IoL Field Gateway: An Integrated IoT Agent using Networked Smart LED Lighting Controller

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Abstract

The LED technology advancement introduce cutting-edge technology on Internet of Things (IoT) to connect the physical world to the digital realm, using digital smart lighting infrastructure called Internet of light (IoL). This paper proposes an Integrated IoT agent on networked smart LED lighting controller called IoL Filed Gateway using lighting infrastructure in which a lighting system that can connect to a network and can be monitored and controlled from a centralized system or via the cloud. The IoL Field Gateway defines new world of smart connected intelligence, lighting can become an integral and responsive part of everyday human life environments. The proposed connected lighting gateway uses the concept of multi-hop ad hoc network using visible light communication (VLC) with RF wireless technologies and Wired PLC (Power Line Communication). This connectivity and intelligence integrated into LED-based luminaires form the backbone of smart buildings and cities and make the Internet of Things (IoT) vision feasible and enables the lighting administrator can control numerous lightings easily and visitors can get visual information from the lightings with their smart devices. The proposed IoL gateway design is emulated on Arduino based HW platform with VLC, RF, and PLC connectivity and evaluated with four sensor interface

I. Introduction

The Internet access on THINGS has made dramatic progress over dynamically and intelligently adapt needs and preferences on connected appliances and machines in recent days. The greatest challenge in designing for the Internet of Things (IoT) is connectivity to connect with internet and cloud [1]. The lighting device evolvement going to play a crucial role on forthcoming developments of Internet of Things (IoT) connectivity and Sensing.

The development on Light Emitting Diode (LED) illumination control switching speed technology design has setups new trend in IoT sensor technology and connectivity infrastructure. The Intelligent Lighting with Big data on LED using high illumination control energy efficiency and long life time considered to focus on LED industry standardization to define the protocol for networked lighting infrastructure [2].

The growth trend on smart devices usage pushed the radio frequency (RF) wireless technologies to their verge of band capacity limits. The current LED design has the capability to change the state rapidly everywhere around human living [3] with fast change of illumination level change control which is not perceived by human eyes [6].

The visible light free-space communication system designed using controller based LED lamp as a transmitter and camera or photo detector (PD) as a receiver for optical wireless communication [3][4][5]. The connectivity on networked LED is enabled using platform independent flexible software defined VLC network stack [7] with defined VLC PHY/MAC layer using VLC protocol standard IEEE802.15.7 [8] is an opted VLC network stack layer model.

This paper proposes the lighting device as an IoT Gateway by integrating connectivity into the light source by, adding IoT agent functional features in addition with sensors, and interconnecting interface using programmable embedded network framework. The proposed IoL Filed Gateway supports node connectivity with the local network to cloud server using built–in internet wired/wireless interface.

The IoL Filed Gateway support local connectivity through PLC wired interface with each lighting End–Device and wireless interface with the IoT/Lighting End–Device using Bluetooth, WiFi, and Low Power RF technologies. This added intelligence in lighting enhance and benefits the IoT infrastructure in next generation in the buildings or in the street management services.

II. Main Body

1. IoT Gateway

IoT enabled service platform uses the three–layer robust infrastructure comprised of sensor nodes, and gateways that connect to the Internet and cloud with energy–efficient communication networks as shown in 〈Figure 1〉.

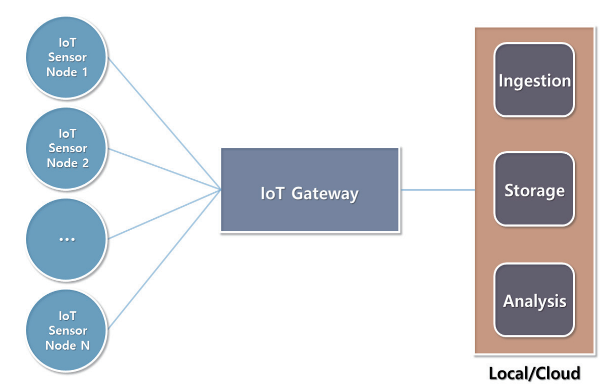

Figure 1. IoT Enabled Service Infrastructure

The IoT sensor nodes are designed with low power, memory and uses the low–energy radio communication to transmit sensor information to a central monitoring location based on Bluetooth Low Energy (BLE), Low Power RF, or Power over Ethernet (PoE). The central monitoring location hub acts as an aggregator of multiple sensor node raw data is called an IoT gateway.

The IoT gateway provides the internet or intranet connectivity between the IoT sensor node and IoT user service unit. The IOT gateway performance and functionality can vary depending on the IoT application. The IoT gateway provides diverse, ranging from low–power, lightweight gateways that collect and pass sensitive information from devices to high–end gateways that manage sensors and provide various security functions. In addition, the IoT gateway can be configured in different way such as an integrated with dedicated equipment, existing equipment (eg, wireless router, CCTV, etc.), or a form in which a gateway function module is mounted in a device such as a smart phone, etc.

The several ways that an IoT gateway can extend connectivity to sensor nodes is shown in 〈Figure 2〉.

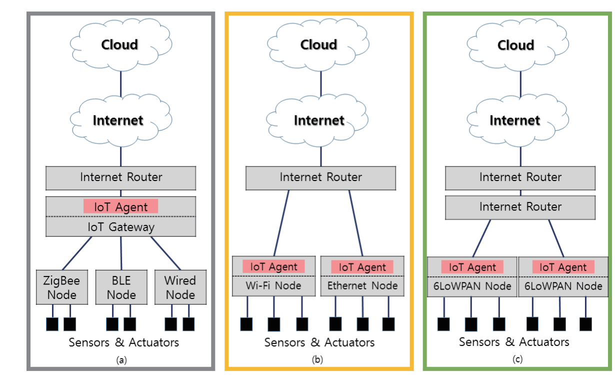

Figure 2. IoT Gateway Connectivity Types
(a) Via IoT Gateway (b) Directly – IoT Nodes (c) Directly – Lite IoT Nodes

In 〈Figure 2 (a)〉, sensor nodes connect to the IoT services via a gateway. The sensor nodes are not IP–based and cannot connect to the Internet/WAN directly. The sensor nodes use either wired or wireless PAN technology to connect to the gateway with low power network device connectivity. The IoT gateway built–in maintains an IoT agent for each sensor node that manages all data to and from all sensor nodes [1].

In 〈Figure 2 (b)〉, sensor nodes connect to the Internet using a WAN connection such as Wi–Fi or Ethernet directly and the IoT gateway serve primarily as a router [1]. 〈Figure 2 (c)〉 is similar to 〈Figure 2 (b)〉 except that nodes connect directly to the Internet using a PAN connection such as 6LoWPAN. In this case, the gateway serves as a translation point between the PAN and WAN [1].

The IoT gateway supports with multiple protocols for accepting the inbound data sent by the sensor nodes and outbound data to a process running in the cloud. The most used outbound protocols in the IoT contexts are REST, MQTT, CoAP, STOMP and even SMS. In some working scenarios, the gateway itself process the data and raise alerts in real time. The best performance and practice is to leave the powerful stream processing pipelines running in the cloud.

2. Networked LED Lights

The LED technology advancement enables networked LED based VLC system design have receiving strong attention from the system designers of the next generation of wireless networks on visible lights. The potential VLC's usages, implementation challenges and market conditions are described in [9] and VLC system model is shown in ⟨Figure 3⟩.

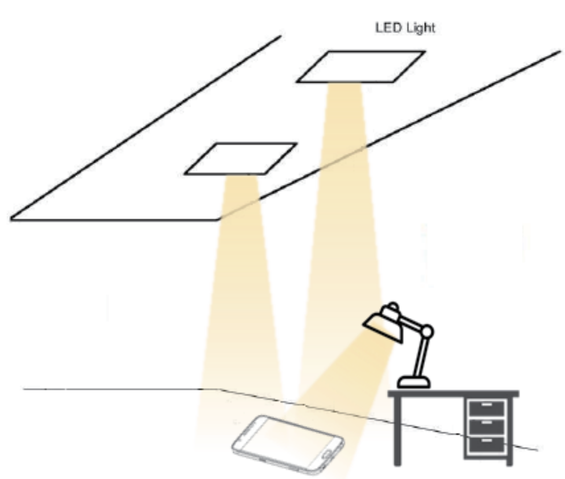

Figure 3. VLC System Model

The IEEE 802.15.7 standard has developed for short-range visible light communication [2]. The VLC IEEE standard species three PHY layers, which support data rate varying from 11:67 kb/s to 96 Mb/s with dimming and light licker prevention features. The software defined radio implementation using 802.15.7 protocol is shown in [10].

The most of the used VLC receiver design uses the photodiodes as a receivers, in [11] and a reverse-biased LED is used to implement a bidirectional LED-to-LED communication. This principle has been exploited by [6] to introduce a LED-to-LED communication network.

The Networked LED lights on VLC network to enable internet connectivity on lighting device based connectivity infrastructure is shown in ⟨Figure 4⟩.

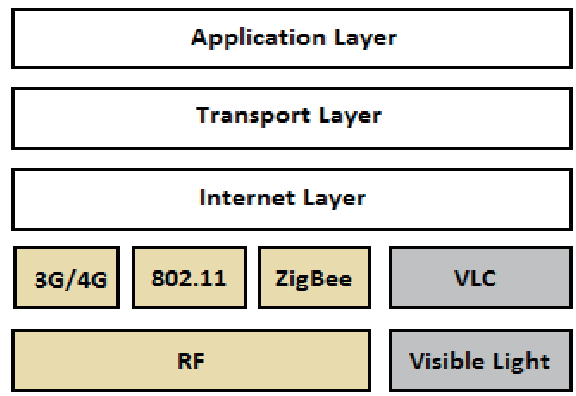

Figure 4. Networked LED Lights Stack [8]

The networked LED lights interface includes the MAC/PHY layer to interface VLC based on network infrastructure on standard TCP/IP stack on embedded development platform.

3. Light of Things

The LED technological advances enable the environment adaptive effective lighting control using ultra-low power semiconductor design have made to new technology innovation by integrating LEDs controller with connectivity and sensors interface which adds the extended space to build a low-power optical wireless sensor nodes to deploy in the environment to obtain physical environmental conditions and behaviours.

These LED lighting devices communicate and each other and creates zero power wireless network called Light of Things or Internet of Lights (IoL) to control lighting effectively. The Lighting of Things infrastructure shown in ⟨Figure 5⟩.

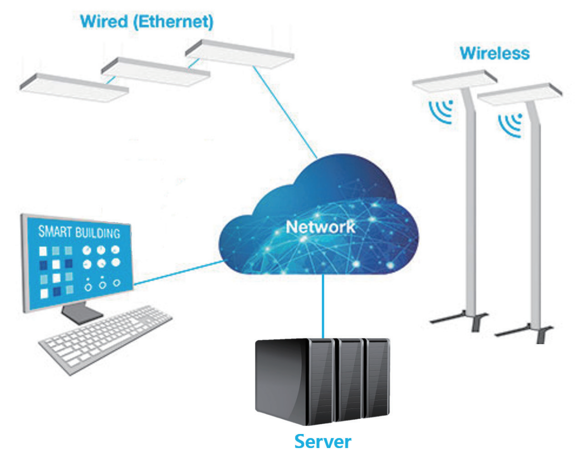

Figure 5. Light of Things Infrastructure

The sensor network technology is key components to enable smartness on device in IoT technology. The lighting device should build with connectivity and sensor network technology to enable smartness on lighting device to function as a part of IoT component. The IoL connected lighting device modules design must have built-in with following interface:

- Light Quality and Optical Interface
- Power Supply and Electrical Interface,
- Dimming and Flicker Performance
- Sensor Integration
- Diagnostics, and Autonomous Operation
- Connectivity, and associated Application Programming Interfaces (APIs)

The connectivity protocols integrated with industry-standard on lighting device enables lighting network infrastructure and that can be easily integrated with wireless sensor networks (WSNs) around the building or living environments.

The building management and security are the primary issues in living areas, the sensory networked lighting devices enables new business trend for building security equipment manufacturers and service providers.

The IoL based building management services is shown in ⟨Figure 6⟩ on following sensing and monitoring functional requirements,

- Lighting: Schedules, Occupancy
- Lifts: Breakdown, Maintenance, Traffic Performance

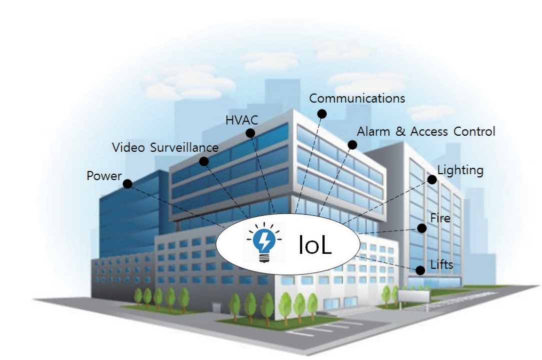

Figure 6. IoL Building Management Services

- Fire: Safety Management
- HAVAC: Temperatures, Performance, Operations
- Communications: Voice, Video, Data
- Video Surveillance: Cameras, Site Recorders
- Power: Metering, Distribution, Back-Up Generation
- Alarm & Access Control: Badge Testers, Intrusion Detection

4. Hybrid Networked LED Device Connectivity

To bringing light to the IoT services, the networked LED should built-in with RF (Bluetooth, Low Power RF, and WiFi), Wired-PLC, and Wired-Ethernet heterogeneous connectivity.

1) PLC-VLC Link

Even though 3G/4G/5G wireless mobile networks and Wi-Fi are used for delivering broadband data, PLC is a more competitive solution especially for indoor networking in buildings.

The early use of PLC has been limited to narrowband and low data-rate voice communication, supervisory control and data acquisition, and remote meter reading services systems. Recently broadband PLC solutions commonly operate in the frequency band starting at about 2 MHz and ranging up to about 30 MHz with data rates more than 100 Mbps. There two standards used in PLC, namely IEEE 1901 and ITU-T G.9960/61.

The strong motivation to explore the integration of the VLC and PLC technologies due to the newly established standards for both PLC and VLC. The resulting PLC-VLC system is an efficient and economical way to fulfill the need of broadband access for indoor users in buildings. The LED lighting system then functions as a wireless broadcaster for data fed from power line communication and enables the deployment of a broadband distribution downlink with very minimal additional cost. The 〈Figure 7〉 explores the integration of PLC and VLC communication infrastructures.

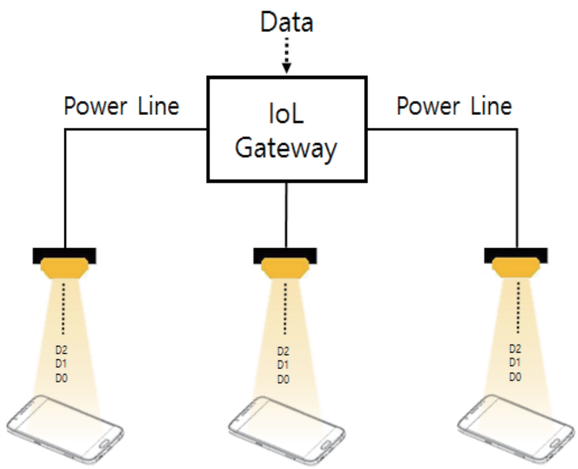

Figure 7. PLC-VLC Link

2) RF-VLC Link

The VLC networks are inspired by modern wireless radio frequency (RF) communication techniques due to easy integration, low power, and low cost wireless modules are in market. The benefit of utilizing RF compatible uplink channels that it allows for a simple integration of the hybrid system and a bidirectional RF channel. In an integrated system, RF channel is able to maintain full connectivity even if a VLC hotspot is unavailable, as long as in range of the RF channel. The 〈Figure 8〉 explores the integration of RF and VLC communication infrastructures

The RF channel interface supports Bluetooth, Low Power RF, and WiFi for broadband connectivity with internet as well local connectivity with all devices. The WiFi, Bluetooth, and Low Power RF Standards evolved and stabilized IEEE 802.11, IEEE 802.15.1, and IEEE 802.15.4 respectively. The strong motivation to explore the integration of the VLC and RF technologies due to the established standards for both RF and VLC.

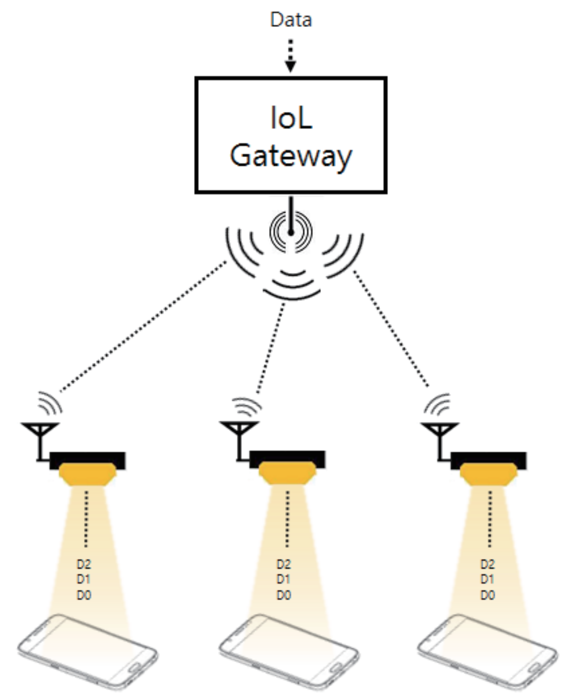

Figure 8. RF-VLC Link

3) Ethernet-VLC Link

The Ethernet interface on VLC system gives efficient broadband access for indoor users in buildings. The Ethernet has been chosen through the LAN architecture due to its adaptability to new technologies, high reliability, high-speed and low cost. The Ethernet-VLC link uses the 10BASE-T / 100BASE-T Ethernet connectivity with networked LED device. The 〈Figure 9〉 explores the integration of Ethernet and VLC communication infrastructures

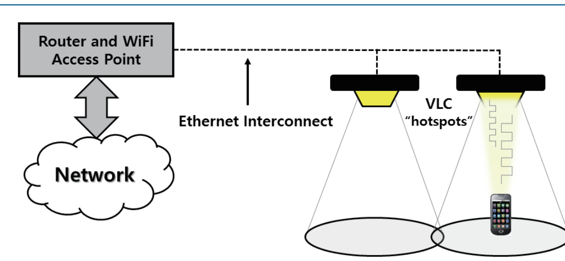

Figure 9. Ethernet-VLC Link

5. IoL Field Gateway Design

The proposed IoL Filed gateway designed with Wired and Wireless connectivity. The Lighting device with IoL Field

Gateway system usage models is shown in ⟨Figure 10⟩. The wired connectivity enabled through 10BASE-T/100BASE-T Ethernet and PLC interfaces. The wireless connectivity enabled through Bluetooth, Low Power RF, and WiFi.

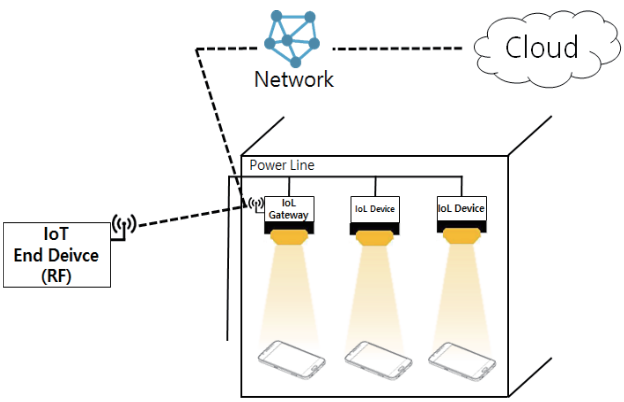

Figure 10. Ethernet-VLC Link

The PLC, Bluetooth, and Low Power RF interface mostly used to interconnect local network with Lighting Sensor device and IoT Sensor device. The WiFi and Ethernet interface to connect with internet and cloud.

The proposed IoL Field Gateway design on this paper to adapt the technology transition of LED lighting from functional mandate to sensory network infrastructure to add a value IoT technology services. The networked LED light source supported connectivity infrastructure on bi-directional wired and wireless connectivity. The ⟨Figure 11⟩ and ⟨Figure 12⟩ illustrate the proposed design of IoL Field Gateway HW and SW block diagram model.

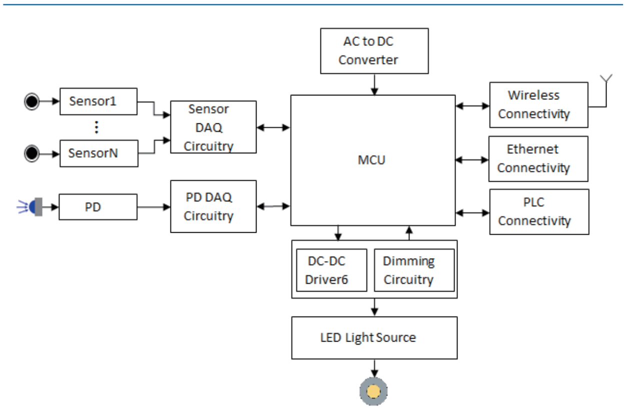

Figure 11. IoL Field Gateway HW Block Diagram

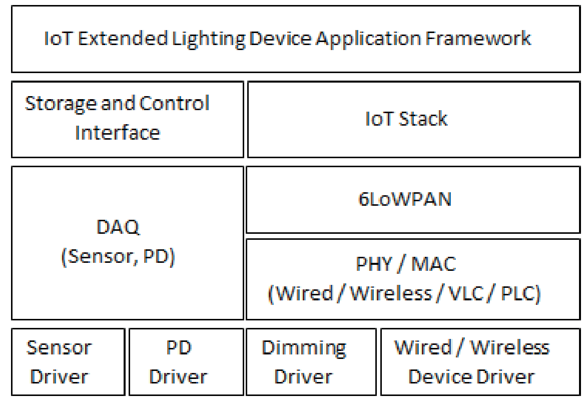

Figure 12. IoL Field Gateway SW Block Diagram

The proposed IoL Filed gateway special characteristics are,

- Light source with fast and efficient illumination switching control features
- Constant-voltage power supply using an integrated DC-DC or AC-DC LED driver with dimming capability
- Low Power Consumption
- Energy Efficient and Comfort Lighting
- Integrated with sensors
- Incorporates wired or wireless communications and Bluetooth LE or similar for hyper local communications
- Connected with Internet server through Wired or Wireless mode of communication in backbone
- Integration of thermal and electrical sensors to implement over temperature and electrical protection
- Integration of monitors its own behavior to predict the remaining life of the fixture or to indicate any issues in an early stage such that the fixture can be serviced in a regular maintenance cycle
- Low Cost

6. IoL Field Gateway Emulation

To evaluate the proposed IoL Field gateway design with networked LED connectivity, the system emulated with hybrid model by integrating PLC, RF and VLC. The designed IoL gateway were able to develop practical networked smart lighting system with internet protocol

(IP) access for proposed intension support like browsing and internet access.

To demonstrate the functional evaluation of IoL gateway, the networked lighting sensor device designed with PLC-RF-VLC link and the IoL Field Gateway designed with PLC-WiFi-RF-Bluetooth link with internet connectivity as illustrated in 〈Figure 13〉. The RF-VLC link and PLC-VLC link can be evaluated using ISC as a receiver to verify the VLC link.

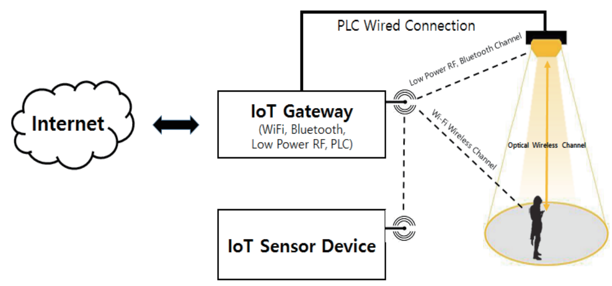

Figure 13. IoL Field Gateway Hybrid Link

The Networked lighting sensor device designed with PLC, Low Power RF and VLC link using down LED light source, Arduino UNO, ProBee RF, NC-EPLCD, Digital MOSFET for dimming control, and sensors like temperature, humidity, motion sensor, current sensor, etc.

The IoL Field gateway designed with PLC, WiFi, Low Power RF and Bluetooth link using Arduino Mega, ProBee RF, NC-EPLCD, Arduino WiFi Shield, HC-06 Bluetooth, to interconnect lighting end device with remote user or server. The connection between gateway and lighting end devices using Low Power RF and PLC link. The internet access added on designed IoL Field gateway using tine uIP open source TCP/IP protocol stack.

The Hybrid VLC link evaluated using android based smart phone camera based receiver. The server model designed using LabView framework to monitor and control through IoT/IoL service.

The networked LED sensor device sends the environmental condition periodically and push the information to remote server using Hybrid PLC-RF-VLC link and monitor on host PC. The VLC links tested with 3 meters far from light source using smart device on Samsung Tab and smartphone with 1kbs on 10-3 error rate. The higher data rate is achievable by changing modulation scheme and android native application based decoding method.

III. Conclusion

This paper presented the IoL Field gateway design and implementation information for networked lighting sensor device and gateway as proposed to for value added IoT services using lighting device infrastructure use of lighting source. The IoL Field gateway designed with Arduino using embedded TCP/IP Links and IEEE802.15.7 PHY/MAC protocol with low cost and low power consumption. The hybrid PLC-VLC link and RF-VLC links performance are evaluated respectively based wireless sensory network requirement of IoT services.

Acknowledgement

"This research partially was supported by the MSIP (Ministry of Science, ICT and Future Planning, Korea, under the ITRC (Information Technology Research Center) support program (IITP-2016-R2718-16-0004) supervised by the IITP (National IT Industry Promotion Agency)"

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