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PHY/MAC Design to Enable Internet Infrastructure Connectivity on VLC

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***Abstract:* -- Recent rapid growth on smart portable computing devices pushed the radio frequency (RF) based wireless technologies to their band capacity limits. The emerging optical wireless communication has been considered as a most viable solutions to respond to the ever-increasing wireless capacity demand. Particularly, Visible Light Communication (VLC) which uses light emitting diode (LED) as a media of transmission and this enables an opportunity and infrastructure for the high/ low rate low-cost wireless communication. This paper proposes the VLC PHY/MAC design to enable the internet connectivity using VLC based network infrastructure. The proposed PHY/MAC design considered to integrate with existing network IP stack in the context of mobile communications given the recent pressing needs in mobile wireless networking. This research deliberate on key challenges involved in Smart Lighting and Wireless Networking to design the next generation wireless technologies using visible light.**

***Index Terms* — VLC, PHY, MAC, NETWORK LAYER, IEEE802.15.7, LED, RF, TCP/IP**

I. INTRODUCTION

In recent decades, the rapid development of semiconductors has advanced the Light Emitting Diodes (LED) development process. The technology advancement in LED technologies gives the fast LED Switching ability to control the LED light illumination compared with traditional lighting source technologies. The high frequency rate of light intensity variation switching ability in LEDs add the value in Visible light communication (VLC) data transmission rate. This enables the VLC based wireless communication to fulfill the mobile wireless traffic demand. VLC technology provided with LED devices is characterized by high area spectral efficiency, unlicensed wide bandwidth high security and dual-use nature.

There are few standards discuss about VLC standardization, say VLCC, IEEE, etc. The first standard for VLC was initiated by the Japan based VLC consortium (VLCC) and discusses more about how data transmission occurs using visible light. The IEEE standard IEEE802.15.7 describes the PHY/MAC protocol standard for VLC on personal area networks, localization, illumination control issues.

Though there has been a more interest on VLC based wireless connectivity in recent years but there is lack of integration with TCP/IP stack to commercialize VLC infrastructure with internet infrastructure connectivity is hindering the progress of the research community. The network based application development platform would add momentum to VLC research and spark the interest of researchers and engineers on VLC based application development. This unexplored application of VLC to networked embedded devices (Networked VLC) research requires a fundamental redesign of the networking stack.

This research takes a first step toward Networked VLC to give internet connectivity over VLC based wireless infrastructure. This paper presents the design of MAC/PHY Layer for Networked VLC Stack implementation to give internet connectivity on VLC network infrastructure. In this proposed approach, LED front-end is interface to a networking platform as physical media to communicate and software framework for Medium Access Control (MAC) and Physical Layer (PHY) layer protocols are designed, implanted, and evaluated. This design provide and implement the primitives, such as signal sampling, symbol detection, coding/decoding, carrier sensing and communication with the Internet layer of the Network stack.

The VLC network interface is presented in clause II. The MAC and PHY design is presented in clause III and IV. The clause V and VI presents the system implantation and result analysis for VLC network infrastructure. Conclusions

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are finally drawn in clause VII.

II. VLC NETWORK INTERFACE

The VLC based system design have receiving strong attention from the system designers of the next generation of wireless networks [1]. The potential VLC's usages, implementation challenges and market conditions are described in [3].

The IEEE has developed the 802.15.7 standard [2] for short-range communication using visible light. This standard species three PHY layers, which support data rate varying from 11:67 kb/s to 96 Mb/s. This PHY layers supports dimming and light licker prevention. The software defined radio implementation using 802.15.7 protocol is shown in [5]. The most of the VLC receiver uses the photodiodes receivers, in [4] a reverse-biased LED is used as a receiver to implement a bidirectional LED-to-LED communication. This principle has been exploited by [6] to introduce a LED-to-LED communication network.

The proposed VLC network interface to enable internet connectivity on VLC based infrastructure is shown in figure 1. The VLC network interface includes the MAC/PHY layer to interface VLC based on network infrastructure on standard TCP/IP stack model. This implementation cost of the VLC network interface solution is however of at least one magnitude higher than targeted platform.

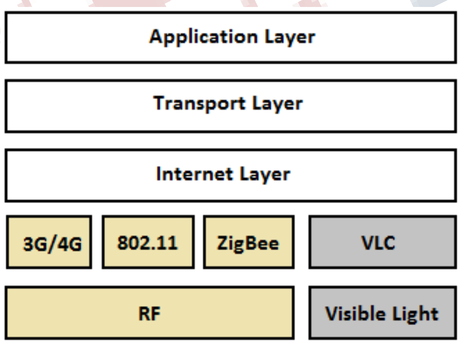

Figure 1: VLC Network Interface

III. MAC LAYER

The MAC layer configures and control all access to the physical layer and is responsible for the Generating network beacons if the device is a coordinator, Synchronizing to network beacons, supporting visibility, Supporting dimming, Flicker-mitigation scheme, Supporting device security, Providing a reliable link between two peer MAC entities, and Supporting mobility in the networks. The MAC layer design for VLC network interface follows the simple MAC Frame format to reduce the overall header overload cost on low date rate based VLC to communication as shown in figure 2.

Frame Payload	FCS
MSDU	MFR

Figure 2: MAC Frame Format

The Frame Payload field has a variable length and contains information specific to individual frame types. The FCS field is 2 octets in length and the frame check sequence (FCS) is calculated over the MHR and medium-access-control service-data unit (MSDU) parts of the frame. The FCS is option is given as an optional option, it is adaptive to RS/CRC/NONE.

IV. PHY LAYER

The VLC PHY layer design focus on dimming support, flicker mitigation, and advanced modulation scheme, etc. The designed PHY layer is adaptive to modulation schemes like OOK, PPM, VPPM, CSK, etc.

The physical-layer data unit (PPDU) frame structure is formatted as illustrated in Figure 3 for VLC Network interface.

Preamble	PSDU
SHR	PHY payload

Figure 3: PPDU Frame Format

The preamble field is used by the transceiver to obtain optical clock synchronization with an incoming message. The standard defines one fast locking pattern (FLP). The MAC shall select the optical clock rate for communication during the clock rate selection process. The preamble shall be sent at a clock rate chosen by the TX and supported by the RX. The preamble is a time domain sequence and does not have any channel coding or line coding. The preamble first starts with a FLP. The FLP is fixed as a pattern “11010010”.

The PSDU field has a variable length and carries the data of the PHY frame. The FCS is appended if the PSDU has a non-zero byte payload. The structure of the PSDU field is as shown in Figure 4.

Figure 4: PSDU Field Structure

V. SYSTEM IMPLEMENTATION

The VLC network interface to enable internet connectivity system design scenario uses hybrid systems integrating RF and VLC are based on system model as shown in figure 5. The designed hybrid systems were able to develop practical system implementation yielding functional IP-based communication supporting web browsing or other Internet access functionalities as proposed intension.

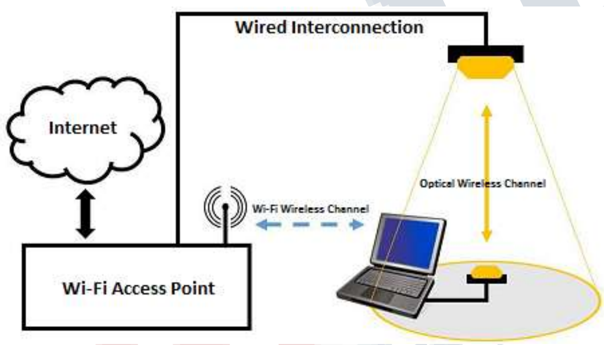

Figure 5: Hybrid RF-VLC Link

The VLC wireless network node (shown in figure 6) is designed using micro IP (uIP) on Arduino based Hardware environment. The uIP is a tiny open source TCP/IP network protocol stack implementation intended for 8- and 16-bit microcontrollers.

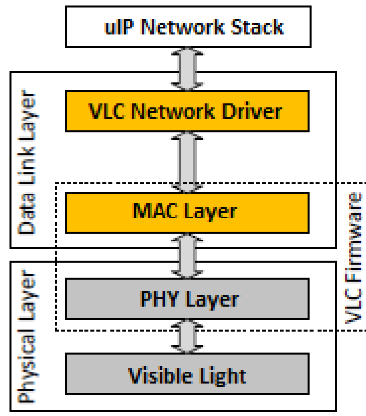

Figure 6: uIP VLC Link

uIP VLC Link is designed and implemented using ATMega328 based Arduino development environment.

VI. EXPRIMENTAL RESULT AND ANALYSIS

In order to investigate and verify the proposed VLC Link, the system is designed as a hybrid model with Wi-Fi RF link and VLC link. The PHY layer designed using OKK modulation scheme on Arduino with Digital MOSFET Switching control. The PHY layer designed components are shown in figure 7.

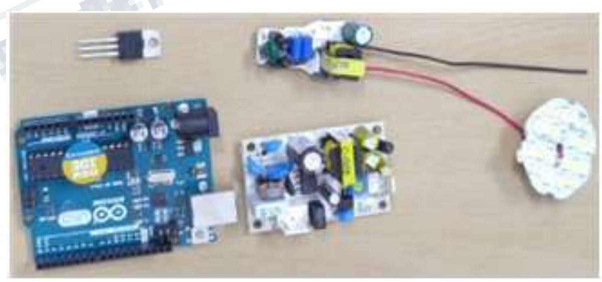

Figure 7: uIP VLC Link – PHY Layer Components

The assembled LED based VLC Link evaluation model is shown in Figure 8 with smart device as receiver.

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Figure 8: VLC Link – Evaluation Model using Smart Device

VLC have a potential to enable fast and environment friendly communication and visible light does not harm human beings as it is the case with other spectrum of electromagnetic radiation VLC technology is relatively new and it still has many issues, like light noise from the Sun and environment lightning.

Advances being made are relatively specific, to encode and transmit data as fast as possible. To use VLC in existing Internet infrastructure still requires some research in the areas of MAC protocol or routing layers. For researcher to develop and measure MAC implementations is essential because implementing and testing one protocol on a real hardware will be expensive and slow.

VII. CONCLUSION

This paper presented the design and evaluation of the visible light based internet connectivity VLC protocol using uIP on Arduino based development environments. This Experiments show that the VLC based TCP/IP protocol stack can achieve appropriate network connectivity with visible light based communication model with low power consumption. This hardware emulation design is both transparent which means that can accept any input from upper or lower layers and it can provide expected output as defined in ISO OSI TCP/IP standard. The designed VLC radio emulation can work with 802.11 or any wireless framework. However, the designed PHY/MAC protocol, in essence, is designed for single omni-directional transceiver, and there are obvious flaws with 802.11 on VLC link.

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