Multiple Access Schemes for Visible Light Communication

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***Abstract*- Visible light communication (VLC) is an emerging technology which can provide ubiquitous connectivity for the fifth generation wireless communication and beyond. For a densely deployed VLC network, multiple access control is an important issue while supporting massive users. Several MA schemes have been proposed in recent works to improve maximum throughput and an increasing number of connected channels. In this paper, we provided an overview of various orthogonal and non-orthogonal MA schemes applied for VLC networks. We make a comparison of the schemes according to their achievable maximum user data rate and bit error probability. Moreover, hybrid schemes are considered in this paper to improve the sum rate of the system.**

Keywords- Visible light communication; multiple access; NOMA; maximum spatial density.

I. Introduction

Due to massive increment of mobile devices, user's data demand in every sector of computing and communication, wireless data traffic is expected to increase over 500 Eb by 2020 [1]. To support next-generation ultra-high-speed wireless network support, researchers are showing much research interests on massive multiple-input multiple-output, mm-Wave, optical bands (infrared, visible light, and ultra-violet) based high-speed network systems [2]. Visible light communication (VLC) uses available bands of order terahertz and can provide up to 100 Gb/s data rate at a 5 m distant wireless communication link [3]. It has been a great opportunity to deploy low-cost VLC system as it offers existing lighting infrastructures to be used as transmitters and low-cost photodetectors as receivers. Moreover, VLC network can provide highly secured communications as visible light cannot penetrate walls and cannot be accessed from outside. In this system, a visible light source is modulated according to the transmitted data above the fusion frequency of the human eye which offers to use the same visible light source to use for both communication and illumination purposes [4]– [6].

As a wireless broadband technology, VLC system has to be compatible with the multiple user supports. The recent development on VLC networks research causes ultra-dense deployment of visible light access points (VLAPs). Consequently, this emphasis on multiple access management, resource utilization, and inter-cell interference (ICI) control. The conventional multiple access (MA) techniques such as time division multiple access (TDMA), code division multiple access (CDMA) and frequency division multiple access (FDMA) cannot support the required level of mobile terminal (MT) loads to be accessed. An extended form of FDMA was proposed for long term evolution. In this paper, we provided an overview of various orthogonal MA (OMA), non-orthogonal MA (NOMA), and hybrid schemes applied for VLC networks. We make a comparison of the schemes according to their achievable maximum user data rate and bit error probability. The rest of the paper is arranged as follows: In Section II, both orthogonal and non-orthogonal MA schemes are described for VLC. Hybrid OMA and NOMA schemes for VLC with their contributions are provided in Section III. Section IV provides a brief conclusion of this paper.

II. Multiple Access Schemes For VLC

Multiple access support is required for densely deployed access points in VLC network. In the next subsections, the review of some proposed MA schemes is provided.

A. *Orthogonal Multiple Access (OMA)*

The simplest and the straightforward orthogonal scheme is time division multiple access (TDMA) which transmits multiple user subcarrier channels through orthogonal time slots. In dense VLC networks, the TDMA approach does not work well due to the demand of an increased number of user access.

Orthogonal frequency division multiple access (OFDMA) based VLC was proposed in [7] named hybrid VLC-OFDMA network model to support multiple access to the numbers of mobile terminals (MTs). In this system, M number of VLC hotspots and an OFDMA access point was linked to a server through a wired connection and OFDMA sub channels were used for uplink connections or downlink connections only when the MTs are out of hotspot coverage area. Their results show that to support increased numbers of MTs, maximum spatial density should obtain a higher value along with the increase of M and OFDMA sub-carrier channels.

Layered asymmetrically clipped optical OFDMA (LACO-OFDMA) can be proposed for highly dense VLC network to access multiple users with better throughputs and low power injects [8]. It performs better than DC-biased optical OFDMA because it eliminates the need for DC power input. This scheme can outperform multi-user access for both throughputs and maximum spatial density.

In [9], orthogonal code division multiple access (OCDMA) system was proposed for VLC to support multiple user communication. In this system, a sequence of code was transmitted for a selected time slot. To support multiple users, link a number of code sequence was designed to transmit for a time period T and T was divided into L slots depending on the user numbers. Random optical codes (ROCs) were used to define each users code sequence because this has an acceptable bit error rate (BER) while varying the users [10]. In the experiment, the authors used pin photodiodes as the optical receiver and LED transmitter which transmits internet protocol packets through a local access network. These packets were encoded modulated using OCDMA and all the system was implemented in Virtex-5 FPGAs tools. Finally, the authors were able to demonstrate the system for 8 users with an average throughput of 160 kbps. The BER was achieved bellow 10^{-5}.

B. *Non-orthogonal Multiple Access (NOMA)*

NOMA which has been proposed for designing the radio access networks for 5G and beyond (5GB) can be used for VLC networks to improve user throughput and BER reduction to a much higher level. In very recent years, researchers working on conventional OMA based VLC networks are switching to NOMA based approaches [11]–[13].

Optical NOMA (O-NOMA) in VLC networks was proposed in [11]. This approach can utilize the entire available frequency band and improve spectral efficiency. NOMA can be classified into two major parts for VLC such as power domain NOMA and code domain NOMA. The authors utilize O-NOMA with successive interference cancellation (SIC) to two receivers. Different power values were assigned to each receiver by applying superposition coding. They examined through simulation that their work achieved 2 times greater data rate than a conventional OFDMA system with a considerably reduced BER.

Another work on NOMA for VLC was proposed by the same author in [12]. They considered an indoor scenario of multiple LEDs where LEDs field-of-view can be slightly overlapped. The LEDs were considered transmitting multiple data of its separate power level considering the NOMA approach. In this case, the user at the cell boundary can experience both the signals of different power.

In [13], the authors proposed a new NOMA based VLC scheme for inter-satellite communication. They considered a cluster of 3 satellites and simulated real-time data transmission. Of which one satellite worked as a master transmitter using VL spectra and other twos shared the VL channel to perform multiple access for that network. Through simulation, they achieved up to several Mbps level data rate and BER of up to 10^{-5}.

NOMA for downlink VLC was proposed in [14]. Their schemes use two-users to access information from a single LED ensures outperformed throughputs and BER reduction than conventional OMA techniques. They introduce optimal power allocation strategies for VLC NOMA considering two important theorems: sum-rate maximization and max-min fairness power allocation. The authors achieved a larger sum rate of the NOMA VLC system than the OMA scheme.

III. HYBRID NOMA & OMA FOR VLC

Conventional NOMA schemes outperform over the OMA based VLC system in terms of user data rate and quality of services and handover management between two adjacent VLC access points (APs) [11], [13]. However, for an ultra-dense VLC APs deployment, the performance degrades for conventional NOMA. Dense deployment of APs causes inter-cell-interference (ICI) among them. Moreover, this scheme faces the limitation of maximum MTs-load limitation advancement of it becomes necessary.

To ensure better performance hybrid NOMA and OMA schemes can be deployed. Implementing frequency reuse technique along with the hybrid system can improve the total sum rate availability and special density as well. In hybrid system, it is important to select strategically that which technique performs better depending on the state of users. A solution approach has been proposed in [15] for the user pairing in an efficient selection strategy for hybrid NOMA and OMA techniques. They analyzed the impact of user pairing for both individual and sum rate. The authors found that distinctive channel pairing outperforms better than similar channel pairing.

Figure 1 depicts the achievable throughput comparison among conventional OMA, power domain NOMA, and hybrid NOMA and OMA schemes for a different number of user terminals. It has been seen that for a conventional OMA-VLC technique the throughput reduces with the increase of user terminals. Whereas, the power domain NOMA technique for VLC shows much higher throughput and achieves better performance for the increased number of users. Also, Hybrid scheme can be applied for the highly dense VLC APs network to support even more user terminals.

IV. CONCLUSION

This work represents a brief overview of OMA and NOMA techniques for dense VLC network. NOMA allows multiple users to access the network by channel multiplexing in the power domain. It can improve the sum-throughput above three times higher than the conventional OMA schemes. However, for a considerably higher number of users' hybrid OMA and NOMA techniques show better performances than NOMA. This scheme outperforms in

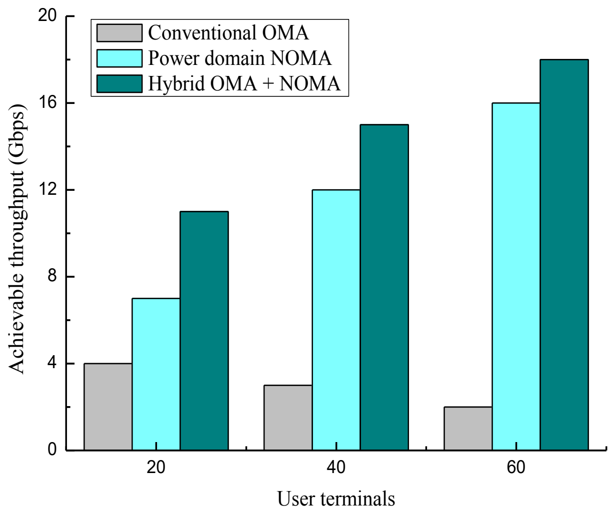

Figure 1. Throughput comparison among conventional OMA, power domain NOMA, and hybrid NOMA and OMA schemes for the different number of user terminals.

terms of data rate and number of user support over other individual techniques.

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