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Abstract: Power line communication (PLC) draws significant attention recently for its wide applications in the smart grid, Internet-of-Things, and intelligent homes. Visible light communication (VLC) using light emitting diode (LED) is becoming a hot topic due to its high capacity and radiation-free benefits, and meanwhile it can be naturally combined with PLC for the cost-effective implementation. In this paper, the framework for deeply integrated PLC and VLC system is introduced. Preliminary laboratory results are presented with the highlights on major technical contents to be further investigated for improved system performance at reasonable cost.

Keywords: Power line communication (PLC), visible light communication (VLC), indoor broadband system, single frequency network (SFN), indoor localization.

I. Introduction

Powerline communication (PLC) using existing low- and medium-voltage power grid infrastructure to convey and deliver the information with the electricity transportation together to the end users, has the advantages of the deep penetration ratio and no need for new wiring, therefore, it is cost-effective and easy for the deployment [1]. PLC has been widely used for the smart grid for both narrowband and broadband communication purposes due to its “through the grid” property. Visible light communication (VLC), which can support both narrow and broadband services by utilizing the illuminating light emitting diodes (LEDs), offers a huge advantage of the unlicensed bandwidth to cope with the ever crowded radio spectrum (RF) for the highly-localized communication systems [2]. Other than this advantage, VLC also has attractive features of radiation-free, wide availability or coverage (the estimated number of LEDs in use is over 14 billions) and high-capacity with wide spectrum, making it a good supplementary to the current RF-based solutions, for example, Wi-Fi. In VLC, the most straightforward solution is to connect different LED lamps with separate network cables, which, however, requires huge modifications on the existing indoor wiring and is neither cost-effective nor practical. The integration of PLC and VLC is therefore proposed based on the observation that almost all the LED lamps are connected to the power cable [3] [4]. This motivates the feasibility study as well as this proposal for the framework of using the power line while providing the electricity to power the LED lamps also serves as the local access of the information source for the VLC systems. With this arrangement, power network and illumination network can be locally combined together and to serve the communication purpose naturally.

II. The Proposed System Structure

The first PLC and VLC integration prototype was proposed in 2003 [3] which uses the binary phase shift keying for low rate transmission. Then orthogonal frequency division multiplexing (OFDM) is applied for higher spectral efficiency under fading channel environment [5]. There has been significant progress in this area since then from the individual technologies to the system design and demonstration, trying to achieve better system performance with low implementation cost. However, from the viewpoint of practical implementation, PLC and VLC integrated systems
still face lots of challenges, such as the optimization of the network structure and network protocol, the precise modeling of the individual and integrated channel, the design of efficient coding/modulation, multiple-service, and multiple-access schemes, and so on.

Traditional PLC and VLC system is shown in Fig. 1 (a). Each LED has a PLC demodulator inside to demodulate the data from PLC and then re-modulates the data via VLC module. This is similar to the decode-and-forward (DF) scheme in relay system. It helps remove the noise and interference accumulation during the signal propagation but inevitably increases the complexity (such as size and power consumption) of the VLC module in LED. It suffers from severe self-interference since adjacent LEDs transmit different signals, and needs frequent handover if user is moving. To overcome these shortcomings, a deeply integrated PLC and VLC system is proposed in [6] and shown in Fig. 1 (b).

![Fig. 1. Different structures of the PLC and VLC systems](image)

Here, all LEDs connecting to the same power cable will receive and transmit the same signal from PLC base station, then amplified (also filtered) and transmitted by the VLC module for the downlink. This can be considered as similar to the amplify-and-forward (AF) scheme in relay system. All the LEDs within this area will transmit the same signal so as to form the so-called single frequency network (SFN) by wireless optical communications through LEDs. This arrangement helps decrease the complexity of the VLC module in LED, minimize the shadowing effect and self-interference from adjacent LEDs transmitting different signals, and avoid frequent handovers when user is under mobility.

III. Preliminary Prototyping Results and Future Work

Laboratory test of a video transmission platform is done for the proposed integrated PLC and VLC system with three LEDs setting up in Fig. 2. The system parameters are: 3 LEDs close to each other with the power cable length of 100m apart (the delay is around 0.548μs), TDS-OFDM system with 16QAM modulation and FEC code rate of 0.8. Almost identical light power from each LED reaches the receiver (3 meters away) and the received spectrum and the demodulated constellation diagram are shown in Fig.3. Corresponding diagrams for one LED case are given in Fig. 4 for comparison.
The test result shows that even under this worst case scenario with significant degradation on signal spectrum and constellation diagram, the reception performance is satisfactory with no...
image stillness or mosaic, proving the superior performance of the proposed system under the severe self-interference.

In the future, more research and development work needs to be done for the proposed framework being practically used, which includes but not limited to

1. Spectrum allocation for both location based service (narrow band) and multimedia transmission (broadband) of VLC, and automatic meter reading (AMR, narrow band, usually below 500 kHz) and multimedia transmission (broadband) for PLC. One solution is to allocate 500 KHz below for the ID information of VLC which won’t interfere AMR, and broadband services share the same spectrum.
2. Aggregated channel and noise/interference modeling of the PLC and VLC integrated system for a better selection of coded modulation schemes. One can take advantage of the sparsity of the channel as well as the interference and use compressive sensing for low-complexity and high accuracy channel estimation [7] and interference mitigation [8].
3. What type of Low Density Parity Check (LDPC) code should be used? Is polar code a good if not better choice? What benefit can be achieved by using APSK instead of QAM?
4. Can the non-orthogonal multiple access provide decent throughput gain when SFN structure is used? How can bit division multiplexing in [9] [10] be applied to this system?
5. Which one is more appropriate for the choice of duplex, TDD or FDD? Should same data link layer protocol be directly applied to the PLC and VLC integrated system?
6. What strategy should be used for the horizontal handover among multiple PLC and VLC integrated systems? What strategy should be used for the vertical handover for the PLC and VLC integrated system?

IV. Conclusion

In this paper, a novel and cost-effective framework for the deeply integrated PLC and VLC system is introduced with preliminary results demonstrating its feasibility. Future work includes the appropriate spectrum allocation for multiple services such as broadband multimedia and narrow band locationing service, better coding and modulation scheme based on the aggregated propagation environment of concatenated PLC and VLC channels, more accurate noise and interference characterization, highly-efficient signal structure and duplex approach, and high-level protocol which provides better system performance at reasonable implementation cost.

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