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Low Rate VLC Receiver Design Using NCP302 Voltage Detector for IoT/IoL Connected Smart Homes

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Abstract

The Internet of Things (IoT) and Visible Light Communication (VLC) is opening up new services in lighting industry by integrating sensory network features in addition to standard illumination functionality. In this progressive developments, the next generation lighting devices for smart homes are capable to sense the environmental conditions and transfer the captured data through lights to gateway controller to access remotely. The smart home environmental sensor information's are few kbps only so VLC systems need to built-in with low rate light connectivity to transfer data to the gateway. To provide error free communication, the quality of a received light signal is important to be considered when designing an VLC receiver. Therefore, this paper proposes the design of robust low rate IoL receiver design using NCP302 voltage detector for micro controller to adapt the IoT/IoL front end module for system integration. To evaluate the proposed system performance, the Arduino UNO based IoT/IoL controller designed with lighting, sensors and lights connectivity interfaces. The experimental result shows that the robust interference rejection is feasible on proposed VOL receiver and possible to have an error-free communication up to 10 kbps at a low SNR using OOK modulation.

Key words: *Internet of Things (IoT), Internet of Lights (IoL), LED, VLC, OWC, lighting Systems, OOK, MQTT, LWM2M, IoT Protocols, Smart Home.*

1. Introduction

In recent days, Internet of Things (IoT) application services extends the connection to all type of resource-constrained things, such as luminaires, electrical / electronics systems and sensors, reaching into the real world in real-time. The IoT development trends and current light industry transformation to LED based

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system design advances lighting system design to increases the lighting system capability from illumination functionality to wireless sensory network controller features. This change allows lighting things to collect the sensor information and the lighting device states can be changed from anytime, anywhere. The lighting things are connected into resource-constrained wireless network access, with low power, low bitrate, lossy communication links with limited communication primitives.

The indoor environment communication always constrained with network access resources because most of the traffic and resources consumed by mobile data so the visible light based short range wireless communication system design with lighting things have receiving strong recommendation from the system designers of the next generation of indoor wireless network access [1] and increases the design complexity in lighting system design open ups with different market segments [2]. The next generation indoor lighting system design is going to built-in with VLC features to overcome resource constrained networks on IoT connected lighting things due to the looming radio frequency (RF) spectrum crisis. VLC is considered as an one of free-space opticals reseach domain for short range data communication with unregulated high bandwidth, secured ommunication, and hazardless to humans with license-free [3-4].

VLC supported optical wireless system consists of LED and photo-diode (PD) as an optical front-end devices. PD is used as an optical sensor in the VLC system with a suitable biasing circuitry and trans-impedance amplifier (TIA) [5-8]. The IEEE 802.15 based PHY/MAC protocol design for low rate optical wireless communication (OWC) is proposed in [9], evaluated with user authentication for door access control systems using color codes [10] and smart TV remote controller function using smart device flashlight [11]. All these OWC applications are constrained with application specific features and not adaptable to sensory data transfer for IoT/IoL connected smart homes.

The VLC receivers using PD's used in indoor applications are affected by ambient noise, shot noise, and electrical pre-amplifier noise. This paper proposes the PD based low rate VLC receiver design using NCP302 voltage detector for IoT/IoL connected lighting indoor devices to work on low SNR. This proposed system is emulated using Arduino UNO based lighting controller and evaluated in real time scenario with error rate below 10^{-4}.

This paper is structured as follows. Section 2 describes the basics for IoT/IoL connected lighting system, and Section 3, introduced the proposed IoL receiver system design and the following Section 4 presented the result and analysis. Finally, this paper concludes in Section 5.

2. IoT/IoL connected lighting system

IoT connected lighting systems are connected with remote users through IoT gateways using IoT protocols Message Queuing Telemetry Transport (MQQT), and Lightweight M2M (LWM2M) to view light sensory data and controls the lighting device status as shown in Figure 1.

Presently, the lighting industry focuses to design next generation lighting system with OWC features and that is called as an IoT/IoL devices. The next generation IoT /IoL design allows the lighting things to built-in with luminaries, sensor interfaces, and PD based optical receiver features. The luminaries are used for sensor data transmission controller using optical wireless technology with standard lighting functions and the PD sensors are used receive the sensor data for relaying as well lighting status control information from remotely. The IoT/IoL connected future lighting system model is shown in Figure 2.

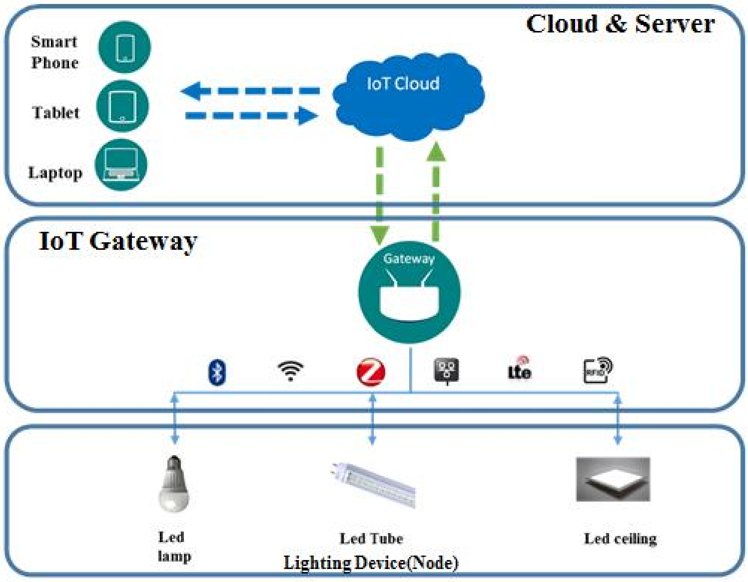


Figure 1. IoT Connected Lighting System

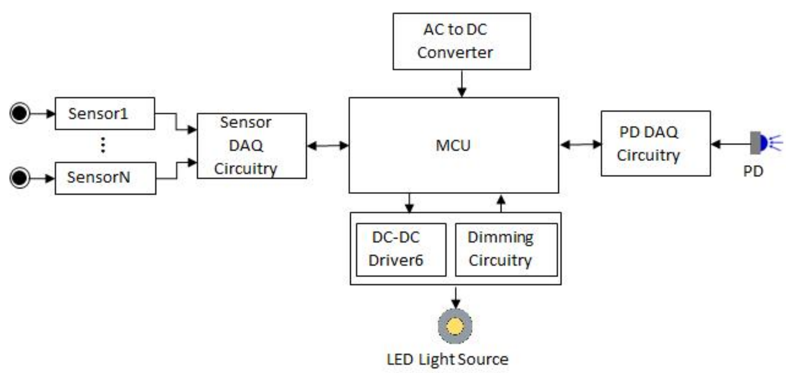


Figure 2. IoT/IoL Connected Lighting System

The IoT/IoL lighting systems gateways are capable of receive sensor data from lighting things and lighting things control data from remote users using IoT protocols through wired or wireless internet / intranet connectivity. The IoT/IoL lighting system gateway model is shown in Figure 3.

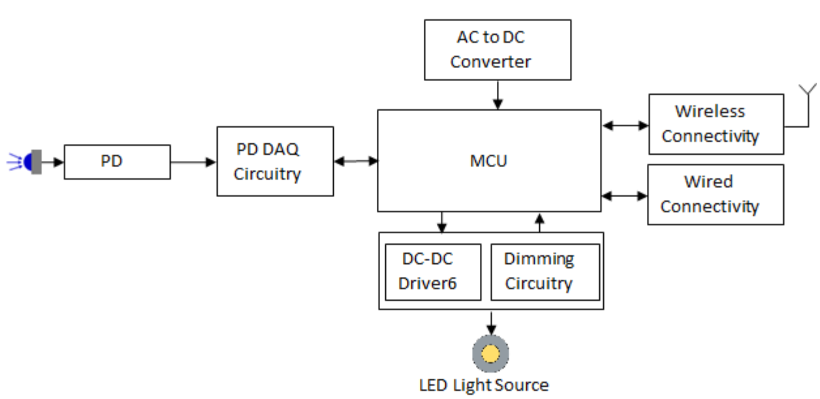


Figure 3. IoT/IoL Lighting System Gateway

3. Proposed IoL receiver model

To integrate a built-in VLC system in a lighting system, need to combine LED and PD for lighting and short range optical personal area networks. In this scenario, the other lighting infrastructures adds the lighting noise interferences and that need to be addressed for IoL receiver system design. The type of light interferences are,

- Artificial light induced interference
- Inter-Symbol Interference (ISI)
- Multipath induced Intra-Symbol Interference

The IoL system model block diagram with interference is show in Figure 4. The ideal IoL receiver signal model mathematical representation is shown in equation (1),

$$V_{RxOpticalSignal} = I_{opticaldetector} * R_f \quad (1)$$

In equation (1), $I_{opticaldetector}$ is the current due to the optical signal and R_f is the impedance at Analog front end of the optical receiver.

The IoL interference receiver signal model mathematical representation is shown in equation (2)

$$V_{RxOpticalSignal} = (I_{opticaldetector} + I_{Amb} + I_{Interference}) * R_f \quad (2)$$

In equation (2), I_{Amb} is the current due to the photocurrent due to sunlight and other ambient noises and $I_{Interference}$ is the intra symbol inference from other IoL optical transmitter.

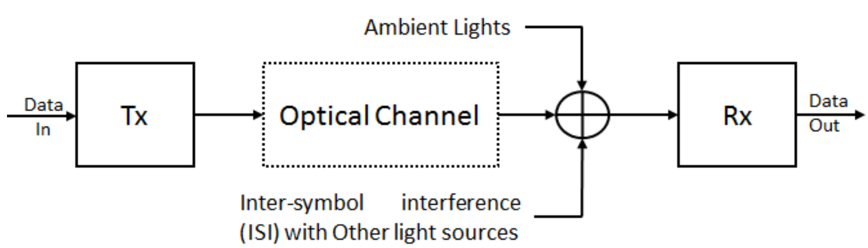


Figure 4. IoL Lighting System Interference Model

In IoT/IoL systems, uses the DC signals with a rectangular waveform based modulation schemes like On-Off Keying (OOK), pulse modulation to transmit baseband data's through lights and the receiver demodulations required and stable signal. The main objective of this paper is to low rate VLC receiver and the proposed receiver model is shown in Figure 5. The VLC receiver system consist of photodiode converting optical signals into electrical signals, a transimpedance amplifier (TIA), the HPF removes low-frequency signals, a voltage amplifier (VA), and a voltage comparator (VC).

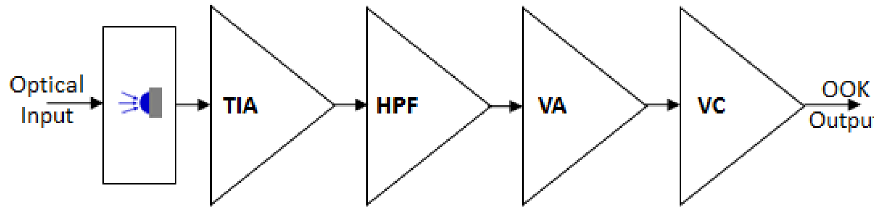


Figure 5. Proposed Low Rate VLC Receiver System

4. Result and analysis

In this paper, IoT/IoL lighting infrastructure is created with 1 W LED lighting device and the proposed low rate VLC receiver is emulated on Arduino UNO based open source HW platform with NCP302 voltage detector to smoothen the high pass filtered optical signal. The emulated VLC receiver system model using Arduino UNO is shown in Figure 6.

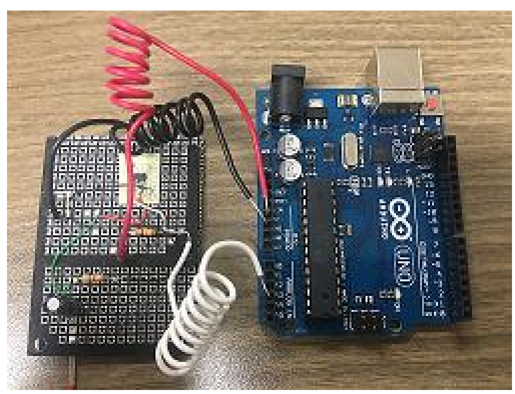


Figure 6. Proposed Real-time Low Rate VLC Receiver System

The IoT/IoL lighting device uses the Arduino based light controller to transmit randomly generated and coded with Manchester coding to avoid repetition of the same data then the coded data is modulated through OOK modulation schemes based on PWM wave form is generated to control the light illumination. The experimental environmental conditions are shown in Table 1. The environmental lighting conditions are measured using illumination sensors.

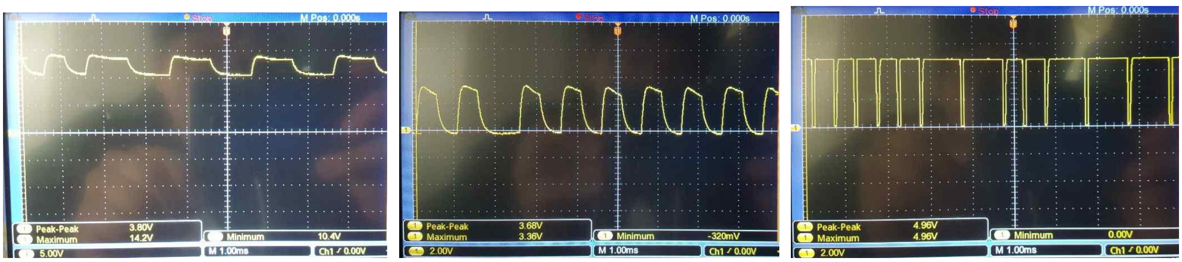
Table 1. Experimental Environmental Conditions

Environmental Condition Item	Symbol	Ratings	Unit
Ambient Light	lux	15	lx
LED Light	lux	45~385	lx
Receiver Sensitivity	V	5	V
Tx Rate	kbps	10	kbps
Distance between LED to PD	m	3	m

The performance of the designed low rate VLC receiver is evaluated with LED lighting system lux from 45 lx to 385 lx in a 3 meters distance with 15 lx ambient noise interferences. The real-time measured Low Rate VLC Receiver System Output Signal Waveforms for 45 lx with 15 lx ambient noise interferences is shown in

Figure 7 for OOK based baseband modulated signal for randomly generated baseband data.

In this experimental analysis observation gives us confirmations that even though we change the amount of light illumination from 45 lx to 385 lx with 15 lx ambient light noise interferences, the final voltage detector output OOK pulse waveform is uniform based on the transmitter data and the peak to peak voltage level is constant. This OOK pulse waveform consistency decoded the OOK modulated data and provides error free IoT/IoL communication up to 10 kbps at low signal to noise ratio (SNR) using 16 bit micro-controllers.



(a) PD Received Light Signal (b) HPF Filtered Signal (c) Voltage Detector Restored Signal

Figure 7. Measured Real-time Low Rate VLC Receiver System Output Signal Waveforms

5. Conclusions

In this paper, we analyzed the impact of designing low rate VLC receiver using NCP302 voltage detector for indoor sensory data transmission for IoT/IoL connected smart homes. As we all know that the environmental condition sensors data are required only limited bandwidth and does not required to add high throughput OWC controller to have an IoT/IoL connectivity for indoor monitoring and controls. The proposed system is implemented on Arduino UNO open source micro controller hardware platforms with light illumination level from 45 lx to 385 lx using 1W LED and with 15 lx ambient light noise. The IoT/IoL receiver provides the consistent OOK pulse waveform on receiver front end circuitry before the signal forward to baseband controller to demodulate the signal. Several level of experiments supervised under low SNR conditions to prove that the proposed low rate VLC receiver can operate error free up to 10kbps using OOK modulation with Manchester coding. This confirms that the lighting ventures can make use of the controller which is used for illumination control and does not required add up any special controller to support VLC controller features other than adding required signal conditioning circuitry.

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