Experimental Demonstration of 17 Gb/s Transmission Over Indoor Optical Wireless Communication Links Using A Low-Power Single-Mode VCSEL

Hossein KAZEMI[1*], Cheng CHEN[1], Elham SARBAZI[1], Nikolay LEDENTSOV JR.[2], Ilya TITKOV[2], Majid SAFARI[3], Harald HAAS[1]

[1]LiFi Research & Development Center, Department of Electronic & Electrical Engineering, University of Strathclyde, Glasgow, G1 1XW, UK

[2]VI Systems GmbH, Berlin, 10623, Germany

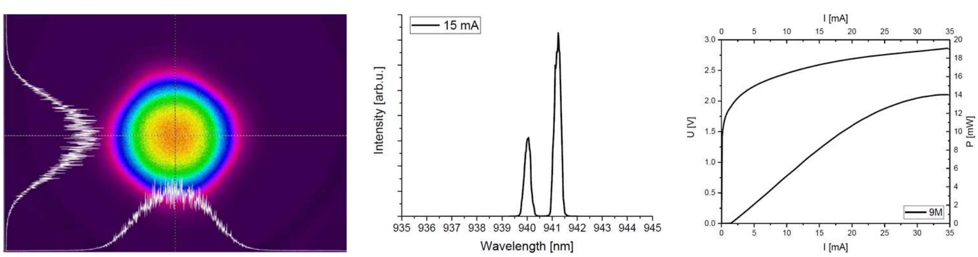
[2]Institute for Imaging, Data and Communications, School of Engineering, The University of Edinburgh, Edinburgh, EH9 3FG, UK

* h.kazemi@strath.ac.uk

Introduction

Optical wireless communication (OWC) is considered as a cost-effective and scalable solution for establishing ultra-high-speed point-to-point links or broadband access networks. Laser-based OWC systems will be capable of supporting the challenging requirements of sixth generation (6G) networks through providing per-user data rates of more than 10 Gb/s and backhaul link capacities of Terabit/s [1].

In this paper, we aim to highlight the potential of a compact and low-power vertical cavity surface emitting laser (VCSEL) for ultra-high-speed laser-based OWC systems. It is a multi-aperture mini array VCSEL in which multiple VCSELs are arranged in an array in close proximity to one another, but they are connected to a common pair of contacts and thus act as a single VCSEL [2]. Multi-aperture VCSELs can achieve higher output powers without compromising their modulation bandwidth and single-mode emission.



a) FF beam profile **b) Emission spectrum** **c) LIV characteristics**

Fig. 1. Static characteristics of the 4-aperture mini array VCSEL used in this work. The FF beam profile was measured at a 4 cm distance and a 15 mA bias current.

a) 2 m link **b) 5 m link**

Fig. 2. Experimental setup for 2 m and 5 m OWC link configurations.

Single-Mode 4-Aperture Mini Array VCSEL

In this work, we use a 940 nm single-mode 4-aperture mini array VCSEL chip designed and manufactured by VI Systems GmbH [3]. The static characteristics of the mini array VCSEL chip are shown in Fig. 1. It has a maximum output power of 14 mW, a far field (FF) divergence half-angle of 18°, and a 3-dB bandwidth in excess of 18 GHz.

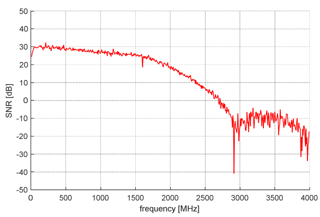
Experimental Setup

The experimental setup used for 2 m and 5 m link configurations is shown in Fig. 2. We use direct current (DC)-biased optical orthogonal frequency division multiplexing (OFDM) with adaptive bit and power loading. The OFDM modulation and demodulation are implemented in MATLAB based on offline digital signal processing (DSP). At the transmitter, the inverse fast Fourier transform (IFFT) operation is applied to a block of quadrature amplitude modulation (QAM) symbols. The resulting digital signal is then converted to an analog signal using the Keysight M8195A arbitrary waveform generator (AWG) at a sampling frequency of $F_s = 16$ Gs/s. The AWG output signal is fed to the Mini Circuits ZFBT-6GW+ bias tee to drive the VCSEL which is biased at a DC current of 10 mA. The Thorlabs ACL7560U-B aspheric lens is used next to the VCSEL to collimate the beam.

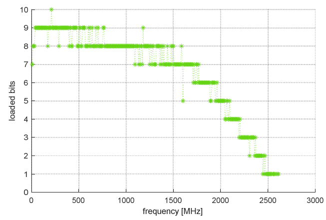
At the receiver, the optical signal is focused onto a high-speed photodetector using an aspheric lens identical to the one employed at the transmitter. We use the Femto HSPR-X-I-1G4-SI amplified Silicon PIN photodiode which has a 3-dB bandwidth of 1.4 GHz. The output signal of the photodetector is converted back to a digital signal by the Keysight MXR608A oscilloscope at 16 Gs/s. The rest of signal processing operations are executed in MATLAB, including FFT, single-tap equalization and QAM demodulation. We set the sample per symbol (SPS) parameter of the AWG to 2, leading to a system bandwidth of $B = F_s/(2 \times \text{SPS}) = 4$ GHz. For each experiment, a total of 150 OFDM frames are sent through the OWC link to measure the bit error ratio (BER) performance.

Measurement Results

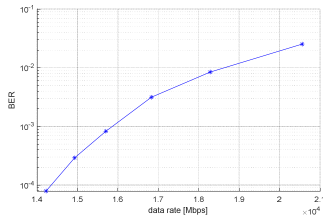
The system performance is measured in terms of the received SNR, the average BER and the achieved data rate. The results for the 2 m and 5 m links are shown in Fig. 3. It can be seen that in both cases, the SNR is close to 30 dB over a wide range of frequencies up to 1.4 GHz, after which it decreases due to the receiver bandwidth at this frequency. From the adaptive bit loading results, 10 bits are allocated to subcarriers with the highest SNR corresponding to 1024-QAM while only 1 bit is assigned to those with the lowest SNR based on binary phase shift keying (BPSK). The achieved data rate is evaluated by [4]:



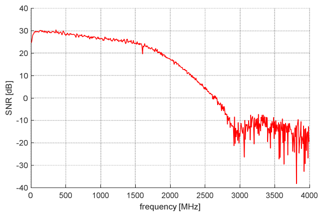
a) SNR vs. frequency



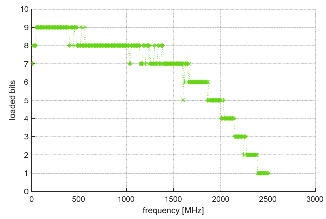
b) Adaptive bit loading



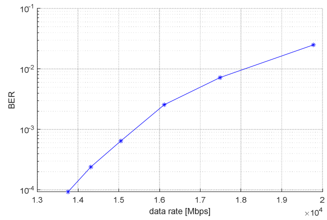
c) BER vs. data rate



d) SNR vs. frequency



e) Adaptive bit loading



f) BER vs. data rate

Fig. 3. Measurement results for (a)–(c) the 2 m link, (d)–(f) the 5 m link.

$$R = 2B \times \frac{\sum_{k=1}^{\frac{N_{\mathrm{FFT}}}{2}-1} \log_2 M_k}{N_{\mathrm{FFT}} + N_{\mathrm{CP}}} \qquad (1)$$

where $N_{\mathrm{FFT}} = 1024$, $M_k > 0$ is the constellation size for the kth subcarrier, and $N_{\mathrm{CP}} = 15$ is the cyclic prefix (CP) length. As shown in Fig. 3, the BER increases with the data rate. At a BER of 3.8×10^{-3}, $R = 17$ Gb/s for the 2 m link and $R = 16.8$ Gb/s for the 5 m link.

Conclusions

We experimentally demonstrated data transmission at 17 Gb/s through indoor OWC links up to 5 m based on a 940 nm single-mode mini array VCSEL device with an optical power of 5 mW. The results evince the potential of such a lower-power light source for realizing ultra-high data rate laser-based OWC links in 6G networks. Extending the link range beyond 5 m will be addressed in our future works.

Acknowledgement

This work was financially supported by the Engineering and Physical Sciences Research Council (EPSRC) under grant EP/S016570/1 'Terabit Bidirectional Multi-User Optical Wireless System (TOWS) for 6G LiFi'.

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