Network Working Group   Seok J. Koh
Internet-Draft   Cheol M. Kim
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Requirements for IoT Services based on Visible Light Communications
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Abstract

This document describes the requirements for IoT Services based on Visible Light Communication (VLC) to effectively provide IoT services in the VLC-based networks. This document includes the overview of VLC technology and the concepts of VLC-based IoT services, and the requirements for IoT services in the VLC-based networks.

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1. Introduction

The VLC has been developed as a wireless communication technology which uses visible lights, infrared (IR), and ultra-violet (UV) spectrum instead of conventional RF band. In particular, the VLC provides the following distinctive features: 1) non-interference to existing RF bands, 2) free license to use the spectrum of visible light, IR, and UV, and 3) VLC can be easily deployed with the existing LED lights. Since the VLC is non-RF based wireless communication technology, it can be complementary wireless communication technology among the RF-based wireless communication technologies (mobile network, WPAN, WLAN). These distinctive features of VLC will be helpful to overcome the shortcomings of the existing RF technologies.

1.1. Terminology and Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14. [RFC2119], [RFC8174] when, and only when, they appear in all capitals, as shown here.

2. Overview

2.1. Visible Light Communication

The Visible Light Communication (VLC) technology has been developed to transmit data through the license-free spectrum of visible light, IR, and UV. [ITU-T_G.9991] [IEEE_802.15.7-2018] Data is encapsulated into VLC frames, and it is coded using digital-based modulation technology, such as Pulse Width Modulation (PWM), Orthogonal Frequency Division Multiplexing (OFDM), and so on. Those coded VLC frames are transmitted by LED or Laser Diode (LD). A Photo Diode (PD) or an image sensor can receive the VLC frames.

The [ITU-T_G.9991] specifies the system architecture, PHY and data link layer of high-speed indoor VLC transceiver, especially for home network. The [ITU-T_G.9991] network comprises on or more domains. Each domain has one domain master and one or more nodes which are registered to the domain master. Global Master (GM) is responsible to coordinate the resources among domains.

For each domain, the [ITU-T_G.9991] specifies the five topologies for indoor VLC: peer to peer (or point to point) topology (P2P), point to multipoint topology (P2MP), multipoint to multipoint (MP2MP), relayed mode, and centralized topology. In addition to network topology, the .[ITU-T_G.9991] specifies the modes of operation in a domain, which includes centralized mode (CM) and unified mode (UM). In centralized mode, the direct communication between domain master (DM) and end-point node (EP) is allowed, while direct communication among end-point nodes are note allowed. The CM supports 3 types of operation mode: a) bi-directional communication, b) broadcast only, and c) hybrid communication. In the unified mode, the direct or indirect communication among nodes is allowed.

The [IEEE_802.15.7-2018] specifies PHY and MAC sublayer for VLC. In [IEEE_802.15.7-2018], it uses the term Optical Wireless Communications (OWC) rather than VLC because the standard explicitly considers the wavelength from 10,000nm to 190nm, which includes visible light, IR, and UV. Also, the standard introduces the term Optical Wireless Personal Area Network (OWPAN) with specifying network topology, addressing, collision avoidance, acknowledgement, performance quality indication, dimming support, visibility support, colored status indication, and color stabilization.

In [IEEE_802.15.7-2018], it classifies three types of devices in OWC: infrastructure, mobile, and vehicle. Table 1 shows the classification of devices.

Features	Infrastructure	Mobile	Vehicle
Fixed coordinator	Yes	No	No
Power supply	Ample	Limited	Moderate
Form factor	Unconstrained	Constrained	Unconstrained
Light Source	Intense	Weak	Intense
Physical mobility	No	Yes	Yes
Range	Short/long	Short	Long
Data rates	High/low	High	Low

Table 1: Device classification in [IEEE_802.15.7-2018]

The [IEEE_802.15.7-2018] specifies three network topologies: peer-to-peer, star, and broadcast. A one device gets a role of coordinator, which is determined by applications. The standard specifies the visibility support across all topologies with flicker mitigation.

2.2. IoT services based on VLC

This document describes the concept of IoT services based on VLC. The goal of VLC-based IoT services is the functionality as follows:

* Device initialization, including device discovery and device registration.

* Data transport using VLC for downlink channel from lighting device to user terminal.

* Data transport using VLC for uplink from user terminal to lighting devices or using other RFs for uplink channel from user terminal to the VLC agent device.

* Light control, such as the configuration of dimming, color, modulation of visible lights.

* Device monitoring.

* Roaming support for mobile user terminal.

Figure 2 and 3 shows the network model for VLC-based IoT services, which uses bi-directional VLC environment and uni-directional VLC environment. Also, those figures describe the network nodes in the VLC-based IoT network: IoT server (IS), VLC Agent (VA), VLC Light (VL), and User Terminal (UT).

```
    +----+ Ethernet +----+ Ethernet/WLAN/WPAN +-----------+
    | IS |<========>| VA |<==================>|    VTs    |
    +----+          +----+                    |(LED Light)|
                                              +-----------+
                                             *             *
                                            *      Data      *
                                           *    through VLC   *
                                          *   (Visible light,  *
                                         *        IR, UV)       *
                                        *                        *
                                                     ^
                  +------------+  bi-directional VLC *
                  |     UT     |      (VT <-> UT)    *
                  |(IoT Device)|<*********************
                  +------------+
```

Figure 1: VLC-based IoT services in bi-directional VLC environment

```
    +----+ Ethernet +----+ Ethernet/WLAN/WPAN +-----------+
    | IS |<========>| VA |<==================>|    VTs    |
    +----+          +----+                    |(LED Light)|
                      ##                      +-----------+
                     ##                      *             *
                    ##  Uplink channel      *     Data      *
                   ##       for UT         *   through VLC   *
                  ##     (WLAN/WPAN)      *  (Visible light,  *
                 ##                      *       IR, UV)       *
                ##                      *                       *
               ##                                     *
          +------------+     uni-directional VLC      *
          |     UT     | (downlink channel, VT -> UT) *
          |(IoT Device)|<******************************
          +------------+
```

Figure 2: VLC-based IoT services in uni-directional VLC environment

As shown in Figure 2 and 3, it is noted that there two kinds of VLC between UT and VL/VA: uni-directional VLC and bi-directional VLC. In the bi-directional VLC case, VLC is performed between UL and VL. That is, both the downlink from VL to UT and the uplink from UT to VL use the VLC. However, in the uni-directional VLC case, only the downlink uses the VLC, whereas the uplink may use the other OF

technologies, such as WLAN or WPAN. In the viewpoint of VLC deployment in real-world networks, the bi-directional VLC is suggested, but the uni-directional VLC may ne used in a certain network.

For VLC-based IoT networks, we consider the following four types of network nodes: Platform Server (PS), Aggregation Agent (AA), VLC Transmitter (VT), and VLC Receiver (VR). Figure 1 shows uni-directional VLC from VT to VR, in which only downlink VLC transmission is allowed from VT to VR, and the uplink or backward transmission will be made between VR and AA by using another network link, such as WLAN or WPAN.

2.3. Network nodes

2.3.1. IoT Server (IS)

IS is responsible for overall management for all devices in VLC-based IoT network. IS performs IP-based protocol operations including the device initialization, device registration, device monitoring, light control, and device roaming. In addition, IS transmits data to VL and UT in the data transport operation. IS is connected to the Internet.

2.3.2. VLC Agent (VA)

For effective management of VLC-based IoT services, one or more VAs can be deployed in the network. VA is purposed to perform IP-based protocol operations and to locally manage its associated VLs and UTs. It keeps an association information between VL and UT, and such information may be updated in the device monitoring and device roaming operations. VA has a responsibility to relay data between IS and VL/UT.

2.3.3. VLC Light (VL)

VL can be installed or embedded on an LED light. In the initialization, VL is registered to IS. After that, VL advertises itself to user terminals in the VLC network by using VLC. VL has a responsibility to translate IP-based data to VLC frames and vice versa.

2.3.4. User Terminal (UT)

UT represents a user device with the VLC functionality. All UTs can be registered to and managed by IS via its associated VL and/or VA in the device initialization and monitoring operations. VLC data are also exchanged between UT and IS by way of VL and/or VA.

3. Requirements for IoT services based on VLC

3.1. Device initialization

To enable IoT services based on VLC, all devices need to find uplink device, join the network, and make them discoverable in the network. The followings are the requirements for device initialization:

* All devices MUST have capabilities of device advertisement and device discovery in VLC-based IoT network.

* Each device MUST generate its unique ID (Identifier) and make association to its uplink device.

3.2. Device monitoring

IS manages all VA, VL, and UT in the network via monitoring operations. The followings are the requirements for device monitoring:

* Each device MUST generate its status information.

* Each device MUST send its status information to its uplink device periodically.

* Each device MUST receive the request of status information from its uplink device and MUST send its up-to-date status information to the uplink device.

3.3. Uplink channel for UT in the uni-directional VLC

In uni-directional VLC environment, the UT, which only has capability of downlink VLC, needs an uplink channel for enabling IoT services. The followings are the requirements for uplink channel management:

* VA MUST create RF based uplink channel for uplink channel in the uni-directional VLC case.

* VA MUST configure RF based uplink channel with the parameters received from its uplink device.

* VA MUST send the information of RF based uplink channel to downlink device.

* VA MUST forward data packets to uplink and downlink channel.

* VL MUST generate a VLC frame which includes the information of RF

based uplink channel and to send the VLC frame to downlink device periodically.

* UT MUST receive a VLC frame from uplink device and to extract the information of RF based uplink channel.

* UT MUST establish the uplink channel with VA when UT has the uni-directional VLC.

3.4. Data transport

In VLC-based IoT services, IP-based and VLC frame-based data need to interoperate in all devices. The followings are the requirements for data transport:

* All devices MUST handle IP-based data packets in VLC-based IoT network.

* VL and UT MUST translate IP-based data packet to VLC frames, and vice versa.

3.5. Light control

IS controls all VL by configuring the parameters associated with LED lights. The followings are the requirements for light control:

* VL MUST handle the request of IS for configuration of LED light.

* VL MUST change the physical characteristics of LED light, as per the request of IS.

3.6. Device roaming

When UT is mobile device, the IoT services need to be continued, even though UT changes its attached VL. The followings are the requirements for device roaming:

* UT MUST discover the neighboring VLs in the roaming case.

* UT MUST generate and exchange the roaming data with its neighboring VL.

* VL MUST detect the roaming event from the association request with the roaming data.

* VL MUST notify the roaming event to uplink VA device.

* IS and VL MUST handle the roaming request appropriately.

4. Security consideration

TBD

5. IANA Considerations

TBD

6. Normative References

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Authors' Addresses

Seok-Joo Koh
Kyungpook National University
Daehakro 80, Bukgu, Daegu, South Korea 41566

Phone: +82 53 950 7356
Email: sjkoh@knu.ac.kr

Cheol-Min Kim
Kyungpook National University
Daehakro 80, Bukgu, Daegu, South Korea 41566

Email: cheolminkim@vanilet.pe.kr