On the Suitability of VLC Enabled Fronthaul for Future Mobile Network

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Abstract—The quest to meet diverse services and applications that are emanating from the increasing inter-connected devices including machine-to-human communication has brought about consideration of massive deployment of small cells for fifth generation (5G) and Beyond network. With densification of small cells, mm-wave and THz frequencies play significant role in delivering mobile services. Consequently, supporting radio frequency (RF) communication with visible light communications (VLC) link exhibits potentials to ameliorate the challenges of RF communication especially bandwidth limitations and interference. Capitalising on the strength of VLC, we propose a basic end-to-end system to experimentally evaluate the suitability of VLC as fronthaul using real-time mobile traffic. Successful downlink (DL) transmission was achieved via VLC. To investigate the performance of the VLC link, transmission signal-to-noise ratio (SNR) and throughput of the VLC and RF Links are measured and compared. The light emitting diodes (LEDs) and Photo-diodes (PD) have shown to have significant effects on the performance of the VLC link. However, the results establish a fundamental premise for the suitability of VLC as fronthaul for small cell network.

Index Terms—RF over VLC, mobile fronthaul, visible light communications

I. INTRODUCTION

The concept of facilitating communication through visible light has been conceived and practiced from time immemorial, with the use of light source (light flashing from semaphore or fireworks) to transmit message in sequential manner to the receivers who in turn decode the message based on predefined formats agreed upon by both parties. Advancing from this fundamental concept, optical wireless communication (OWC) is evolving and consistently attracting significant research interests in diverse areas of applications including mobile networks [1]–[3]. As an emerging technology with dynamic research interests, OWC is proffering a vast number of solutions to complex communication challenges. With particular reference to evolving mobile network, high capacity, high data rate and reduced link interference for short-range communication are among obvious considerations to meeting the requirements of beyond 5G (B5G) mobile network to support innovative services and applications like virtual reality and augmented reality (AR) that consume high bandwidths.

As dense small cells are envisaged in heterogeneous architecture like fifth generation (5G) and beyond network to achieve high capacity, mm-wave and THz wireless communication are receiving tremendous attention to facilitate support for diverse services including machine-type communication (MTC) and the internet of things (IoT). Considering the enormous bandwidth potential of OWC, desired high-speed data transmission at considerable minimal latency could be accomplished. Visible light communication (VLC) is a class of OWC that is operating in the visible band (390–750 nm) and offers huge bandwidth that could support 5G and beyond services [4]–[7]. Unlike radio frequency (RF) channels, VLC links are characterised by their immunity to electromagnetic interference, immense unlicensed spectrum, health safety compared to infrared (IR) communication, seamless integration into existing infrastructure, cost-effectiveness and energy efficiency because of the use of light emitting diodes (LEDs) [8], [9].

Based on the aforementioned promising benefits offered by VLC, its adoption as mobile fronthaul for small cells for outdoor and indoor applications is increasingly being investigated [10], [11]. Apparently, VLC enabled fronthaul will help to avert the inherent limitations of RF in densely populated mobile cells while also serving as lighting facilities. Consequently, there are significant volume of research efforts geared towards diverse applications of VLC. An
end-to-end connectivity solution proposed for dense urban scenarios is introduced in [12] by integrating 5G, PON and VLC technologies which, according to the authors, supports ubiquitous communication. Also, a hybrid VLC-OFDMA network model comprising a dynamic number of VLC hotspots is proposed in [13] to solve hotspot’s multi-user access challenges. Furthermore, for a hybrid LiFi/WiFi network, [14] reports, using simulations, that an OFDMA based LiFi system shows better performance compared to TDMA systems. Similarly, hybrid power line communication (PLC)/VLC/RF fronthaul was considered in [15] to enhance the sum rate capacity of the hybrid system. In [16], a mobile fronthaul (MFH) consisting of low-cost light-emitting diode-based VLC links and a spectral efficient fiber is reported to achieve cell coordination in a less dense network environment.

Considering available research works reported in the literature, using a real-time mobile signal for experimental demonstration of VLC based MFH is rarely mentioned. With this in mind, we developed an emulation of end-to-end LTE system based on software-defined radio (SDR) to generate real-time mobile traffic over a combined RF and VLC link. Further, we experimentally evaluate the performance of VLC link for transmission of the real-time mobile signal. This work provides a fundamental step towards investigating VLC based fronthaul for 5G and beyond mobile networks. To the best of our knowledge, this works presents for the first time, an experimental demonstration involving real-time mobile traffic for evaluation of VLC link.

The rest of the paper is organized as follows. In Section II, we present a brief background information on VLC system while the experimental setup is described in Section III. Thereafter, we present and discuss our preliminary results in Section IV. Finally, conclusions and the future research direction are presented in Section V.

II. A BASIC VLC SYSTEM

Conceptually, a VLC system uses lighting facility for dual purposes of providing illumination and indoor communication simultaneously. A simplified structure of VLC system is represented in Figure 1, comprising a transmitter and a receiver and operating on intensity modulation/direct detection (IM/DD) scheme. A basic VLC transmitter is composed of an array of LEDs, a driver circuit for driving the LEDs by DC bias current and a modulator which modulates data onto rapidly switching light being emitted from the LEDs. Moreover, laser diodes can also be used in place of LEDs as lighting sources for VLC systems because they possess large bandwidths [17]–[19]. However, LEDs are cheaper but have limited bandwidth of a few MHz [20].

For the VLC receiver, a photo-diode (PD) module or an imaging sensor is normally used. PD uses semiconductor device to convert the received optical intensity to an electrical signal, while with a camera, the imaging sensor device captures visible light signal and recovers the transmitted data. Compared to imaging sensors, PDs are capable of supporting more than 1 Gsps (Giga-symbols per second), which is greater than 3000 times the symbol rate offered by imaging sensors as VLC receiver due to limitation of frame rate and non-uniform exposure to light [21], [22]. Key parameters considered for designing a PD include bandwidth, responsivity and noise level. The optical input power conversion to the electrical output current is represented by the PD responsivity. The transmitted optical intensity is normally affected with additive noise including thermal and shot noises. Furthermore, the channel impulse response is dependent on the position of the receiver relative to the transmitter, corresponding to line-of-sight (LOS) and non-line-of-sight (NLOS) parts of the received light. Meanwhile, several channel models have been proposed by researchers, however this is out of the scope of this paper.

III. EXPERIMENTAL SETUP

The experimental setup consists of a simple physical arrangement of a full end-to-end mobile network connectivity, a VLC assembly, a frequency mixer and local oscillator as shown in Figure 2. The end-to-end mobile network is realized by using srsLTE, an open source based software and two software defined radio (SDR) devices. By deploying srseNB on a commodity microprocessor system, monolithic processing of the baseband functions is accomplished. We selected USRP B210, SDR device made by Ettus/ National Instruments to provide RF frontend for the srseNB and srseUE. The USRP B210 operates on continuous frequency ranging from 70 MHz to 6 GHz and allows a 61.44 sampling rate which is in conformity with the sampling rates defined in 3GPP specifications. The USRP B210 provides interface to the user equipment (UE). As common with most of the SDR devices, USRP B210 allows flexible configurations and end-genders analog-to-digital and digital-to-analog conversions close to the antenna. However, for our setup, RF cable is employed for the UL transmission while the downlink (DL) is provided by the VLC link. Also, the UE is developed by deploying srseUE component of srsLTE software on general purpose processor (GPP). Interestingly, srsLTE software has facility for measuring metrics of the signal being transmitted and is used to capture the signal-to-noise ratio (SNR) in dB which is presented in Figure 4.

For the VLC system, we employ a low cost LED module which has 7 white LEDs for the transmitter section and a PD assembly for the receiver. A line-of-sight (LOS) distance of 0.5m between the LED module and PD assembly is considered to establish DL transmission. Furthermore, considering that the low-cost LEDs module used for this
work is limited by intrinsic modulation bandwidth to a few MHz as typical with most Commercial off-the-shelf (COTS) LED modules. A local oscillator is used for up and down frequency conversion as shown in Figure 2. It should be noted that the radio access network (RAN) operates at 2.68 GHz and 2.56 GHz RF for DL and UL, respectively (Band 7). Furthermore, considering that the low-cost LEDs used for this work is limited by intrinsic modulation bandwidth to a few MHz, a local oscillator is used for down-conversion and up-conversion allowing an output frequency of 2 MHz that falls within the range supported by the LEDs. Consequently, the channel is configured with 1.4 MHz (6 Physical Resource Blocks (PRB)), 3 MHz (15 PRB), 5 MHz (25 PRB) and 10 MHz (50 PRB). The generated real-time signal is transmitted for each aforementioned bandwidth while the SNR and data rate of the VLC link for each channel configuration is measured.

IV. PRELIMINARY RESULTS AND DISCUSSION

For each channel bandwidth, transmission of real-time radio over VLC link is established. Successful data transmission is achieved when the mobile network was operating at 1.4 MHz and 3 MHz as shown with the data rate measured data rate representation in Figure 3 and the measured SNR at the UE side as shown in Figure 4. However, no successful data is transmitted on 5 MHz and 10 MHz channel bandwidth configuration as a result signal degradation that is contributed by limitation arising from inherent modulation bandwidth of COTS LED. Consequently, this effect is reflected in the measured SNR for transmission on the configured bandwidth. As expected, transmission at 3 MHz has better SNR than 1.4 MHz channel bandwidth with RF (no VLC).

However, the SNR characteristics differ when VLC is connected to the network, with 1.4 MHz channel bandwidth showing higher SNR compared to 18 dB SNR of 3 MHz bandwidth, thus justifying the limitation of the commercially
available LEDs [23]. The SNR pattern is further reflected on the mobile data rates shown in Figure 3 as measured by the iperf tool. While a maximum of 8.5 Mbps and 5.2 Mbps are achieved for 1.4 MHz and 3 MHz respectively when transmitting with RF (no VLC), 4.2 Mbps and 3.1 Mbps for 1.4 MHz and 3 MHz respectively are measured as maximum DL data rates when transmitting via the VLC. These preliminary results further illustrate the effect of intrinsic modulation bandwidth occasioned with COTS LEDs.

V. Conclusion

In this work, an experimental demonstration of realtime mobile signal over VLC channel is presented, for the first time to our knowledge, by adopting a low cost VLC system, leading to successful transmission to a UE from the base station of an end-to-end LTE mobile network. The results provide a foundation towards the adoption of VLC technology for 5G and beyond network. Furthermore, the preliminary results demonstrate the effect of intrinsic modulation bandwidth as occasioned by COTS LEDs. Notwithstanding, successful transmission can be achieved at higher channel bandwidths with more sophisticated LED modules and by adopting MIMO techniques which involve the use of multiple LED elements. Further enhancement of the VLC performance could be introduced as a future work with the adoption of micro-LEDs to support gigabits per second (Gbps) data rates. However, the challenge of weak radiation power of micro-LED has to be investigated to achieve practical demonstration of micro-LED based VLC.

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