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On the capacity of MIMO-OFDM based diversity and spatial multiplexing in Radio-over-Fiber system

Moussa El Yahyaoui [a], Ali El Moussati [a,*], Ghaïs El Zein [b]

[a] Department of Electronics, Informatics and Telecommunications, ENSAO, Oujda, Morocco
[b] Institute of Electronics and Telecommunications of Rennes, France

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ABSTRACT

This paper proposes a realistic and global simulation to predict the behavior of a Radio over Fiber (RoF) system before its realization. In this work we consider a 2×2 Multiple-Input Multiple-Output (MIMO) Orthogonal Frequency Division Multiplexing (OFDM) RoF system at 60 GHz. This system is based on Spatial Diversity (SD) which increases reliability (decreases probability of error) and Spatial Multiplexing (SMX) which increases data rate, but not necessarily reliability. The 60 GHz MIMO channel model employed in this work based on a lot of measured data and statistical analysis named Triple-S and Valenzuela (TSV) model. To the authors best knowledge; it is the first time that this type of TSV channel model has been employed for 60 GHz MIMO-RoF system. We have evaluated and compared the performance of this system according to the diversity technique, modulation schemes, and channel coding rate for Line-Of-Sight (LOS) desktop environment. The SMX coded is proposed as an intermediate system to improve the Signal to Noise Ratio (SNR) and the data rate. The resulting 2×2 MIMO-OFDM SMX system achieves a higher data rate up to 70 Gb/s with 64QAM and Forward Error Correction (FEC) limit of 10^{-3} over 25-km fiber transmission followed by 3-m wireless transmission using 7 GHz bandwidth of millimeter wave band.

1. Introduction

In order to answer the increasing demand of Gb/s throughput, much interest is given to unlicensed Millimeter Wave (MMW) band, 56–64 GHz. This band offers a large bandwidth of 7 GHz, which can provide high capacity of multi-Gb/s. There are several standards developed to work at MMW e.g. 802.15.3c, 802.11ad, and WirelessHD. However, these standards use just a part of MMW band which limits the throughput. In this work, we consider the 7 GHz of MMW band. Moreover, MIMO technology, which is largely used to improve the spectral efficiency, is investigated. There are three main MIMO types; Spatial Diversity (SD), Spatial Multiplexing (SMX), and beam diversity. Among the three types, SD and MXS are considered in this work. SD allows a good reliability at high noise channel, while MXS increases the data rate linearly with the number of antennas [1]. However, millimeter waves cannot penetrate the walls and are limited to a single room. In this work, we use the RoF solution to overcome this limitation. RoF system combines the benefits of huge fiber bandwidth and high wireless connection mobility. RoF technology is a mean to extend the coverage of MMW signals [2–7].

Compared with traditional wireless communication systems, RoF communication systems cover wider ranges, have more bandwidths, incur lower costs, consume fewer powers and are easier to deploy [8]. Many techniques have been proposed to distribute high capacity MIMO wireless links over optical fiber, such as Single Side-band (SSB) [9,10] and Double Side-band (DSB) [11]. However, these schemes transmit one MIMO RF signal over fiber, and at the base station the RF optical signal is split and de-correlated by an optical fiber to form independent MIMO RF signals. Two independent MIMO RF signals can be simultaneously transmitted over optical fiber, using one of the following techniques: Polarization Division Multiplexing (PDM) [12], PDM with optical heterodyne up-converter at base station [5], or optical subcarrier multiplexing [6]. In our previous work [13], we proposed 2×2 MIMO optical architecture using two independent optical sources with optical subcarrier multiplexing. This work is based on [6], where the authors used optical subcarrier multiplexing based on Optical Carrier Suppression (OCS) technique, using Dual-Parallel Mach–Zehnder Modulator DP-MZM, to transmit two MIMO signals over Single Mode Fiber (SMF). However, our architecture uses two separated

* Corresponding author.
E-mail address: a.elmoussati@ump.ac.ma (A.E. Moussati).

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Lithium Niobate (LiNb) MZM instead of DP-MZM. In order to predict the behavior of RoF systems, this architecture is implemented using a platform based on MATLAB and OptiSystem co-simulation [14,15], which combines Digital Signal Processing (DSP) and electrical/optical environment.

To ensure a good transmission quality at 60 GHz, it is necessary to have a precise channel model that is simple to implement, which will enable us to test the solutions proposed and to evaluate their performance with high accuracy. Most of the earlier studies of the 60 GHz RoF systems have been developed with experimental measurement configurations [2–7,9–11,16,17] or with simplified models such as the Rayleigh and Rice propagation models [18]. Lately studies have been carried out with MIMO only systems using channel statistical models on the basis of the measured data and are found to be accurate in environments with fairly regular geometries and uniform dielectric properties which are Site-general models [19,20]. From this choice, the MIMO channel model used in this work is based on TSV model [21]. This model was proposed by the National Institute of Information and Communication Technology (NICT) Japan to the 802.15.3c Channel model subgroup [22]. Based on experimental architectures already realized [6] and using a more precise channel model, we propose in this work a global architecture including a hybrid system of optical and wireless communication at 60 GHz. The prediction of the behavior of such a system is carried out by a global simulation using the real characteristics of the functions: baseband, optical/RF and transmission environment. To validate our approach we have evaluated and compared two techniques of diversity (SD and SMX) and modulation (QPSK, 16QAM, and 64QAM) with coded Low-Density Parity-Check (LDPC) code for the LOS desktop environment.

The rest of this paper is organized as follows: Section 2 presents the 2×2 MIMO channel model. Section 3 shows the RoF principle. In Section 4 we describe the experimental setup. In Section 5, we present the obtained results and we give a comparison between a complete RoF system and a MIMO system without optical link. Finally, conclusions are given in Section 6.

2. Channel modeling overview

The 60 GHz channel model of MIMO system under LOS condition can be driven from SISO channel model [23]. We have considered the TSV SISO channel model to extend it to MIMO channel. The TSV channel model developed by TG3C is a statistical model whose basic assumption is that multipath components arrive in clusters in both the temporal and spatial domains [22,24]. It incorporates some of the antenna parameters within the channel accounting for their effects. We have used the model of Desktop environment which is a typical office desktop and computer cluster. Task group [24] specified nine channel models for five environments (residential, office, library, desktop, and kiosk) with LOS and NLOS scenarios (a scenario is classified as an LOS scenario if there are no obstacles between the transmitter and the receiver). Path Loss (PL) exponent, the Half Power Beam Width of antennas (HPBW), the distance between antennas, the dimensions of the environment, and existing furniture mainly characterize these environments. To test our channel model, we chose a single case that is the desktop environment with an LOS scenario. This choice is justified because there are several studies with this environment [20,21] and this is the most constraining case compared to other environments. The classic desktop environment, that is, a desktop with its PC and hardware, is the environment targeted by very high-speed data transfer applications between multimedia devices. In almost all cases, this is an LOS configuration where the receiving antenna is pointed towards the transmit antenna, providing a first direct path. Nevertheless, given the angular opening of the antennas, some reflections can take place with all the equipment surrounding the transmitter and the receiver. This model is based on conical horn antennas for Tx and Rx with beam width of 30 degrees and gain of 10 dBi.

Table 1
Desktop LOS parameters.

Desktop parameters	LOS (CM7) Tx-30, Rx-30
Λ [1/ns]	0.037
λ [1/ns]	0.641
Γ [ns]	21.1
γ [ns]	8.85
σ_c [dB]	3.01
σ_r [dB]	7.69
σ_ϕ [degree]	34.6
L	3
Δk [dB]	11
$\Omega(d)$ [dB]	4.44d - 105.4
d_0 [m]	1
h_1 [m]	Uniform distribution in [0, 0.3] range
h_2 [m]	Uniform distribution in [0, 0.3] range
n_d	2

2.1. SISO TSV model

The baseband Channel Impulse Response (CIR) of the TSV model is composed of two terms, LOS and Multipath components [24], as given by

$$h(t,\phi) = \beta\delta(t) + \sum_{l=0}^{L-1}\sum_{m=0}^{M_l-1} \alpha_{l,m}\delta(t-T_l-\tau_{l,m})\delta(\phi-\Psi_l-\psi_{l,m}) \times \sqrt{G_r\left(0,\Psi_l+\psi_{l,m}\right)} \tag{1}$$

where $h(t)$ is the complex envelope of the channel impulse response, β the amplitude factor of LOS component, $\alpha_{l,m}$ the complex amplitude of the mth path of the lth cluster, $\delta(.)$ the delta function, L the total number of clusters, M_l the total number of paths in the lth cluster, T_l the arrival time of the first path of the lth cluster, Ψ_l the arrival angle of the first path of the lth cluster, $\tau_{l,m}$ the delay of the mth path of the lth cluster relative to T_l, $G_r\left(\theta_1,\theta_2\right)$ is the gain of the Rx antenna at the elevation θ_1, and azimuth θ_2 and $\psi_{l,m}$ the arrival angle of the mth path of the lth cluster relative to Ψ_l.

Amplitude factor of LOS path is calculated statistically by two-path response as

$$\beta\,[dB] = 20\log_{10}\left[\left(\frac{\mu_d}{d}\right)\left|\sqrt{G_{t1}G_{r1}} + \sqrt{G_{t2}G_{r2}}\Gamma_0\exp\left[-j\frac{2\pi}{\lambda_f}\frac{2h_1h_2}{d}\right]\right|\right] - PL_d\left(\mu_d\right) \tag{2}$$

where

$$PL_d\left(\mu_d\right)[dB] = PL_{d_0} + 10n_d\log_{10}\left(\frac{d}{d_0}\right) \tag{3}$$

and PL_d, λ_f, μ_d, d_0, n_d, d, Γ_0 , h_1 and h_2 are the path loss in first impulse response, wave-length, mean distance, reference distance, path loss exponent, Tx–Rx separation, reflection coefficient on the ground and walls, and height of the Tx and Rx, respectively. G_{t1}, G_{t2}, G_{r1}, and G_{r2} are the gain of the Tx antenna for path 1 and path 2 and the gain of the Rx antenna for path 1 and path 2, respectively.

The parameters of Desktop LOS environment used [24] are presented in Table 1.

2.2. Extended MIMO channel model

The received signal y as a function of transmitted signal x and noise n is given by

$$y = Hx + n \tag{4}$$

where H is $M_R \times M_T$ channel matrix of MIMO system, M_R and M_T are the number of transmit and receive antennas respectively, and it