MIMO, as shown in Fig. 1. Due to the low loss of optical fibre, the RoF DAS readily enables a wide MIMO antenna spacing. Moreover, the integration of MIMO and RoF improves the throughput performance and extends the wireless coverage by increasing the received RF power and the spatial degrees of freedom [2-4]. Recently several studies have been carried on both theoretically and experimentally, and some technical issues, such as the effect of optical loss imbalance and different lengths of optical cables, the RoF link noise influence, and the appropriate antenna separation optimization etc, have been analyzed [3,5].

In this paper, we experimentally demonstrate the performance of a 3×3 RoF-enabled MIMO system in indoor light-of-sight (LOS) scenario for both conventional and distributed antenna arrangements. It is shown that the conventional closely-spaced MIMO system has 2.3 times the capacity of the equivalent SISO system, Moreover, an improvement of 7.4% in average capacity is observed in the experiment for linearly distributed transmitting antennae with 2-m separation over the conventional MIMO antenna arrangement, and for distributed transmitting antennae arrangement with 4-m separation around the edge of the 'cell' the increase is 11.3%, with a more uniform throughput distribution in this case.

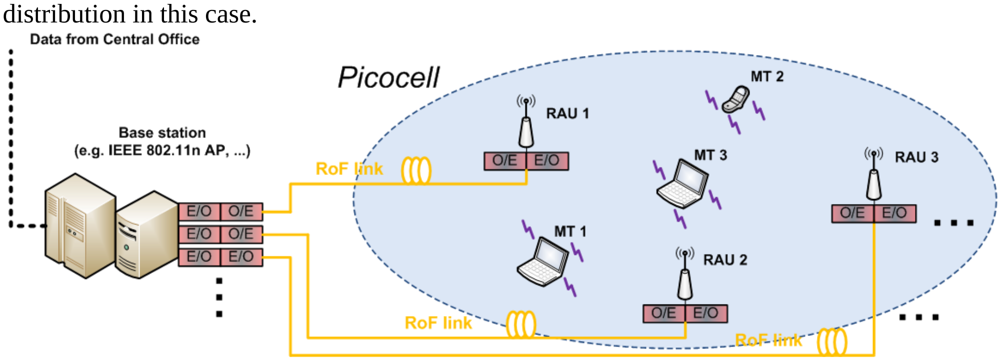

Fig. 1. RoF-enabled distributed MIMO antenna system for indoor wireless applications (RAU: remote antenna unit; MT: mobile terminal.)

2. Principle and experimental setup

The experimental setup for the indoor 3 × 3 MIMO channel measurement based on radio-over-fibre technology is shown in Fig. 2. A vector network analyzer (VNA, Agilent 8722ET) is used to perform measurements of the wireless channel over a 22-MHz bandwidth (2.401-2.423 GHz, Wi-Fi Channel 1). Commercial omnidirectional Wi-Fi antennae are employed on the TX (base-station) side, whilst the RX side makes use of an integrated 3 element omnidirectional MIMO antenna. A Zinwave 2700 DAS is used to provide the RoF links over 30-m OM1 MMF. Each link is normalised to provide equal gain. A PC and ARM microchip control the antenna selection through the two RF switches to obtain the 3 × 3 complex channel transfer matrix H. Based on the measured values, the MIMO system capacity is calculated using the expanded Shannon capacity expression [1,6].

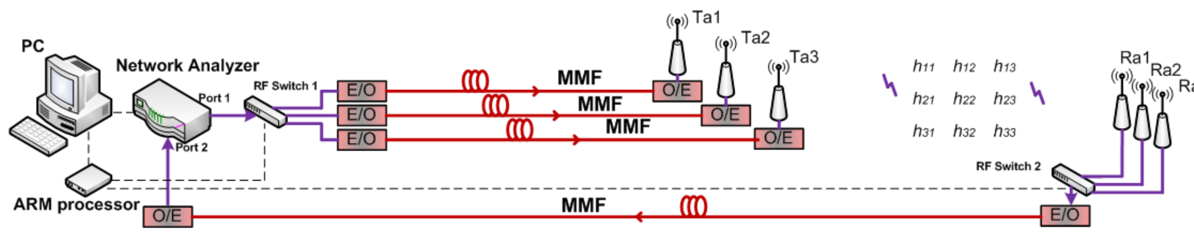

Fig. 2. Experimental setup for indoor 3 × 3 MIMO channel measurements based on radio-over-fibre technology (MMF: multi-mode fibre; E/O: electrical-to-optical converter; O/E: optical-to-electrical converter; Ta: transmitting antenna; Ra: receiving antenna.)

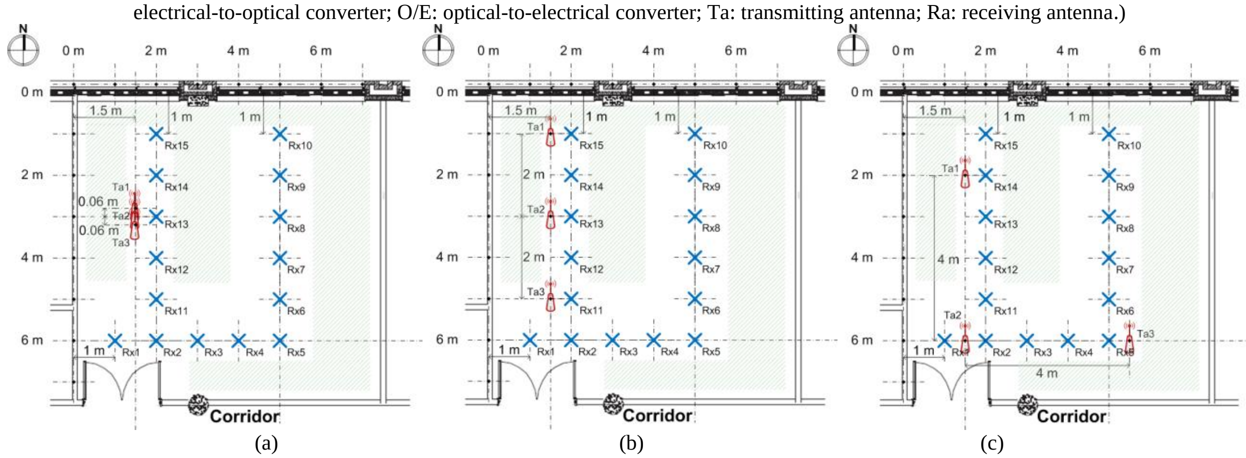

Fig. 3. Building schematic with transmitting MIMO antenna arrangement (red icon) and receiving MIMO antenna locations (blue cross) for indoor LOS scenario (a) for traditional in-line transmitting antennae with 0.06-m separation; (b) for in-line transmitting antennae with 2-m separation; (c) for distributed transmitting antennae with 4-m separation.

The experiments are carried on in a modern laboratory with equipment, metal racks, and optical benches etc in the shaded area shown in Fig. 3. The distance between every receiving location (shown as blue cross) is one meter and separations for the transmitting antennae (shown as red icons) are 0.06 m (half of the wavelength at 2.4 GHz), 2 m, and 4 m for (a), (b), (c) respectively. For each transmitting arrangement and receiving location, the channel matrix *H* is measured with 1600 frequency bin samples in the 22-MHz bandwidth and averaged over 16 sweeps.

3. Experimental results and discussion

Fig. 4 shows the system capacity results for the 15 receiving locations in a 22-MHz bandwidth. A total transmit power of -5 dBm shared between the three transmit antennas and -60 dBm noise floor at the receiver are assumed to allow the capacity to be calculated. The calculated capacity of a single-input-single-output (SISO) system with diversity by taking the maximum SISO from {Ta1, Ta2, Ta3} in Fig. 3(a) is shown in Fig. 4(a) for comparison. It shows a mean capacity of 201 Mbps with a maximum value of 284 Mbps and a minimum value of 137 Mbps in this situation. By comparing Fig. 4(a) with 4(b), 4(c) and 4(d), it is obvious that the effect of MIMO-RoF gives significant capacity benefits in all cases. Fig. 4(b) shows the system capacity when a conventional MIMO transmit antenna array arrangement is employed with half wavelength separation as shown in Fig. 3(a). The average capacity over all the locations is 475 Mbps with a maximum value of 627 Mbps and a minimum of 359 Mbps. Next, the spacing between the adjacent antennae is increased to 2 m using the RoF links as shown in Fig. 3(b). In this case, the capacity performance increases to an average of 510 Mbps, a peak value of 653 Mbps, and a minimum value of 378 Mbps, as shown in Fig. 4(c). Finally Fig. 4(d) shows the overall capacity performance when distributed transmitting antenna arrangement is employed with 4-m separation as shown in Fig. 3(c). For this absolute MIMO-RoF-DAS system, the average capacity increases by 11.3% to 530 Mbps over the conventional MIMO system. The maximum and minimum capacity values are 484 Mbps and 632 Mbps respectively in this situation.

Besides the overall capacity improvements, it is worth noting that the minimum value increases by over 100 Mbps for the most distributed antenna arrangement. In a realistic usage scenario it is likely that the minimum capacity over the coverage area will be an important metric. The cumulative distribution functions (CDF) are shown in Fig. 5(a). It can be seen that for the conventional closely spaced MIMO system 54.3% of the measurement locations and frequencies have a capacity less than 22 bits/s/Hz, whereas in the case of RoF-enabled MIMO, only 42.6% are below this threshold with 2-m separation, and 19.5% with 4-m separation. The improvement in throughput for the distributed MIMO system is due to the reduction of spatial correlation and also a more uniform power distribution. The average relative received power in the 22-MHz bandwidth also increases by about 3 dB, as shown in Fig. 5(b).

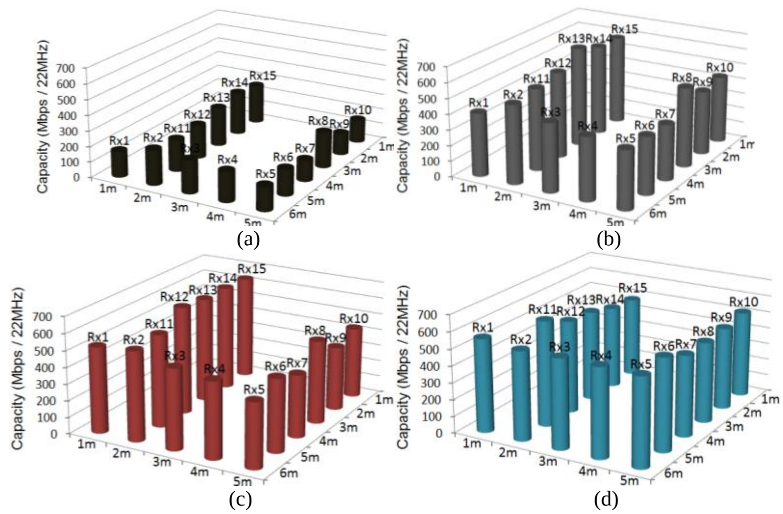

Fig. 4. System capacity results of different receiving locations in 22-MHz bandwidth (a) for SISO system; (b) for conventional MIMO arrangement of in-line transmitting antennae with 0.06-m separation; (c) for MIMO arrangement of in-line transmitting antennae with 2-m separation; (d) for distributed MIMO arrangement of transmitting antennae with 4-m separation.

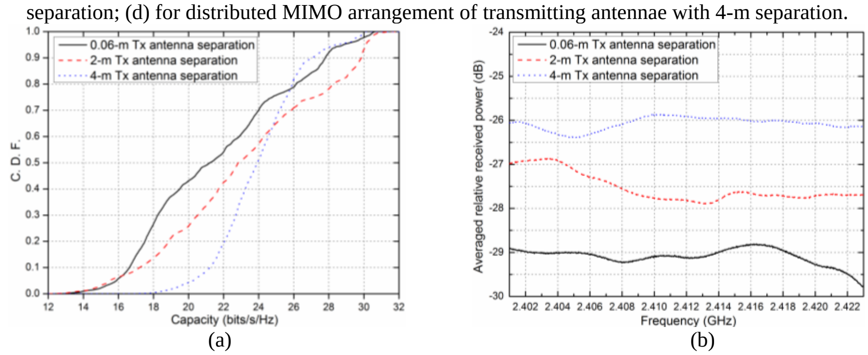

Fig. 5. (a) Cumulative distribution functions of the MIMO-RoF system capacity in 3 scenarios with the same average transmitting power and noise floor. (b) Averaged frequency response in 22-MHz bandwidth in 3 scenarios.

4. Conclusion

We present the capacity performance of a 3×3 RoF-enabled MIMO system with different base station antenna spacing. The conventional MIMO system with closely spaced antennas has a capacity of 475 Mbps, 2.3 times that of the equivalent SISO system (201 Mbps). With MIMO DAS using a 4-m antenna element separation, readily enabled by RoF technology, the mean capacity increases to 530 Mbps. At the same time as increasing the mean capacity, the standard deviation of the capacity is reduced from 92 Mbps for the conventional MIMO system to 39 Mbps with the wide separation MIMO DAS. This will greatly enhance the user perceived quality of coverage.

Acknowledgments

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