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Optical Repeater Assisted Visible Light Device-to-Device Communications

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Abstract—Device-to-device (D2D) communication is considered a promising technique to provide wireless peer-to-peer communication services. Due to increasing demand on mobile services, available spectrum for radio frequency (RF) based communications becomes scarce. Recently, visible light communications (VLC) has evolved as a high speed wireless data transmission technology for indoor environments with abundant available bandwidth. In this paper, a novel VLC based D2D communication that provides wireless peer-to-peer communication is proposed. Potential low operating power devices for an efficient D2D communication over increasing distance of separation between devices is analyzed. Optical repeaters (OR) are also proposed to enhance the performance in an environment where direct D2D communications yield degraded performance. Simulation results show that VLC plays an important role in providing efficient D2D communication up to a distance of 1 m between devices. It is also found that the OR significantly improves the coverage distance up to 3.5 m.

Keywords—Visible light communication, light emitting diode, device-to-device, optical repeater.

I. Introduction

WITH the advancement in the present wireless technology, the use of smartphones and advanced ubiquitous smart devices is undergoing unprecedented growth. This has resulted in an ever-growing demand for high speed wireless data communication. As mobile operators attempt to accommodate the demand of existing mobile users, new data intensive applications such as Internet-of-Things (IoT), smart homes etc. emerge. Traditional radio frequency (RF) communications suffer from limited channel capacity and spectrum, and have reached a bottleneck to meet increasing data rate needs [1]. In view of this, device-to-device (D2D) communication is proposed to lessen scarce spectrum and capacity. The D2D communication appears to be a promising component in the next generation of communication [1], [2].

The D2D communication allows two nearby devices to communicate with each other. The communication can be in licensed RF band with or without the involvement of base station. It can also be in unlicensed band, e.g. bluetooth. The unlicensed band communication would entail uncontrollable interference and less secure transmission. It does not provide the quality of service (QoS) similar to RF band [3]. Although significant research works have been reported to overcome the issues related to interference and efficient resources allocation, scarce licensed and unlicensed spectrum available for RF communication cannot cope with an ever-growing demand of exponentially increasing users and devices [2].

With various advantages such as license-free spectrum, electromagnetic interference-free transmission and high security, visible light is now able to provide a data rate of gigabits per second (Gbps) [4]. As a result, the visible light communications (VLC) with abundant bandwidth (in terahertz) has emerged as a compelling technology that has potential to change the face of future wireless communications [5].

A VLC system uses light emitting diodes (LEDs) as transmitters and photodetectors (PDs) as receivers. It relies predominantly on intensity modulation and direct detection (IM/DD) technique for communication. VLC used to offer two unique functionalities: illumination and communication. Interestingly, another unique functionality of motion detection based on VLC has recently been reported in the literature [6]. Together with other known advantages, such as cost-effectiveness and no harm to humans and electronic devices, the deployment of VLC systems is envisioned to grow rapidly for years to come.

The abundant bandwidth available in THz, high data rates in Gbps, highly secure communication and applications in smart homes [7] make VLC a potential candidate for the D2D communication. In this paper, a novel VLC based D2D communication is presented. The conventional VLC networks connect to control unit and fulfil the functionality of illumination and communication. The D2D communication, however, requires the devices to be in proximity and direct connectivity. Moreover, the performance of a VLC system depends largely on both the optical power received from the line-of-sight (LOS) transmission path and the distance between the devices. In addition, due to design constraints in VLC, the devices are power limited for transmission. Therefore, this paper presents a novel VLC based D2D to address possible direct connectivity without the involvement of control unit infrastructure at low operating power of devices.

In the proposed work, on-off keying (OOK) modulation scheme that is a IEEE 802.15.7 PHY II standard modulation [8] is employed for transmission with a data rate of 9.6 Mbps. The bit error rate (BER) and achievable data rate (ADR) performance of the D2D communication are analyzed by varying the distance of separation between the devices. With the increase in distance between the devices, the performance severely degrades. To address this performance degradation, the optical repeaters (OR) [9] are installed within the indoor environment.

The remainder of paper is organized as follows. Section II

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presents the description of the proposed D2D communication using VLC. In Section III, the results are discussed and analyzed. Conclusions are drawn in Section IV.

II. Proposed System

A. D2D Communication with VLC

Fig. 1 shows the proposed D2D communication in an indoor scenario using VLC. The device 1 (D1) and device 2 (D2) are the two devices equipped with the phosphor based white LED (transmitter) and PD (receiver with a physical area of 1 cm^2) with blue optical filter. The utilized phosphor based white LED has optical output power equal to 120 mW with 60° LED half angle. D_{comm} represents the maximum distance over which the two devices can communicate effectively, while d is the distance of separation between the devices.

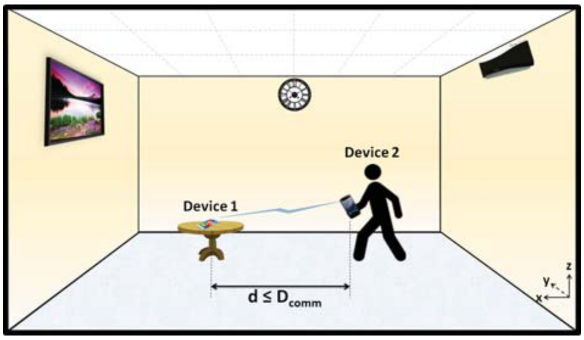

Fig. 1 Device-to-device communication using VLC

In the proposed D2D communication, initialization for communication between the devices is performed using a special frame structure. The source device (D2) initially requests a VLC link by transmitting a request frame. The request frame is an extended version of the frame structure defined by IEEE standards [8]. Fig. 2(a) shows the structure of the request frame which consists of a preamble for synchronization, a PHY header (frame length, modulation and coding), data payload, source device ID and destination device ID.

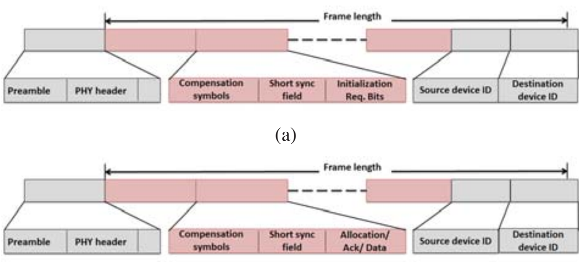

Fig. 2 Frame structure (a) Request frame (b) Acknowledgement frame

This initial request for connection is received by the receiver of destination device (D1). On the basis of the request from the source device, the destination device initializes the connection for that device. The notification of initialization is then sent back to the source device using a frame called initialization frame from the destination device. Figure 2(b) depicts the initialization frame. After the reception of the initialization frame, the source device acknowledges the successful reception of initialization frame using a similar frame structure i.e. acknowledgement frame.

It is worth noting that the initialization frame, the acknowledgment frame and the data frame can be differentiated by using different types of pre-defined sequence in the place of Ack/Initialization/Data bits as shown in Fig. 2(b). For example, a sequence of *111000111000111000....* can be placed in the initialization frame. Likewise, a sequence of *1010101010...* can be used in the acknowledgment frame. The data transmission is carried out using the data frames in which actual data bits are loaded. The sequence diagram associated with the proposed D2D communication is shown in Fig. 3.

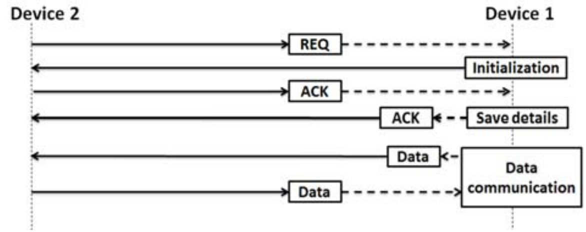

Fig. 3 Sequence diagram

To avoid interference during the D2D communication, we employ half duplex communication between the devices. To minimize the interference from indoor lightings, it is assumed that different colors between indoor lightings and the D2D communication are used. The focus of the present study is placed on the D2D communication using a VLC link, i.e. the connectivity between the devices using visible light.

B. D2D Communication Using Optical Repeater

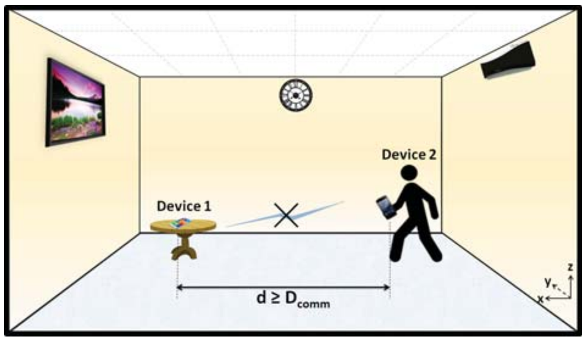

Fig. 4 Device-to-device communication with separation distance between devices

As described earlier, the devices employed for the D2D communication using VLC are power limited due to design constraints. Hence, if the distance of separation between the devices, d, is more than D_{comm}, the performance severely degrades, making communication impossible as shown in Fig. 4.

To improve the distance of communication between the devices, OR units are installed on each wall of the indoor environment as shown in Fig. 5. The ORs are intermediate transceiver units consisting of LEDs and PDs [9]. In the proposed work, each OR unit consists of 100 LEDs and 2 PDs with a blue optical filter to filter out data from LED of devices. The number of LEDs used in OR is such that it sufficiently covers the entire indoor environment to provide efficient D2D communication.

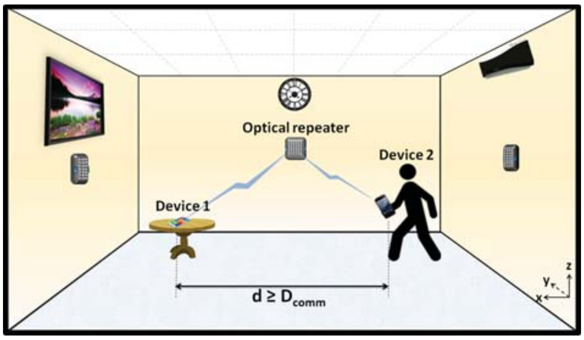

Fig. 5 Device-to-device communication with optical repeater

III. Result and Analysis

To evaluate the effectiveness of the proposed direct LOS D2D communication, we performed simulations under additive white Gaussian noise (AWGN). Simulation parameters are listed in Table I.

TABLE I
Simulation Parameters

Parameters	Value
Number of LED in each device	1
Transmitted power (per LED)	120 mW
Half-angle FOV	60°
Area of PD	1 cm^2
Semi-angle at half power	60°
Responsivity of optical filter	1

TABLE II
BER and Achievable Data Rate

No.	d (m)	BER	ADR (Mbps)
1	0.6	0	9.6
2	0.7	0	9.6
3	0.8	9.0×10^{-6}	9.5136
4	0.9	4.5×10^{-5}	9.168
5	1.0	4.35×10^{-4}	5.4240
6	1.1	2.806×10^{-3}	0
7	1.2	1.143×10^{-2}	0

We analyzed the system for the LOS communication using the OOK modulation by varying the distance of separation between two devices in the scenario described in Fig. 1. The obtained BERs and ADRs [10] for the communication between two devices are listed in Table II. It is clear from Table II that the BER performance of the direct link for D2D communication is efficient when the distance between the devices is less than 1 m.

Figs. 6 and 7 represent the BER and ADR for the D2D communication between two devices in the scenario described in Fig. 1.

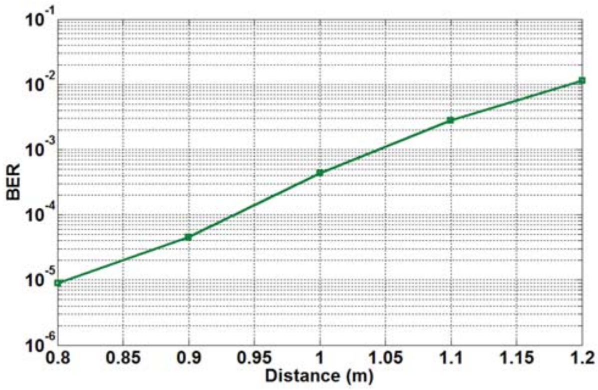

Fig. 6 BER performance of proposed D2D communication with increasing distance

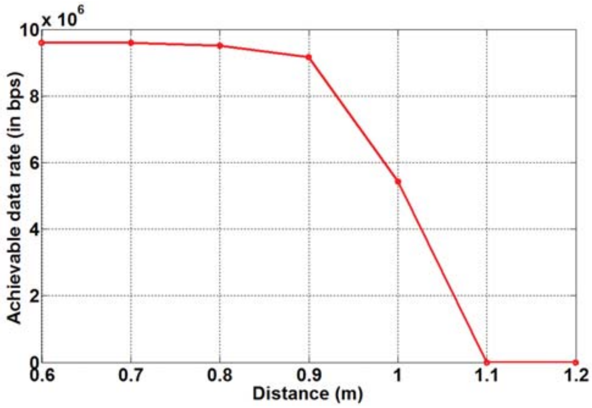

Fig. 7 Achievable data rate of proposed D2D communication with increasing distance

As it can be observed from Table II as well as Figs. 6 and 7, the communication distance between the devices is limited to a maximum of 1 m. This is due to the limited power available at the devices. To observe the effect of OR, the performance of D2D communication is evaluated with the ORs installed on each wall.

TABLE III
Simulation Parameters for OR

Parameters	Value
Room dimension	5m × 5m × 3m
OR position	(0, 2.5, 1.5), (2.5, 0, 1.5), (5, 2.5, 1.5), (2.5, 5, 1.5)
Number of LEDs per OR	100
Number of PDs per OR	2
Transmitted power (per LED)	60 mW
Centre luminous intensity	0.75 cd
Half-angle FOV	60°
Area of PD	1 cm^2
Semi-angle at half power	60°
Responsivity of optical filter	1

Table IV shows the BER and ADR with the increasing distance of separation between the devices. With the installation of ORs, the performance of D2D communication significantly improves. It is evident from the results that the devices can communicate up to a distance of 3.5 m. Therefore, it can be said that the installation of ORs enhances the D2D communication coverage up to 2.5 m in the underlying indoor environment.

TABLE IV
BER AND ACHIEVABLE DATA RATE WITH OR

S.No.	d (m)	BER	ADR (Mbps)
1	1.1	2.0×10^{-6}	9.6
2	1.5	1.0×10^{-6}	9.6
3	2.0	1.0×10^{-6}	9.6
4	2.5	1.0×10^{-6}	9.6
5	3.0	4.0×10^{-6}	9.6
6	3.5	2.679×10^{-3}	2.7

IV. CONCLUSION

A VLC based D2D communication scheme is presented to fulfil the growing demand of communication between the devices in indoor environments. The devices equipped with the VLC transmitters and receivers can communicate efficiently over a distance of up to 1 m with a data rate of up to 5.4 Mbps. The frame structure is designed to identify the source and destination device in the presence of multiple devices within the room. The ORs are also employed to further the distance of communication between the devices. It is found that the devices can communicate up to 3.5 m. In addition, the ORs significantly improve the performance of D2D communication. Therefore, the VLC based D2D communication would be an efficient scheme to lessen the increasing demand on RF spectrum and can be a promising technology for an effective, secured and faster communication link between the devices.

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