519.21Gbps Optical Interconnect Using 50-Channel Pre-equalized WDM Visible Light Laser Communication System

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Abstract: We demonstrate a record-breaking 519.21Gbps transmission using an integrated WDM visible light laser communication system and hardware pre-equalization for the first time. It is a promising solution for next generation optical interconnects in data centers.

1. Introduction

The proliferation of Internet services and data-intensive applications such as 5G, AR, VR and HD video, is placing unprecedented demands on data center (DC) interconnection networks. The individual lane data rates nearing 100Gbps and 200Gbps to achieve aggregate transmission capacities of 400G and beyond have created a growing need for more efficient optical interconnect schemes capable of delivering high throughput, low latency and cost-effectiveness [1]. Proposed technologies to achieve these goals encompass higher line rates, advanced modulation formats and wavelength division multiplexing (WDM). Additionally, visible light communication (VLC) has emerged as a promising technique that offers numerous advantages [2]. VLC leverages the unlicensed and abundant visible light spectrum to provide high-speed and low-latency communication. And it can be implemented with low-cost components. These attributes position it as a promising solution for next generation optical interconnects.

Recent advancements in visible light laser communication (VLLC) systems utilizing WDM techniques have been documented. In 2019, Wei et al. utilized R/G/B-LDs with polarization multiplexing technology to achieve the highest total data rate of 40.665Gbps in a 2m free space [3]. In 2020, Wang at el. used QAM discrete multitoned (DMT) modulation for R/G/V LDs to obtain a 34.8Gbps data rate in a 0.3m free space [4]. In 2022, Hu et al. used DMT bit-power-loading algorithm along with R/G/B tricolor laser transmitter, achieving a recorded data rate of 46.41Gbps in a 0.3m free space [5]. However, previous efforts have not fully enabled optical interconnects beyond 400G. One key approach involves expanding the communication channels or multiplexing more wavelengths.

Here, we demonstrated a record-breaking 519.21Gbps data transmission using an integrated 50-channel WDM VLLC system, which multiplexed 31 different wavelengths within the visible band. As far as we know, it represents the highest data rate achieved by VLLC systems. Furthermore, we employed a bridged-T hardware pre-equalizer [6] with a central frequency of 2GHz to mitigate high-frequency fading in VLLC systems for the first time. This data rate was attained over 1m MMF-17cm FSO-1m MMF links, with the BER of each laser channel remaining below the %7 FEC threshold of 3.8E-3. Experimental verification has confirmed that the demonstrated WDM VLLC system holds the potential to serve as a high-capacity and cost-effective solution for optical interconnects in DCs.

2 System Design

Fig.1 shows the system design of the 50-channel hardware bridge-T pre-equalized WDM VLLC system. Fifty

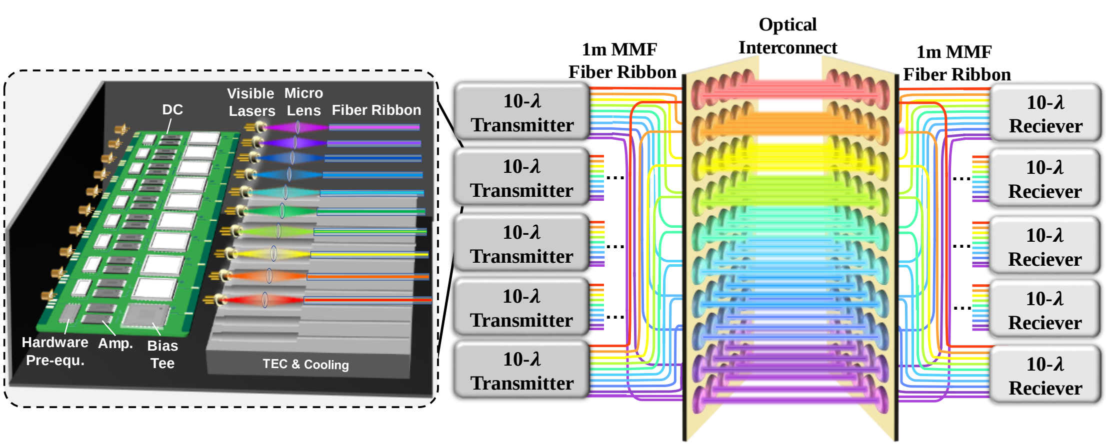

Fig.1. The design of our proposed 50-channel WDM Visible Light Laser Communication System.

transmitter units are integrated across five 4U chassis, with each chassis accommodating ten units. Each chassis is equipped with a TEC device and cooling system for temperature regulation. Within the transmitter, each channel' RF signal is pre-equalized and amplified before being coupled with a DC source to drive lasers. These electrical components are consolidated onto a single PCB board. The emitted light is coupled into a fiber ribbon via micro lens. The output from 50 channels is guided to the optical antenna array through 1m MMF ribbon. After traveling through 17cm free space, the signal is delivered to corresponding receivers through another 1m MMF fiber ribbon.

3. Experimental Setup

Fig.2 illustrates the experimental setup. Our system employed adaptive bit-power-loading DMT modulation and LC algorithm as presented in [7]. SNR for each subcarrier is estimated by transmitting QPSK test sequence, and then LC allocation algorithm is utilized to determine the maximum order that each subcarrier can optimally support.

At the transmitter, input data is mapped to QAM symbols and up-sampled after bit-power loading. Subsequently, IFFT transforms it into a time-domain signal and cyclic prefix(CP) is added. The generated signal is loaded into an arbitrary waveform generator (AWG, M8190A, Keysight) for digital-to-analog conversion. To resist high frequency fading, we introduced a hardware pre-equalization circuit based on T-Bridge in the visible laser system for the first time. Its amplitude response curve is shown in Fig.2, with a central frequency of 2GHz. With a 10dB maximum attenuation at DC and a 1GHz frequency where attenuation reaches 50%, it significantly enhances the high frequency portion to counteract fading. After that, it is amplified by an electrical amplifier (EA, ZHL-1042J+, Mini-Circuits) and coupled with DC by Bias-Tee (ZFBT-4R2GW-FT+, Mini-Circuits) to drive lasers. The transmitted light beams are conveyed to an optical antenna lens array by 1m MMF. After traveling through 17 cm of free space, the signal is received by another optical antenna lens array and directed to PDs (DET025AFC, Thorlabs).

On the receiver side, the detected signal is initially sampled by an oscilloscope (OSC, MSO9404A) for offline DSP. Subsequently, it is resampled and synchronized before DMT demodulation. Zero-forcing equalization is employed to alleviate signal distortion and inter-symbol interference (ISI). Original data can be restored by QAM de-mapping. Images of the constructed VLLC system are included in Fig.2. The overall view is shown in Fig.2(b). The details of the transmitter are illustrated in Fig.2(a), while the receiving end is displayed in Fig.2(c).

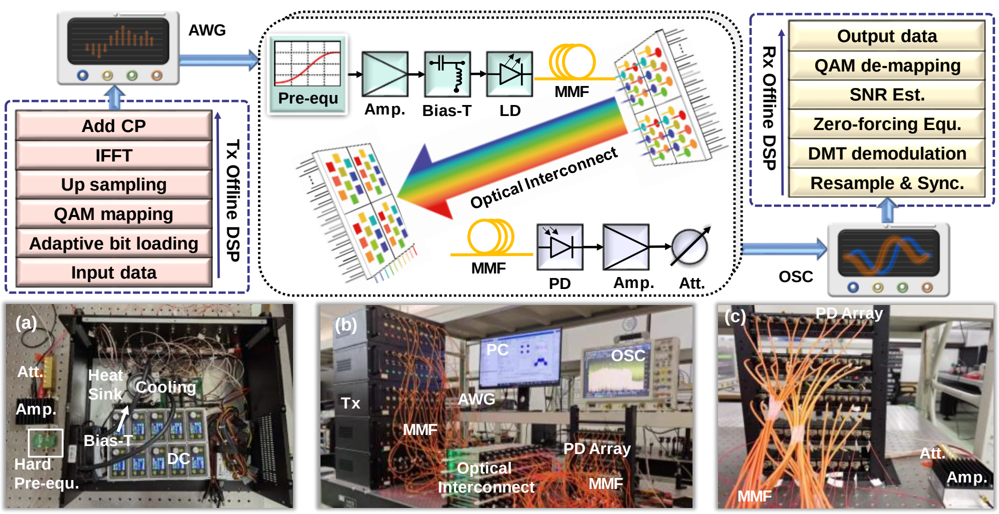

Fig.2 Experimental Setup. (a) The details of the transmitter; (b) The overall view of our constructed VLLC system; (c) The receiving end. Amp: amplifier; Att.: attenuator; SNR Est.: SNR Estimation; Sync.: Synchronization; Pre-equ.: Pre-equalization.

4. Experimental Results

We first examined the impact of the hardware pre-equalization circuit in our VLLC system. Fig.3(a)-(c) illustrate data rates as a function of signal Vpp at three typical wavelengths (486.803nm, 517.724nm and 638.662nm), respectively. Data rates with hardware pre-equalization consistently outperform those without. Specifically, the data rate increases from 7.89Gbps to 9.40Gbps at 486.803nm, from 7.68Gps to 8.70Gbps at 517.724nm, and from 9.20Gbps to 10.39Gbps at 638.662nm, with 7% FEC BER threshold of 3.8E-3. The spectrum for these three wavelengths, both with and without hardware pre-equalization, are inserted in Fig. 3(a)-(c), respectively. Observably, hardware pre-equalization enhances the high-frequency portion, resulting in improved SNR and data rate. Fig.4 (a) displays the optical spectrum of the 50 visible lasers. We multiplex 31 different wavelengths, spanning from

484.479nm to 688.603nm. Achievable data rates of 50 visible lasers and their corresponding BER are depicted in Fig. 4(b). The maximum data rate reaches 12.15Gbps, while the minimum data rate is 6.45Gbps. Ultimately, we achieved a total data rate of 519.21Gbps, with each channel's BER falling below the %7 FEC BER threshold.

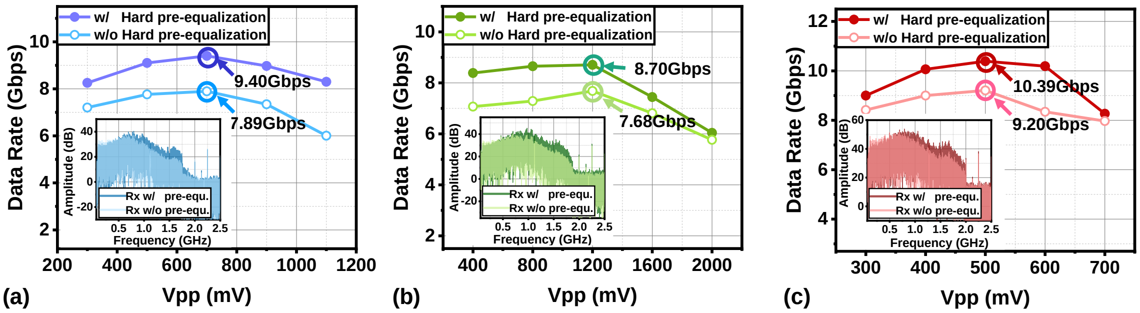

Fig.3 The data rates versus signal Vpp for (a)486.803nm; (b)517.724nm; (c) 638.662nm. Both the spectrums with and without hardware pre-equalization for these three wavelengths are inserted in (a)-(c), respectively.

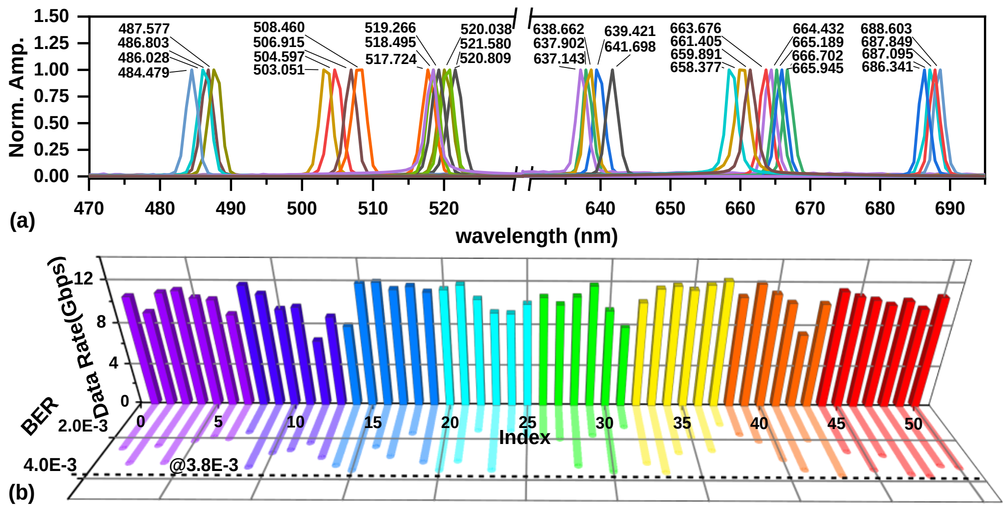

Fig.4 (a)The optical spectrum of 50 visible lasers. (b) The data rates and BER of 50 VLLC channels.

5. Conclusions

In this paper, we achieved a record-breaking 519.21Gbps data transmission over 1m MMF-17cm FSO-1m MMF links using a 50-channel hardware bridged-T pre-equalized WDM VLLC system for the first time. As far as we know, it represents the highest data rate achieved by VLLC systems employing WDM technology. The hardware pre-equalizer is experimentally verified to increase data rate significantly. The demonstrated system emerges as a promising solution for cost-effective and high-speed optical interconnects for data centers.

6. Acknowledgement

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7. References

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