Radio over Fiber Transport of mm-Wave 2×2 MIMO for Spatial Diversity and Multiplexing

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Abstract—DWDM-RoF transport and photonic generation of millimeter-wave MIMO signals has been demonstrated. Generation and modulation of independent data streams over different wavelengths provides allocation flexibility and centralization. EVM results show that this low-cost technique provides antenna diversity/multiplexing gain for STBC-Alamouti and Zero-Forcing algorithms based OFDM-MIMO.

Keywords—Radio over Fiber, Dense Wave Division Multiplexing, Multiple Input Multiple Output, EVM

I. INTRODUCTION

Photonic generation of millimeter-waves (mmW) using a single laser source results in stability and low phase noise for communication [1]. Direct photonic upconversion reduces costs and complexity at the remote antenna unit (RAU), important since large numbers of RAUs need to be deployed. Optical mmW generation provides centralized control and the Radio over Fiber (RoF) transport of Gb/s data rates spectrally efficient. Indoor mmW communications to support multi-gigabit data rates even over short distances can have difficulties providing coverage to multiple user locations due to high path loss and the need for directive line-of-sight (LOS) transmission. Spatial diversity, achieved through transmission of multiple data streams improves the transmission reliability over wireless channels while spatial multiplexing increases the capacity of the system without increasing the transmission power or bandwidth. Millimeter-wave antennas with large directional gain may seem to be opposed to the high channel diversity needed for MIMO systems but LOS links can provide considerable spatial diversity gains for mmW MIMO transmission, with optimum spacing between the transmitting antennas [2-3]. Technical convergence of mmW over fiber transport and MIMO processing is necessary to provide reliable solution to the future mmW-based access systems.

Space-Time Block coding (STBC) uses orthogonal coded data streams transmitted through independent antennas, providing spatial diversity gain at the receiver end for MIMO system [4]. This results in increased SNR and thus capacity of the overall system and has been demonstrated for RoF based systems [5] in providing transmit diversity gain. In 2×2 MIMO operation, for transmit symbols S_1 and S_2, the received signal Y in terms of the noise N and STBC codeword matrix $\begin{bmatrix} s_1 & -s_2^* \\ s_2 & s_1^* \end{bmatrix}$ (where * represents the complex conjugate) is given by Eq. (1).

$$Y = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} S + N \tag{1}$$

The degree of decorrelation among the data streams at the receiver can be characterized in terms of condition number (CN). High CN indicates an ill-conditioned MIMO channel and thus low spatial multiplexing gain which results in high error magnitude vector EVM value after the MIMO processing [6]. The exploitation of STBC based MIMO transmission at mmW can provide increased coverage and improved performance compared to SISO system.

Methods have been presented for photonic generation of mmW MIMO signals with modulation of a single set of data and using an optical delay line to generate the decorrelation between the two MIMO signals [6, 7]. Generation of separate sets of data has also been shown using a single wavelength for the two RAUs but performance analysis has only been presented for a single user location at a particular wireless distance [8]. We present a DWDM OFDM-based mmW over fiber system transporting two independent data sets modulated on different wavelengths. The system has flexibility for the wavelength selection/allocation to a specific RAU and centralized control and does not rely on optical delay lines deployed after the base station. This scheme can also be used for multiple sets of data, for example, in the case of spatial multiplexing. All-photonic generation of both mmW signals at the central unit provides flexibility, and is a low-cost, centralized approach for MIMO operation. In this paper, RoF transport and optical generation of mmW is demonstrated to show that the proposed system provides spatial diversity gain using STBC, and spatial multiplexing gain using zero forcing. An EVM comparison is presented between 2x2 MIMO for each algorithm at different receiver locations with the performance of the Single input single output (SISO) system. The EVM is also evaluated for a set of transmission separation distances at different wireless distances to achieve the optimum spacing between the transmitting antennas in order to achieve spatial diversity gain for STBC receiver and multiplexing gain for the zero forcing receiver.

II. EXPERIMENTAL SETUP

A. DWDM-Radio Over Fibre Transport

Fig. 1 shows the experimental setup in which the two un-correlated OFDM-STBC (16-QAM, 512 IFFT length, 1/8 cyclic prefix, 8 pilots) encoded data streams at 1Gb/s data rate are generated at 1.5GHz intermediate frequency (IF) using an Arbitrary Waveform Generator. 23.5GHz separated optical lines are generated using an optical phase modulator whose output is filtered using a 25GHz DWDM filter. Data channels are

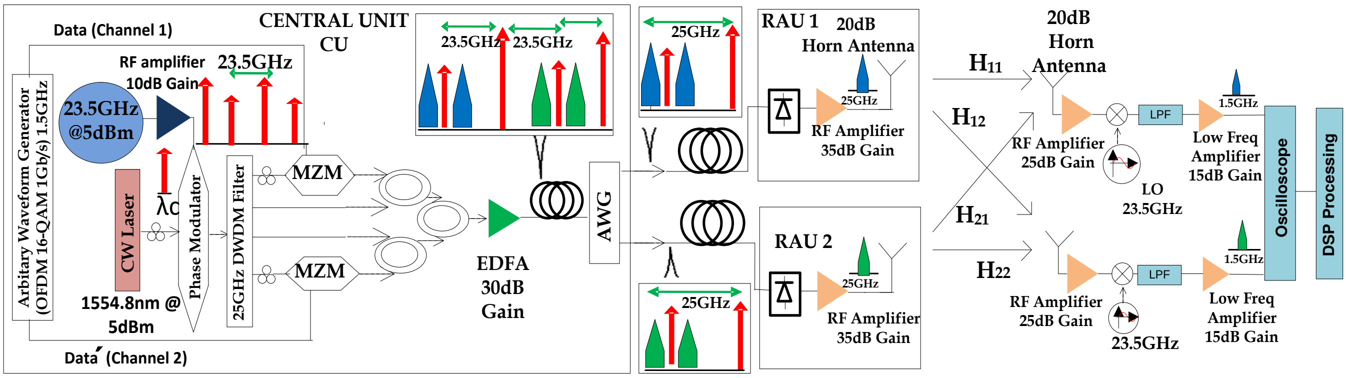

Fig. 1 Experimental setup of optical generation and modulation of mmW for 2×2 MIMO

modulated on different wavelengths using a pair of Mach-Zehnder modulators (MZMs), both biased at null point to ensure maximum suppression of the optical carrier and optimized performance in single wavelength modulation [1]. At the output of the DWDM filter, modulated optical wavelengths are combined with un-modulated lines and the resultant signal is passed through an Erbium Doped Fiber Amplifier (EDFA). After transmission from the central unit CU through an optical fiber of 2km, an Arrayed Waveguide Grating is used to filter optical signals for the two RAUs. At each RAU, a high bandwidth photodiode provides direct photonic upconversion to generate the mmW. Data modulated signals at 25GHz are amplified and transmitted through 20dBi gain horn antennas, after 3dB power attenuation to ensure that the overall transmitted power for MIMO is the same as the SISO transmission.

B. Millimeter-Wave MIMO setup

Multiple transmit antennas provide different paths for spatial diversity in MIMO transmission. The downlink system architecture in Fig.1 demonstrates that the 2×2 MIMO operation is achieved through seamless conversion of photonically generated 25GHz signals. After wireless transmission, at the receiver end, a similar set of antennas are used which are placed next to each other. The half-power beamwidth of the two transmitting antennas was found to be similar, around 20° from anechoic chamber measurements as plotted in Fig. 2.

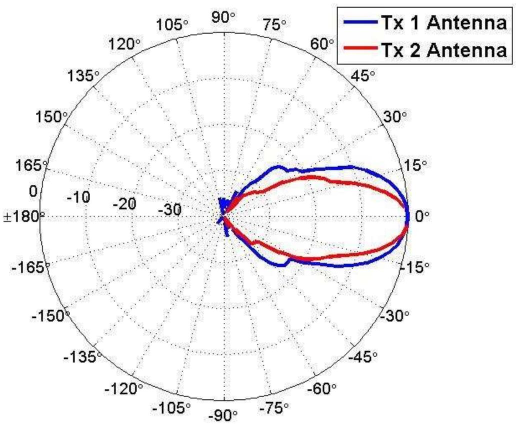

Fig. 2: Radiation pattern of the two transmitting horn antennas

The performance of MIMO operation, hence the spatial gain depends upon the degree of de-correlation for the two received signals. In LOS MIMO, this in turn depends upon the number of antennas, transmitter antenna spacing and the transmission distance as they all affect the angle of the received signals. The 20° beamwidth from each transmitting antenna was found to be adequate to provide coverage to both receiving antennas for the geometric layout of the experimental setup shown in Fig. 3. The received signal as given by (1) is amplified, downconverted and filtered before data capture with a high sampling rate oscilloscope for further MIMO processing, accomplished by an STBC decoder in Matlab. The EVM is used to analyze the performance of the system. The input IF power was set to the level where both noise and non-linear distortion effects were low. In the first step, experiments were performed for six different locations of the receiver (A to F) with a step of 30cm over a distance of 1.5m for a fixed transmission distance as presented in Fig. 3. Then the transmitter separation distance was varied from 40cm to 100cm with step-size of 20cm to analyze the optimum spacing for MIMO operation for different user locations. For each measurement, the transmitting antennas were pointing towards the receiver. This was accomplished by manual alignment to ensure that good signal strength from both transmitters is received. In the next step, for a fixed user location, between C and D, the transmission distance was varied to evaluate the effect of antenna spacing on the distance between transmitter and receiver.

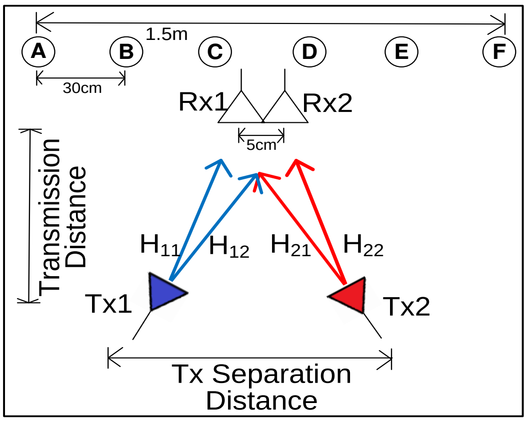

Fig. 3: Geometric orientation of experimental setup

Finally, in order to achieve multiplexing gain, the zero forcing algorithm was implemented by transmitting different data streams. The performance of the zero forcing decoder to multiplex the data streams in a multi-user environment was evaluated for different transmission distances. The results in the next section show that the orthogonality between the two channels can be introduced, to achieve sufficient de-correlation, through optimum transmit antenna separation.

III. RESULTS

A. STBC Alamouti MIMO processing

The feasibility of the proposed mmW over fiber based DWDM-MIMO transmission is demonstrated by the EVM results. Fig. 4 shows a comparison between performances of SISO transmission for the two links (one transmitting at a time) and MIMO using STBC at different user locations. The measurements were initially taken after 3m transmission distance with 60cm antenna separation. It can be seen that MIMO operation generally improves the performance at different user locations in comparison with individual SISO links. Depending on the coding scheme, EVM requirements for 16-QAM are different and the 12.5% limit defined in the LTE is used as an example here. The coverage (for EVM < 12.5%) is limited to only 3 receiver locations for SISO transmission while using STBC 2×2 MIMO, the coverage is increased to all 6 receiver locations for the same overall power as the transmit power for MIMO was regulated by introducing a 3dB penalty at each transmitting antenna unit.

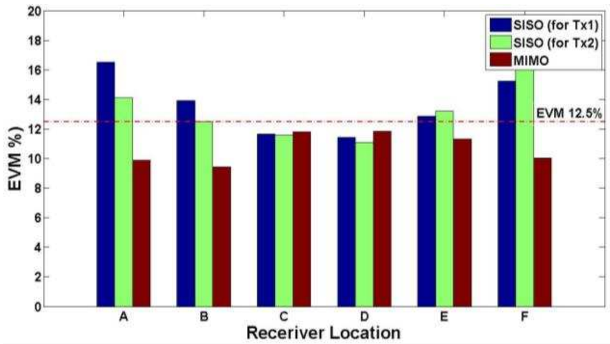

Fig. 4: Performance of 2×2 STBC at different user locations

For a fixed transmission distance of 3m, the transmit antenna spacing was varied from 40cm to 100cm, with a step of 20cm, to examine the effect of separation distance on MIMO performance. Best overall separation was found to be 60cm as EVM for each location was observed to be under 12.5%. As the transmission distance is increased for deeper investigation, for different antenna spacing values, the EVM changes slightly for a few receiver locations, as shown in Fig. 5. This is due to the change in geometric orientation of the transmitting antennas relative to the receiver which shows the angular dependent nature of MIMO. Increasing transmission distance shows that 80cm separation gives better results and indicates that the optimum separation distance value increases with the wireless distance in mmW MIMO. The EVM values after varying the wireless distance changes slightly due to the change in level of decorrelation of the two MIMO channels. But the variation due to transmission distance is relatively smaller as compared to the different transmitter antenna spacing for a fixed wireless distance.

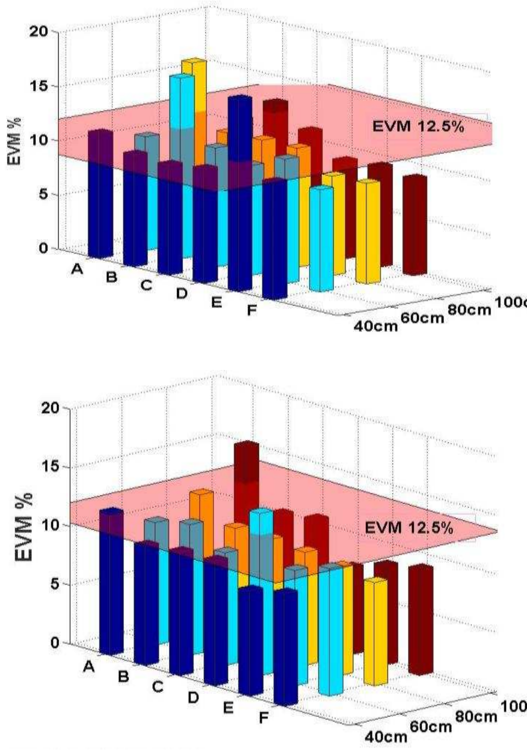

Fig. 5: EVM for STBC at different receiver locations for different transmitter separation distances over transmission distance of (top) 3.5m (bottom) 4m

To examine the receiver sensitivity for various transmission distances for a fixed transmission power, EVM versus the received power is plotted in Fig. 6 for different transmission distances, using a fixed separation of 80cm. It can be observed that receiver EVM falls below 12.5% at -50dBm of received power in most of the measurement results and decreases further, which shows the availability of enough power budget to increase the wireless distance.

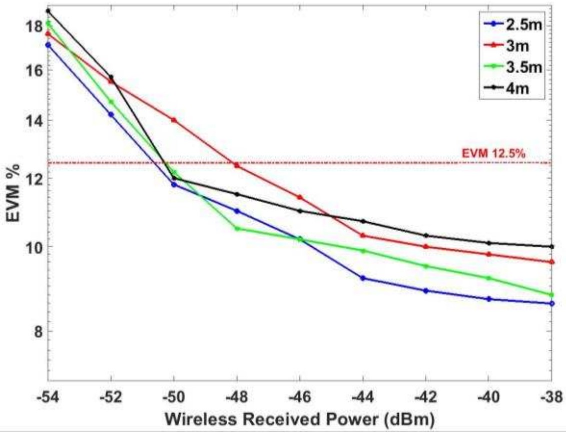

Fig. 6: EVM Performance of 2×2 MIMO as function of wireless received power after STBC decoder

The downlink EVM was also found to be below the threshold for different optical fiber transmission distances up to 2km. The 2×2 MIMO STBC results in considerable reduction in EVM proving the effectiveness of the proposed system for increased coverage using mmW MIMO.

B. Zero Forcing Receiver Performance

The results using the zero forcing algorithm were above the EVM limit for 16-QAM for transmission distances less than 4m because of not achieving sufficient decorrelation between the two channel paths. The EVM performance of the two SISO links (each transmitting at 0.5Gb/s) at different user locations versus the 2×2 zero forcing operation (with overall multiplexing data rate of 1Gb/s) is shown in Fig. 7. After wireless transmission of 5m with antenna spacing of 100cm, the proposed DWDM-RoF setup with LOS MIMO can provide double the data rate using spatial multiplexing with the zero forcing algorithm.

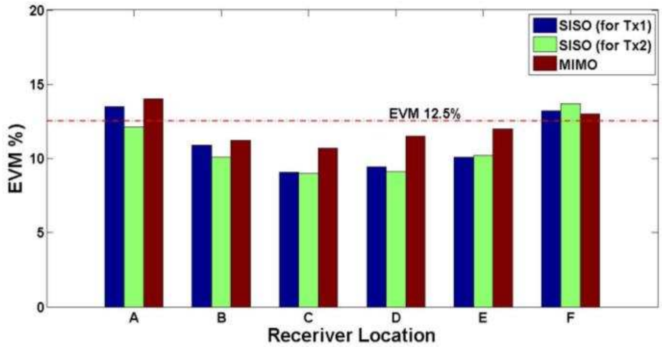

Fig. 7: EVM of SISO with 0.5Gb/s at different receiver locations compared to spatial multiplexing-MIMO with each antenna transmitting 0.5Gb/s

MIMO operation using zero forcing also depends upon the antenna spacing for a specific transmission distance as concluded by the experimental EVM results for wireless distance up to 6m and antenna separation distance from 60cm to 140cm with a step size of 20cm. The best spacing was found to be 100cm or 120cm for longer distances as it was close to the EVM limit for most of the cases as shown in Fig. 8.

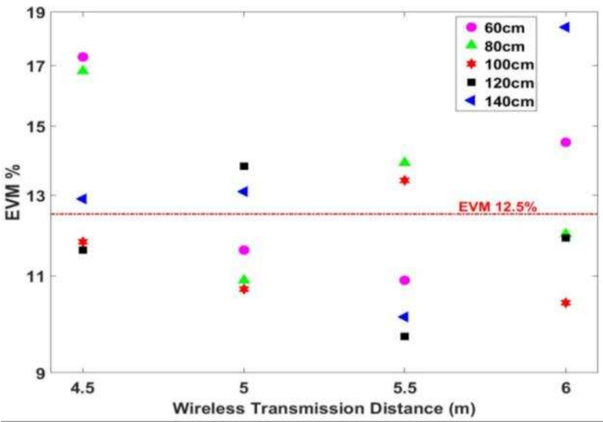

Fig. 8: EVM versus wireless transmission distance for different transmitter separation for Zero-Forcing algorithm

IV. Conclusions

OFDM transmission over a DWDM-RoF setup has been demonstrated for a 2×2 mmW MIMO system by modulating distinct sets of data onto different optical wavelengths. The performance of STBC Alamouti (for diversity gain) and zero forcing (for spatial multiplexing gain) algorithms were experimentally investigated and the EVM results show that the respective gains can be achieved using the proposed optically generated mmW setup after 2km of RoF transport and wireless distance up to 6m. It is also shown that the coverage for mmW transmission using Gb/s data rates can be increased to multiple receiver locations, with optimum antenna separation of the transmitting units. Diversity can be achieved for shorter distances but multiplexing requires longer transmission distances in mmW MIMO.

Acknowledgment

This work has been supported by the EU's H2020 programme, contract 643297 (RAPID).

References

[1] J. James, P. Shen, A. Nkansah X. Liang, N.J. Gomes, "Nonlinearity and noise effects in multi-level signal millimeter-wave over fiber transmission using single and dual wavelength modulation," IEEE Transactions on Microwave Theory and Techniques, 58(11), pp. 3189-3198, 2010.

[2] L. Liu, W. Hong, H. Wang, G. Yang, N. Zhang, H. Zhao, et al., "Characterization of line-of-sight MIMO channel for fixed wireless communications," IEEE Antennas and Wireless Propagation Letters, vol. 6, pp. 36-39, 2007.

[3] I. Sarris, A.R. Nix, "Design and performance assessment of high-capacity MIMO architectures in the presence of a line-of-sight component," IEEE Transactions on Vehicular Technology, vol. 56(4), pp. 2194-2202, 2007.

[4] T.H. Liu, "Analysis of the Alamouti STBC MIMO System With Spatial Division Multiplexing Over the Rayleigh Fading Channel," IEEE Transactions on Wireless Communications, vol. 14(9), pp. 5156-5170, 2015.

[5] A.E. Aighobahi, N.J. Gomes, "Capacity and Error Performance Verification of Multi-Antenna Schemes in Radio-over-Fiber Distributed Antenna System," Journal of Lightwave Technology, vol. 34(99), 2016.

[6] C.H. Ho, W.R. Jiang, R. Sambaraju, W.Y. Lee, T.H. Lu, C.Y. Wang, et al., "Performance Evaluation of a 60 GHz RoF System Employing MIMO and OFDM Modulation," IEEE Journal on Selected Areas in Communications, vol. 31(12), pp. 780-787, 2013.

[7] A. Kanno, T. Kuri, I. Hosako, T. Kawanishi, Y. Yoshida, Y. Yasumura, K.I. Kitayama, "Optical and millimeter-wave radio seamless MIMO transmission based on a radio over fiber technology," Optics Express, vol. 20(28), pp. 29395-29403, 2012.

[8] L. Cheng, M.M.U. Gul, F. Lu, M. Zhu, J. Wang, M. Xu, et al.,"Coordinated Multipoint Transmissions in Millimeter-Wave Radio-Over-Fiber Systems," Journal of Lightwave Technology, vol. 34, pp. 653-660, 2016.