Real-time Demonstration of Software Reconfigurable Dynamic Power-and-subcarrier Allocation Scheme for OFDM-NOMA based Multi-user Visible Light Communications

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Abstract: For the first time, we experimentally demonstrated a novel software-reconfigurable dynamic power-and-subcarrier allocation scheme for real-time multi-user OFDM-NOMA VLC. It is markedly adaptive to dynamic demand while maintaining better user fairness and system flexibility.

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1. Introduction

Visible light communication (VLC) has been recognized as a promising technology for future optical wireless communication because of its low cost and high security [1, 2]. To unleash full potential of VLC, efficient multiple access techniques are needed to explore multi-user VLC applications. Recently, the power domain non-orthogonal multiple access (NOMA) has been gaining tremendous interests from both industry and academia. In NOMA-based systems, multiple users sharing the same spectral resource are capable of transmitting signals configured with different power weights, leading to better user fairness and enhanced system throughput [3-5]. In [5], the combination of orthogonal frequency division multiplexing (OFDM) and NOMA were applied to VLC via offline demonstrations, and showed larger system throughput than that of the conventional OFDM. However, the scheme is less suitable for practical applications under dynamic and diverse channel conditions, as static parameter loading is assumed [5]. Moreover, subcarrier allocation is crucial for system performance optimization, especially when considering different power fading conditions over each subcarrier/user in the bandwidth-limited VLC system. Therefore, it is highly desirable that the software-reconfiguration can be supported in real-time to dynamically handle parameters such as power ratio and subcarrier number, in order to realize flexible system capacity and manage resource allocation according to user demand in OFDM-NOMA based VLC systems.

In this paper, for the first time, a real-time software-reconfigurable dynamic power-and-subcarrier allocation scheme is proposed and experimentally demonstrated in an OFDM-NOMA based VLC system. It is shown that the power ratio can be dynamically adjusted under varying channel conditions, resulting in better user fairness as well as optimal transmission performance. Furthermore, with the help of software-reconfigurable subcarrier allocation, data rates of each user can be flexibly controlled to fulfill the corresponding capacity demand. By using the proposed scheme, up to 1.84-Gbit/s real-time OFDM-NOMA VLC transmission is successfully demonstrated.

2. Operation principle of dynamic power and subcarrier allocation for OFDM-NOMA

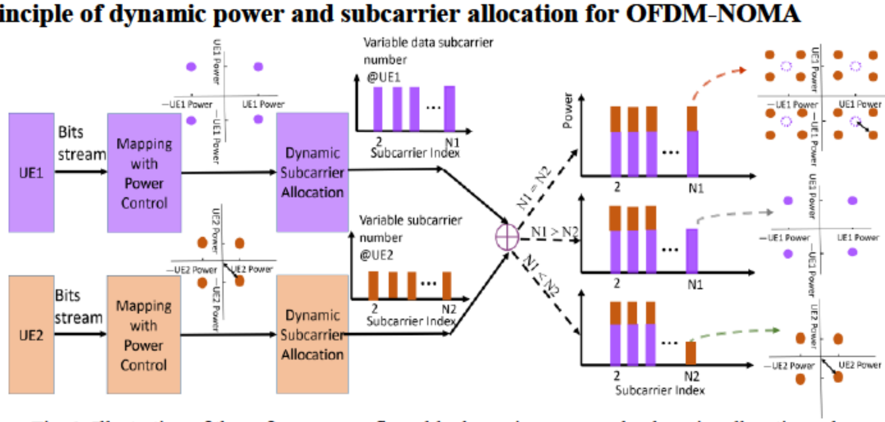

Fig. 1. Illustration of the software-reconfigurable dynamic power-and-subcarrier allocation scheme.

Fig. 1 illustrates the operation principle of the proposed dynamic power-and-subcarrier allocation scheme. It is assumed that two users have different channel conditions. The user with an inferior channel condition, denoted as UE1, requires a larger power. A small power is allocated to the user with a good channel condition (denoted as UE2). The two users both employ QPSK mapping and the constellation points of each user are scaled by the corresponding power weights, so as to realize power control. Then, the symbols are placed on the available subcarriers according to the demand of user's data rate. Before utilizing IFFT, the symbols of both users are superposed in the power domain. Note that three different cases might arise due to the possibility that the number of the allocated subcarrier of UE1 may be larger/smaller than or equal to that of UE2. When the same numbers of subcarriers are allocated to UE1 and UE2, the resulting NOMA constellation, which is the overlapped signal of UE1 and UE2, will be a 16-QAM-like constellation. The other two cases will result in a 20-QAM-like constellation. In order to recover the users' information, the successive interference cancellation (SIC) technique is utilized to solve multi-user interference (MUI). Namely, at the receiver of UE1, the recovered signal is directly de-modulated, while the interference from UE2 is treated as noise. However, at the receiver of UE2, the signal component of UE1 is firstly decoded. Subsequently, the desired signal of UE2 can be decoded by subtracting the signal component of UE1. In the cases that some subcarriers are assigned to one user only, there is no MUI over these subcarriers.

3. Experimental setup and results

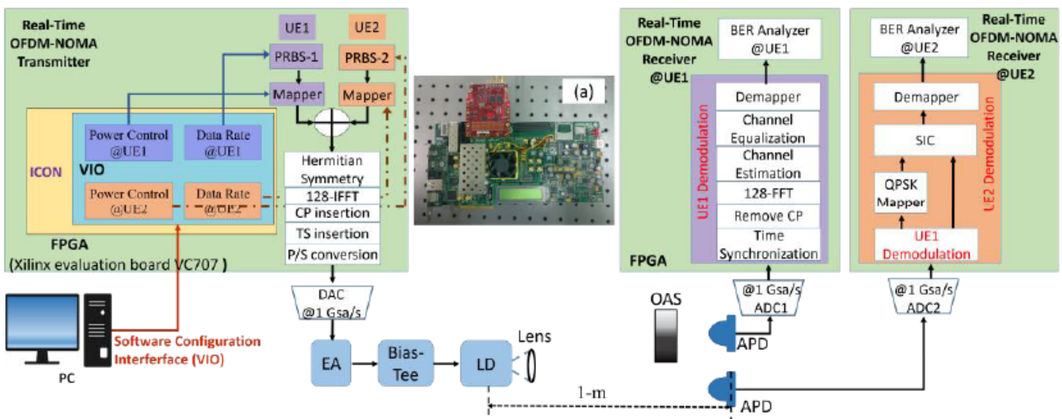

Fig. 2. Diagram of the real-time OFDM-NOMA VLC system. Inset (a) shows the FPGA board and the DAC/ADC card used for experiments.

The experimental setup of the real-time software-reconfigurable OFDM-NOMA based VLC system is shown in Fig. 2. The OFDM-NOMA transmitter and receiver are implemented in real-time by using a Xilinx evaluation board (VC707) and a 4DSP daughter card (FMC110) which provides dual-channel analog-to-digital converter (ADC) and dual-channel digital-to-analog converter (DAC). At the transmitter, the two generated pseudo-random binary sequences (PRBS) are mapped into QPSK symbols for UE1 and UE2, respectively. The power weighting factors of symbols of UE1 and UE2 can be dynamically controlled by a virtual input/output (VIO) intellectual property core [6], leading to the software-reconfigurable power allocation. Furthermore, the numbers of effective data subcarriers of UE1 and UE2 can also be adjusted by VIO in real-time. After symbol overlapping of UE1 and UE2 in the frequency domain, Hermitian symmetry is imposed on the subcarriers before feeding into 128-point IFFT to obtain real-valued OFDM-NOMA signals. The digital OFDM-NOMA signal is converted into analog signal by a 12-bit 1-GS/s DAC after 8-sample cyclic prefix (CP) and training symbols (TS) insertion, and parallel-to-serial (P/S) conversion. The output of the DAC is firstly amplified by an electrical amplifier (EA). The amplified signal, together with a DC bias, is then used to drive a blue laser diode (LD, Osram PL450). In front of the LD, a bi-convex lens is placed to collimate the light. After 1-m free-space transmission, two identical APDs are used for signal detection. A variable optical attenuation slice (OAS) is placed in front of the APD of UE1 to attenuate the received light, so as to emulate an inferior channel condition. At the receiver of UE1, the detected electrical signal by the APD is then converted into digital signal by an ADC with a 1-GS/s sampling rate. After the digital signal processing (DSP) shown in Fig. 2, which includes synchronization, CP removal, 128-point FFT, channel estimation, equalization, and QPSK demapper, error counting is performed to attain the BER of UE1. As aforementioned, the interference from UE2 is treated as noise, due to its small power allocation. At the receiver of UE2, UE1's demodulation is firstly carried out, and then the SIC algorithm is utilized to recover the signal of UE2.

Firstly, we investigate the impact of power allocation on different channel conditions between UE1 and UE2 with fixed subcarrier allocation. Given the data rate of each user is 0.92 Gbit/s, i.e., 60 data subcarriers are assigned to UE1 and UE2, respectively, the received light power of UE2 is fixed at 40 mW. By varying the received light power of UE1 to be 20 mW, 10 mW and 5 mW, the BERs versus the power ratio between UE1 and UE2 are depicted in Fig. 3(a-c), respectively.

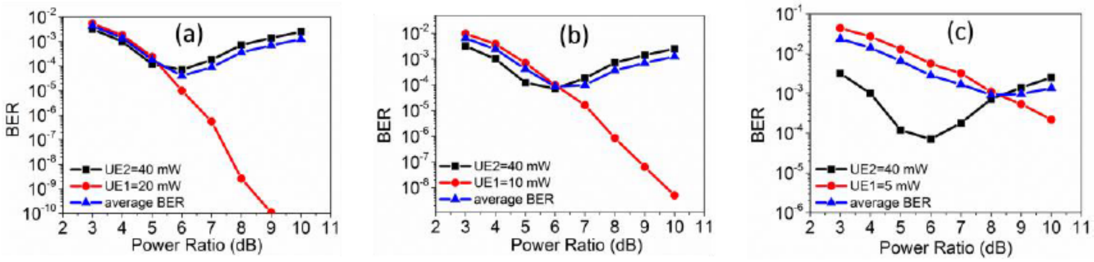

Fig. 3. BER versus the power ratio between UE1 and UE2, with UE1's received the power being (a) 20 mW, (b) 10 mW and (c) 5 mW.

In the experiments, the power ratio is software-reconfigurable and is dynamically adjusted in real-time. The BER of UE1 monotonically decreases with the increase in power ratio, as more power is allocated to UE1. In contrast, for UE2, reducing power ratio will first decrease the BER. Then, the BER will increase with further reduction in power ratio, which is due to the error propagation as the SIC algorithm is adopted. In order to obtain an optimized overall performance as well as better user fairness for the real-time OFDM-NOMA system, the average BER of UE1 and UE2 is taken as the metric in our experiment. It can be seen that, for the three different cases, the optimal average BERs are 4.05×10^{-5}, 8.45×10^{-5} and 2.84×10^{-3}, which corresponds to optimal power ratios of 6 dB, 6 dB and 8 dB, respectively. Meanwhile, at the optimal power ratios, the BERs between UE1 and UE2 are most comparable, ensuring better user fairness.

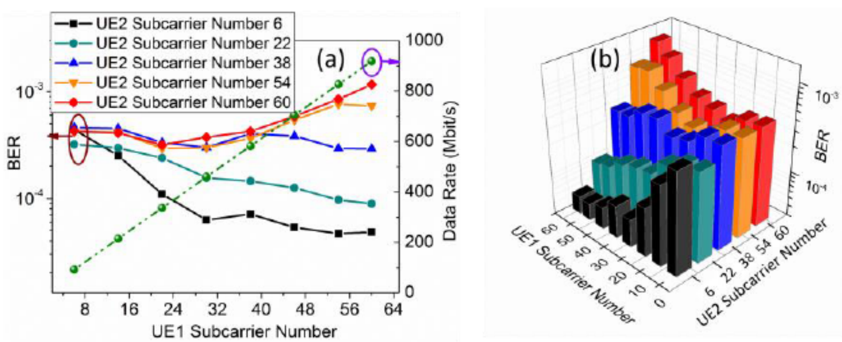

Fig. 4. (a) BER and data rate versus UE1's subcarrier number with different subcarrier numbers of UE2, (b) the corresponding 3-D plotting.

To further investigate the impact of subcarrier allocation on the OFDM-NOMA based VLC system, at a received power of 5 mW for UE1, the data rate of UE1 is dynamically adjusted by allocating different numbers of subcarrier to UE1 under different data rate of UE2, while the power ratio is fixed at 8 dB. The corresponding results are shown in Fig. 4. It is seen that UE1's BER performance gradually improves with the decrease of the subcarrier number of UE2, which results from reduced MUI. With a BER lower than 3.8×10^{-3}, up to 1.84 Gbit/s aggregate capacity can be realized. More importantly, with the help of adjusting the user's subcarrier number in real-time, the corresponding data-rate demands of users can be dynamically fulfilled, as shown in Fig. 4. Therefore, the proposed real-time dynamic power-and-subcarrier allocation scheme is a flexible solution for practical OFDM-NOMA system to fulfill the quality of service requirements among users, as well as to ensure better user fairness.

4. Conclusion

We have proposed and experimentally demonstrated, for the first time, a real-time, software-reconfigurable dynamic power-and-subcarrier allocation scheme for OFDM-NOMA based VLC. The flexibility and robustness of dynamic power/subcarrier allocation have been experimentally demonstrated. Transmission of 1.84-Gbit/s real-time OFDM-NOMA transmission has been realized with a BER well below the 3.8×10^{-3} FEC limit. Our proposed scheme provides a flexible solution for multi-user VLC system to ensure better user fairness and fulfill different capacity demands. *This work was supported in part by NSFC project of China (61775054), Science and Technology Project of Hunan Province (2016GK2011) and HKSAR RGC grant (GRF 14201217).*

5. References

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