

IDMP-VLC: IoT Device Management Protocol in Visible Light Communication Networks

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Abstract—The Internet of Things (IoT) can be used to help a variety of things connected to the network in home, building, factory, city, and so on. In the meantime, the Visible Light Communication (VLC) based on Light Emitting Diode (LED) has been focused as future communication facility. In this paper, we propose the IoT Device Management Protocol (IDMP) with VLC, named IDMP-VLC, which can be used to manage IoT devices in VLC networks. The IDMP-VLC protocol is a simple and self-configurable device management protocol. It provides device initialization and management operations, and data transmission operation. The IDMP-VLC will use IPv6 with IPv6 over Low power Wireless Personal Area Network (6LoWPAN). In the proposed scheme, the two different transmission schemes are used for communication between lighting device and IoT device: VLC for downstream from lighting to IoT device and WPAN (ZigBee or Bluetooth) for upstream from IoT device to lighting device. The proposed protocol is implemented and experimented with various devices on top of the Java Virtual Machine (JVM). From the experimentation, it is shown that the proposed IDMP-VLC can be effectively used for initialization, management, and data transmission with IoT devices over VLC networks.

Keywords—Visible Light Communication, Internet of Things, IDMP, 6LoWPAN, CoAP

I. INTRODUCTION

In recent years, the Internet of Things (IoT) has been focused on, as shown in the numerous researches in smart city^[1-3], healthcare^[4-6], smart grid^[7,8], and so on. Sensor and actuator devices play a key role in the IoT network environment.

In the meantime, the Visible Light Communication (VLC) has been developed as a new wireless access technology, which is based on the Light Emitting Diode (LED) technology^[9,10]. Because the VLC uses the light source instead of the radio wave, there is no need of wireless resource allocation scheme. In addition, it does not need additional infrastructure, and the location management of VLC devices is relatively easy because each VLC device should be equipped with the light source, compared to the conventional wireless technologies.

It is noted that the Constrained Application Protocol (CoAP) was developed as a key protocol for management of IoT

devices. The CoAP is a specialized web transfer protocol used for constrained nodes and constrained networks^[11].

In this paper, we propose a new IoT Device Management Protocol over VLC networks, named IDMP-VLC. The proposed IDMP-VLC is a simple and self-configurable device management protocol that can be used in the IoT networks with the VLC devices. It can operate on any devices which support JVM (Java Virtual Machine). It is designed to use IPv6 over Low Power Wireless Personal Area Networks (6LoWPAN)^[12]. By adopting the CoAP protocol, the proposed IDMP-VLC protocol supports reliable transfer and simple management. It uses the two different communication channels for VLC: the downstream VLC channel from lighting device to IoT device and the upstream WPAN (e.g., ZigBee or BLE) channel from IoT device to VLC device. The use of WPAN technology for upstream channel from IoT device to VLC device is adopted because the current VLC transmission technology is difficult to support the upstream channel. For the proposed IDMP-VLC protocol was implemented and experimented over in a testbed environment.

This paper is organized as follows. Section II describes the overview of IDMP-VLC protocol. Section III gives a more detailed architecture of the IDMP-VLC protocol. Section IV discusses the implementation and experimentation of the proposed IDMP-VLC protocol in a testbed environment. Finally, Section V concludes this paper.

II. IDMP-VLC PROTOCOL OVERVIEW

The IDMP-VLC protocol is a self-configurable and simple device management protocol that operates on top of CoAP.

Figure 1 shows the use case of IDMP-VLC protocol. The communication nodes of IDMP-VLC are Platform Server (PS), Aggregation Agent (AA), Lighting Device (LD), and IoT device. IDMP-VLC can be deployed in building, home, and city network. The AA manages its edge network, and LDs forward packets from the AA to IoT devices using VLC, and from IoT devices to AA using WPAN. IoT devices may be any devices which use VLC and WPAN.

Figure 2 shows the communication model of IDMP-VLC protocol. The IDMP-VLC communication between Platform server (PS) and Aggregation Agent (AA) uses the legacy

standard protocols for physical and link layers. For example, if the platform server is in a data center and an aggregation agent is in a home, the server and agent may use the Ethernet.

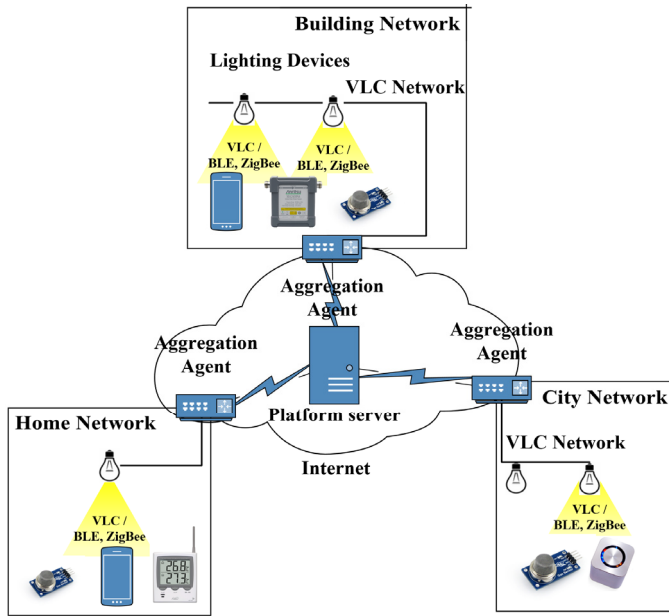


Figure 1. Network model for IDMP-VLC protocol

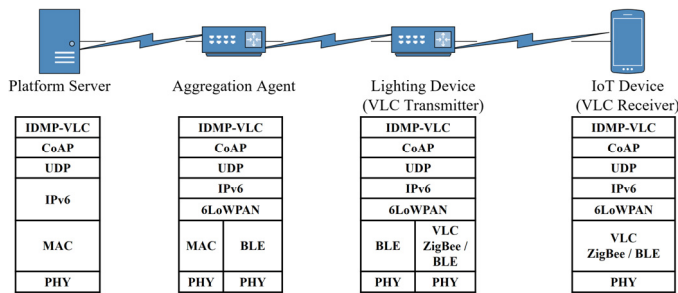


Figure 2. The protocol stack of IDMP-VLC

Communications among aggregation agent and lighting devices use the 6LoWPAN technology because the lighting devices will be constrained devices. Such communication is done using BLE, ZigBee, or other standards compatible with 6LoWPAN.

For communication between lighting devices and IoT devices, the IDMP-VLC uses the two different transmission channels. The downstream communication from VLC lighting device to IoT device uses the IEEE 802.15.7 VLC technology, whereas the upstream communication from IoT device to VLC lighting device uses the IEEE 802.15.4 WPAN technology. This is because the IEEE 802.15.7 VLC standard does not support the full-duplex bidirectional communication in real-world products.

For management of IoT devices, the IDMP-VLC protocol uses the Constrained Application Protocol (CoAP) among all communication nodes. It is a reasonable choice to use the CoAP for IoT device management because CoAP is designed for constrained network environment^[13,14].

III. IDMP-VLC PROTOCOL ARCHITECTURE

A. Communication nodes

1) Platform Server (PS, level 0): The platform server manages aggregation agents, lighting devices, and IoT Devices. The server has a global IPv6 address and database. The address is used for communication with others. The database contains the status of each node and the mapping information between device and IPv6 address.

2) Aggregation Agent (AA, level 1): The aggregation agent is used to aggregate the communication messages which are exchanged between PS and LDs, and between PS and IoT devices. The agent has a global IPv6 address which is used to communicate with others.

3) Lighting Device (LD, level 2): The lighting device has two units: light unit for VLC and 6LoWPAN communication unit. The light unit consists of a LED light and a light controller. The controller has its coding and flicking scheme for communicating through VLC light. The 6LoWPAN communication unit implements 6LoWPAN and forwarding operations from IoT devices to a platform server, and vice versa.

4) IoT Device (level 3): The IoT device is user-equipment. It can be any “thing” such as sensors, actuators, smartphones, etc.

B. Registration and discovery operations

B-1. Two-way handshaking scheme

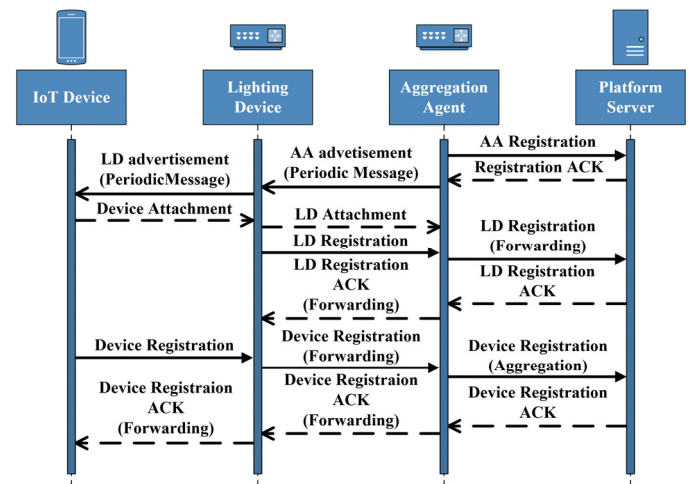


Figure 3. Device initialization – two-way handshaking

Figure 3 shows the two-way device initialization flow of IDMP-VLC.

1) AA registration: For LDs and IoT devices to communicate with a platform server, an AA should be registered with the server. The AA knows the IPv6 address of the platform server. The address can also be configured by an administrator.

2) Device advertisement: For every 5 second, LDs and AAs should advertise their status toward their subnetwork such

information may include identifier, IPv6 address, physical address, availability, and so on.

3) Device attachment: Communications using CoAP is done over IPv6 enabled network. To enable IPv6 communication, the higher-level devices should be connected to the network of lower level device. Therefore, after higher level devices receive advertisement messages of lower level device, the higher-level devices should be attached to them by sending device attachment messages.

4) Device registration: To communicate among PS and higher level devices, the server should know their locations. Therefore, after the device attachment is completed, they should send the device registration message to the PS.

B-2. Three-way handshaking scheme

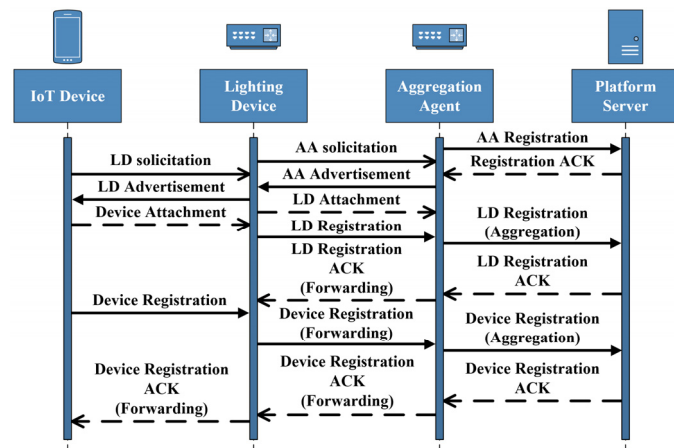


Figure 4. Device initialization – three-way handshaking

Figure 4 shows the three-way device initialization flow of IDMP-VLC.

1) AA registration: This process is the same with the AA registration process of two-way handshaking case.

2) Device solicitation: If the higher-level devices did not receive any advertisement messages of lower level device, they should send solicitation messages to lower level devices.

3) Device advertisement: Once the devices received the solicitation message, they should send advertisement messages without using the advertisement timer.

4) Device attachment: This process is the same with the device attachment of two-way handshaking case.

5) Device registration: This process is the same with the device registration of two-way handshaking case.

C. Device management operations

Figure 5 shows the device management flow of IDMP-VLC.

1) Device management request: This message is used to manage the status and operation of devices. It may contain the data payload which are associated with the change of device

status or operation. When PS sends the request to LD, AA forwards the message to the LD.

2) Device management response: This message contains the result of requests such as changed status, error code, etc. When LD sends this message to PS, the AA forwards the message to the PS.

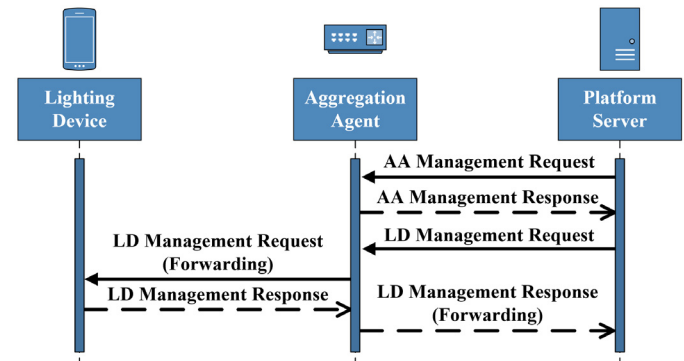


Figure 5. Device management operations

D. Data transmission operations

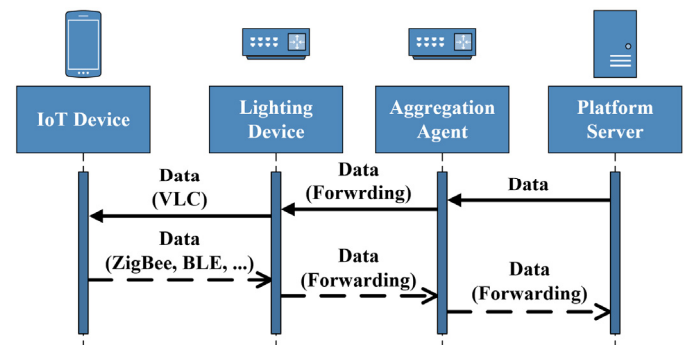


Figure 6. Data transmission operations

Figure 6 shows the data transmission flow of IDMP-VLC.

1) Data transmission from PS: When PS wants to send data to IoT devices, it searches the location where the IoT device is located and connected. Then it sends data to the device.

2) Data forwarding: For data from PS to an IoT device, an AA forwards the data to LD, and the LD forwards it to the corresponding IoT device, and vice versa.

3) Data receiving: Every downstream data from LDs to IoT devices will be sent through VLC.

4) Data transmission from IoT Device: Every upstream data from IoT devices to LDs uses WPAN such as ZigBee, BLE, etc.

IV. IMPLEMENTATION AND EXPERIMENTATIONS

In this section, we discuss the implementation and experimentation of the proposed IDMP-VLC protocol.

A. Testbed environment

Figure 7 shows the corresponding testbed environment. We made PS which integrates the AA. The PS is a personal computer. the LD is Raspberry Pi. The IoT device is Raspberry Pi connected with Arduino. PS and LD are connected through Ethernet, and LD and IoT Device are connected through 6LoWPAN enabled BLE connection. Figure 8 shows the devices used for testbed configuration.

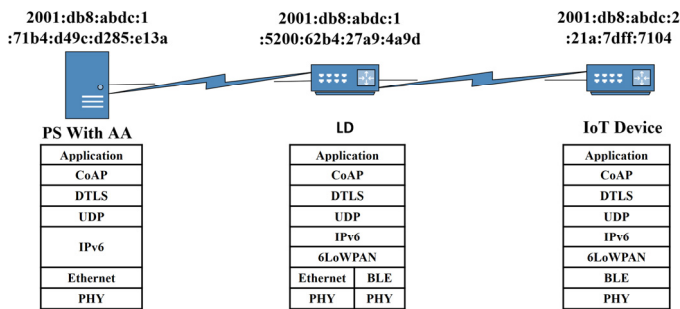


Figure 7. Testbed environment

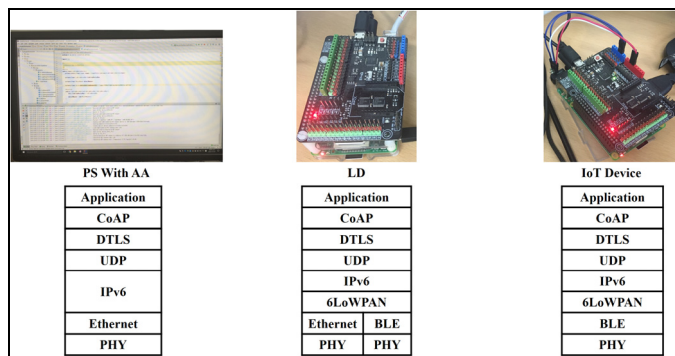


Figure 8. Testbed devices

The PS is implemented using Spring Framework based on JAVA and its database is implemented by using MYSQL. LD and IoT devices are also implemented over the Spring Framework.

We did not implement the VLC light unit yet. Instead, we implemented the LD device using the 6LoWPAN enabled BLE as the upstream and downstream transmission channels. We also implemented the forwarding function of the LD.

The IoT device is connected to the Arduino. A temperature/humidity sensor is connected to the Arduino. The Raspberry Pi of IoT device communicates with the Arduino using the Universal Asynchronous Receiver/Transmitter (UART) communication. The device periodically updates the temperature/humidity data.

B. Implementation detail

1) Device Initialization: Because the AA is combined with the PS, the AA registration process is not needed. Figure 9 shows

the device initialization flow in testbed environment. The LD sends the CoAP request to the PS. After that, the PS responds with a 2.01 created message with the LD. We assume that the IoT device was already attached to LD. Since that, IoT Device sends CoAP request to PS. Then, the PS responds with a 2.01 created message with the IoT device. Figure 10 and Figure 11 show the packet captures of these operations.

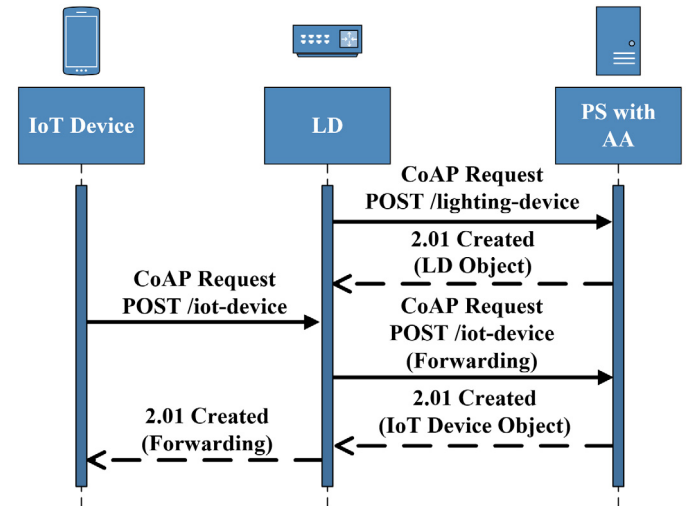


Figure 9. Device initialization - testbed environment

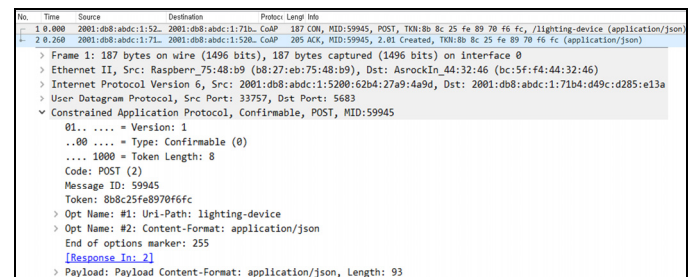


Figure 10. Lighting device initialization - packet capture

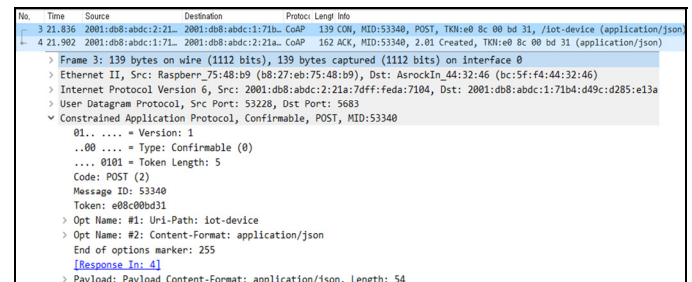


Figure 11. IoT device initialization - packet capture

2) Device management: To manage the devices, CoAP messages can be exchanged. For example, the device settings can be changed by device management. Figure 12 shows the process of the LD. The PS sends a CoAP request to change the parameters of LD. Retrieving parameters are also possible by sending the CoAP GET request of the same resource. Figure 13 shows the packet of this process.

3) Data transmission: The data transmission is done by sending the CoAP GET request. Figure 14 shows the process of such data transmission. The PS sends a data request to an IoT device. In the middle of the figure, we can see that LD forwards the request from PS and the response from IoT Device. Figure 15 shows the packet of this process.

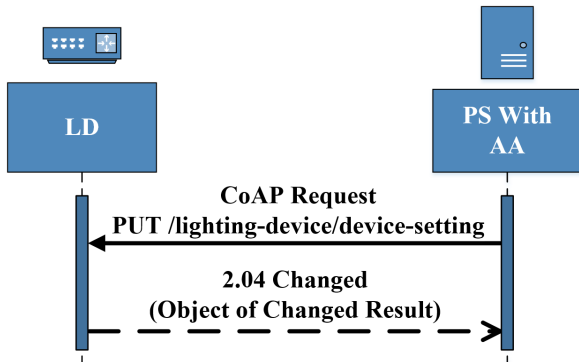


Figure 12. Device management - testbed environment

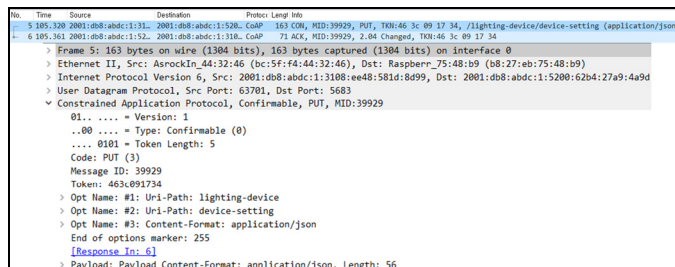


Figure 13. Device management - packet capture

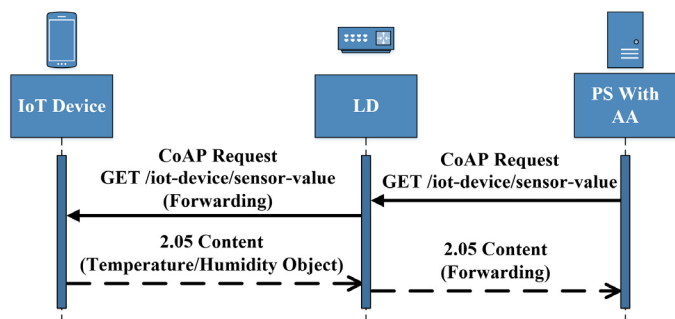


Figure 14. Data transmission - testbed environment

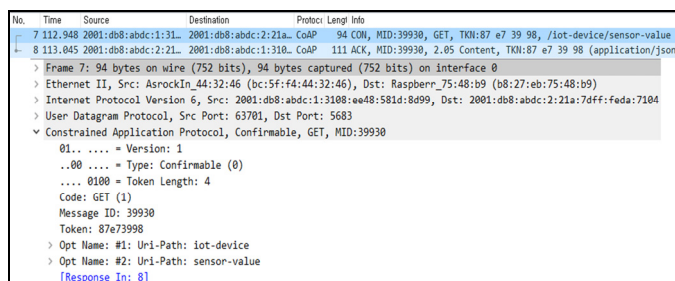


Figure 15. Data transmission - packet capture

V. CONCLUSIONS

The Internet of Things (IoT) can be used to help a variety of things connected to the network in home, building, factory, city, and so on.

In this paper, we propose the IoT Device Management Protocol (IDMP) with VLC, named IDMP-VLC, which can be used to manage IoT devices in VLC networks. The IDMP-VLC protocol is a simple and self-configurable device management protocol. By implementation and experimentation, we see that the proposed IDMP-VLC protocol can be used for device initialization and management operations, and data transmission operation.

This work is still in development and improvement. For further study, we will add some more features such as location management, service management, and so on. The light unit is also in development. In the future work, we will progress the test with the light unit.

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