Channel Measurements and Ray Tracing Simulations for MIMO Light Communication at 200 MHz

Hossien B. Eldeeb[1], Murat Uysal[1], Sreelal Maravanchery Mana[2], Peter Hellwig[2], Jonas Hilt[2],and Volker Jungnickel[2]
1Department of Electrical and Electronics Engineering, Ozyegin University, Istanbul, Turkey, 34794
2Photonic Networks and Systems, Fraunhofer Heinrich Hertz Institute, Einsteinufer 37, 10587 Berlin, Germany

***Abstract*— In this paper, we investigate 2 × 2 MIMO light communication channels using non-sequential ray tracing simulations, and measurements over 200 MHz bandwidth using a MIMO channel sounder. Results indicate good agreement between simulations and measurements validating the accuracy of ray-tracing.**

Keywords*— *Optical wireless communications, light communications, channel modeling, channel measurements, ray tracing

I. Introduction

Today, light communication (LC) technology is gaining more attention with attractive features such as operation in unregulated large bandwidth and robustness to electromagnetic interference. Both infrared (IR) and visible light (VL) wavelengths can be used to design LC systems which can be positioned as either an alternative or complementary to radio communications [1]. In order to characterize the LC channels, there are two ways. The first one is based on the simulation while the second uses experimental measurements [2]. Although simulations can performed on every personal computer, they have to validate at least once against the measurements in a real scenario.

The IEEE 802.15.13 and 802.11bb standardization groups agreed upon reference channel models generated using non-sequential ray tracing simulation tools [3]. In this approach, evaluation of the impulse response for environments with complex geometries becomes possible. Also, a large number of reflections can be considered, and the impact of wavelength-dependent reflectance of surface as well as different types of reflections (specular, diffuse or mixed) can be taken into account for more accuracy. In [4], simulation results for different LC scenarios are generated based on this approach while measurements for same scenarios are taken using frequency-sweeping technique. The considered LC scenarios are however limited to an empty room and employ only single transmitter (TX) and single receiver (RX)

In this paper, we carry out the multiple-input multiple-output (MIMO) channel measurements using the channel sounder set up and validate the results using the simulations. We consider a furnished conference room where a multiuser MIMO link with two distributed optical frontends and two mobile users is employed. Each transmitter and receiver use multiple IR LEDs and multiple photodiodes (PD), respectively. A wide bandwidth of more than 100 MHz is reached in the optical frontends through impedance matching and bootstrap amplification. The channel sounder is capable of performing broadband channel measurements at frequencies up to 250 MHz for a maximum configuration of 8×8 MIMO. In the accompanying simulation, we consider the same setup carefully taking into account the radiation pattern of LEDs, the effect of the RX directivity, wavelength-dependent reflectance of the walls and objects inside the room, etc. to allow a one-to-one comparison between simulation and measurements. The remainder of the paper is organized as follows. In Section II, we explain the ray tracing methodology used in our study. In Section III, we explain the measurement methodology based on channel sounder. In Section IV, we present and compare the results of simulations and measurements. Finally, we conclude in Section V.

II. Simulation Methodology

In this section, we explain the channel modeling approach. We first create the 3D simulation model of the test environment under consideration in OpticStudio®, and import the CAD models of the objects (i.e., furniture, human beings, etc.). The coating materials of such CAD objects are defined in the simulation platform where the wavelength-dependent reflectance as well scatter fraction can be specified. Then, the light source specifications such as optical power, radiation pattern, orientations, and the number of emitted rays are defined. Additionally, the specifications of the detector such as sensitive area, field-of-view angle, orientations, and directivity are defined. After that, non-sequential ray tracing is performed (i.e. there is no predefined sequence of surfaces which rays being traced must hit) to obtain the path length and power of each ray emitted from the light source and arrived at the detector. Such information is imported into MATLAB® for further processing. Finally, the simulated channel impulse response is constructed as

$$h^{ij}(t) = \sum_{k=1}^{M} P_k^{ij}\,\delta(t-\tau_k^{ij}) \qquad (1)$$

This work has been supported by H2020 Marie Sklodowska-Curie Innovative Training Network (ITN-VisIoN) under Grant 764461. The work of Murat Uysal has been supported by the Turkish Scientific and Research Council (TUBITAK) under Grant 215E311.

where M is the maximum number of rays received by all photodetectors and δ is the Dirac delta function. For each transmitters j and each receiver i, P_k and τ_k denote the optical power and the propagation delay of the k^{th} ray received by the photodetector respectively, $k = 1, 2, \ldots, M$. The channel frequency response for all links can be then calculated by taking the fast Fourier transform (FFT) of (1).

Fig. 1. Furnished conference room where measurements carried out.

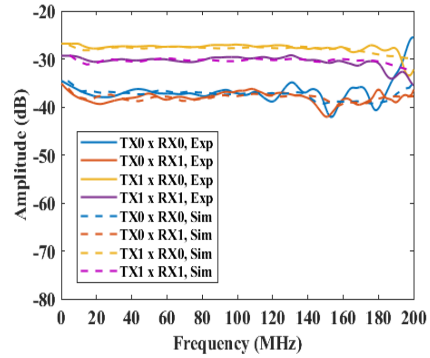

Fig. 2. Amplitude response of simulations and measurements.

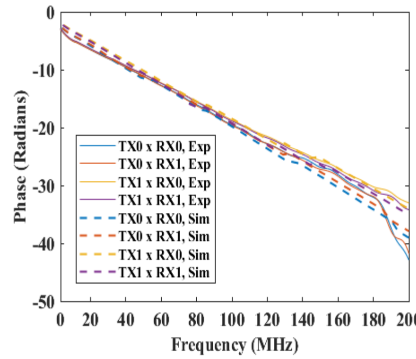

Fig. 3. Phase response of simulations and measurements.

III. Measurement System

The channel sounder is based on a SPECTRUM generator NETBOX and a digitizer NETBOX capable of performing simultaneous MIMO measurements at frequencies up to 250 MHz (https://spectrum-instrumentation.com/de). The generator and digitizer are each connected to two optical frontends using Tx and Rx ports, respectively. Each Tx frontend consists of four OSRAM OSLON SFH-4715AS LEDs having the centroid wavelength at 850 nm. Each Rx frontend consists of five HAMAMATSU-S6968 PDs with a high sensitivity around 850 nm. Tx and Rx have wide beam width and field-of-view (FOV) maximizing the number of transmitted and captured rays, which is critical to include non-line-of-sight signals present in realistic mobile devices. The measurement software is based DC-OFDM as described in [5]. For each link, the measured frequency response contains the response of Tx and Rx frontends. The frontend response is calibrated out as in [4, 6] to retrieve the channel response of the MIMO channel.

IV. Simulation and Experiemental Results

In this section, we present both simulation and experimental results of the 2x2 distributed multiuser MIMO channel characteristics. The considered room dimensions are 7.1 m × 5.8 m × 3 m. Two TX frontends (TX0 and TX1) are installed at the ceiling with a height of 2.9 m while two users represented by two laptop devices are located above a table and their corresponding RX frontends (RX0 and RX1) are located beside as shown in Fig. 1.

Figs. 2 and 3 show the amplitude and phase responses of LC channels obtained by simulations and measurements which obviously agree very well with each other. The frequency responses depend on distance, where the shorter the transmission distance is, the flatter the frequency response. For TX1 (which is located closer to both receivers), the channel is nearly flat up to 150 MHz. A flat channel is obtained at lower frequencies when using TX0 but there is more ripple above 120 MHz compared to the longer transmission distance. Note that there is an increase of noise above 100 MHz in the measured results due to the frontend response. But part of the ripple is also present in the simulation results which contain no noise. Hence, this part can be attributed to multipath components which become little more significant with respect to the line-of-sight (LOS) component if distance gets larger. Hence, when considering wideband LC channels over longer distances, it is increasingly important to include multipath effects.

V. Conclusion

In this paper, an experimental study of MIMO LC channels has been carried out to validate the channel models produced by non-sequential ray-tracing. The measurements based on channel sounder are capable of analyzing MIMO channels together with optical array frontends at both transmitter and receiver sides indeed simultaneously. Results of both approaches have indicated a very good match for both amplitude and phase responses. Our results confirm that ray-tracing creates very realistic LC channel models when using MIMO with distributed optical frontends and multiple mobile users.

References

[1] Z. Ghassemlooy et al., “Emerging optical wireless communications-advances and challenges,” *IEEE JSAC*, vol. 33, no. 9, pp. 1738–1749, 2015.

[2] A. Al-Kinani et al., “Optical wireless communication channel measurements and models,” *IEEE Comm.Surv. & Tut*., vol. 20, no. 3, pp. 1939–1962, 2018.

[3] M. Uysal, et al, “IEEE 802.11 bb reference channel models for indoor environ-ments,” *IEEE, 2018, doc: IEEE* 11-18-1236-01-00bb, July, 2018.

[4] H. B. Eldeeb et al., “Channel modelling for light communications: Validation of ray tracing by measurements,” *IEEE CSNDSP* 2020, accepted.

[5] P. Wilke Berenguer et al., “Optical Wireless MIMO Experiments in an Industrial Environment,” *IEEE JSAC*, vol. 36, no. 1, pp. 1–9, Jan. 2018.

[6] S. M. Mana et al., “Experiments in non-line-of-sight Li-Fi channels,” *2019 Global LIFI Congress (GLC), Paris, France,* 2019.