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Internet of things and smart cities and communities – Frameworks, architectures and protocols

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Framework of Internet of things services based on visible light communications

Recommendation ITU-T Y.4465

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Recommendation ITU-T Y.4465

Framework of Internet of things services based on visible light communications

Summary

Recommendation ITU-T Y.4465 describes a framework of Internet of things (IoT) services based on visible light communications (VLC). After describing the technical overview of VLC and the concepts of IoT services based on VLC, this Recommendation describes requirements and a reference model.

History

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Introduction

The VLC has been developed as a wireless communication technology that uses visible lights, infrared (IR), and ultra-violet (UV) spectrum instead of conventional radio frequency (RF) band. In particular, the VLC provides the following distinctive features: a) non-interference to the existing RF bands, b) free license to use the spectrum of visible light, IR, and UV, and c) VLC that can be easily deployed with the existing light emitting diode (LED) lights.

It is noted that the VLC technology is easily deployed because the LED lights are widely deployed in real-world indoor communication network. Also, the data rates of VLC are enough to transmit multimedia data. Since the VLC is non-RF based wireless communication technology, it can be complementary wireless communication technology among the RF-based wireless communication technologies (e.g., mobile network, wireless personal area network (WPAN), wireless local area network (WLAN)). These distinctive features of VLC will be helpful to overcome the shortcomings of the existing RF technologies, and the IoT services based on VLC can be provided as a complementary solution.

Recommendation ITU-T Y.4465

Framework of Internet of things services based on visible light communications

1 Scope

This Recommendation describes a framework of IoT services based on visible light communications (VLC), which includes the followings:

– Technical overview of VLC and concepts of IoT services based on VLC;

– Requirements for IoT services based on VLC;

– Reference model of IoT service based on VLC.

NOTE – This Recommendation focuses on how to provide IoT services based on VLC. The modification or enhancement of the VLC technology is outside the scope of this Recommendation.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T Y.4000] Recommendation ITU-T Y.4000/Y.2060 (2012), *Overview of the Internet of things.*

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 channel [b-ITU-T G.9960]: A transmission path between nodes. One channel is considered to be one transmission path. Logically, a channel is an instance of a communication medium used for the purpose of passing data between two or more nodes.

3.1.2 data [b-ITU-T G.9960]: Bits or bytes transported over the medium or via a reference point that individually convey information. Data includes both user (application) data and any other auxiliary information (overhead, including control, management, etc.). Data does not include bits or bytes that, by themselves, do not convey any information, such as the preamble.

3.1.3 data rate [b-ITU-T G.9960]: The average number of bits communicated (transmitted) in a unit of time. The usual unit of time for data rate is 1 second.

3.1.4 device [ITU-T Y.4000]: With regard to the Internet of things, this is a piece of equipment with the mandatory capabilities of communication and the optional capabilities of sensing, actuation, data capture, data storage and data processing.

3.1.5 dimming [b-IEEE 802.15.7]: Reducing the radiant power of a transmitting light.

3.1.6 identifier [b-ITU-T Y.2091]: An identifier is a series of digits, characters and symbols or any other form of data used to identify subscriber(s), user(s), network element(s), function(s), network entity(ies) providing services/applications, or other entities (e.g., physical or logical objects). Identifiers can be used for registration or authorization. They can be either public to all networks, shared between a limited number of networks or private to a specific network (private IDs are normally not disclosed to third parties).

3.1.7 image sensor [b-IEEE 802.15.7]: A sensor that captures an image and translates it into a light-coded output signal.

3.1.8 Internet of Things (IoT) [ITU-T Y.4000]: A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies.

NOTE 1 – Through the exploitation of identification, data capture, processing and communication capabilities, the IoT makes full use of things to offer services to all kinds of applications, whilst ensuring that security and privacy requirements are fulfilled.

NOTE 2 – From a broader perspective, the IoT can be perceived as a vision with technological and societal implications.

3.2 Terms defined in this Recommendation

None.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

CM	Centralized Mode
DCD	Device Control Data
DM	Domain Master
EP	End Point
GM	Global Master
ID	Identifier
IoT	Internet of Things
IP	Internet Protocol
IR	Infrared
IS	IoT Sever
ISD	IoT Service Data
LED	Light Emitting Diode
LCD	Lighting Control Data
LD	Laser Diode
MAC	Medium Access Control
MP2MP	Multipoint to Multipoint
MCU	Microcontroller Unit
OWC	Optical Wireless Communications
OWPAN	Optical Wireless Personal Area Network
P2MP	Point To Multipoint
P2P	Peer-To-Peer
PC	Personal Computer

PD	Photo Diode
PHY	Physical layer
RF	Radio Frequency
UM	Unified Mode
UT	User Terminal
UV	Ultra Violet
VA	VLC Agent
VL	VLC Light
VLC	Visible Light Communications
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Network

5 Conventions

In this Recommendation:

The keywords "**is required to**" indicate a requirement which must be strictly followed and from which no deviation is permitted if conformance to this Recommendation is to be claimed.

The keywords "**is recommended**" indicate a requirement which is recommended but which is not absolutely required. Thus, this requirement need not be present to claim conformance.

The keywords "**may**" indicate an optional requirement which is permissible, without implying any sense of being recommended. These terms are not intended to imply that the vendor's implementation must provide the option and the feature can be optionally enabled by the network operator/service provider. Rather, it means the vendor may optionally provide the feature and still claim conformance with the specification.

6 Overview

6.1 Visible light communications

The visible light communications (VLC) technology has been developed to transmit data through the license-free spectrum of visible light, infrared (IR), and ultra violet (UV) [b-ITU-T G.9991], [b-ITU-T G.9992] and [b-IEEE 802.15.7]. Data is encapsulated into VLC frames, and it is coded using digital-based modulation technologies. These coded VLC frames are transmitted by light emitting diodes (LED) or laser diodes (LD). A photo diode (PD) or an image sensor can receive the VLC frames.

Recommendation [b-ITU-T G.9991] specifies a system architecture which contains physical layer (PHY) and data link layer of a high-speed indoor VLC transceiver, especially for a home network. The network specified in [b-ITU-T G.9991] comprises one or more domains. Each domain has one domain master (DM) and one or more nodes that are registered to the DM. Global master (GM) is responsible for coordinating the resources among domains.

For each domain, [b-ITU-T G.9991] specifies the five topologies for indoor VLC: a) peer to peer (P2P) (or point to point) topology, b) point to multipoint (P2MP) topology, c) multipoint to multipoint (MP2MP), d) relayed mode, and e) centralized topology. In addition to the network topology, [b-ITU-T G.9991] specifies the modes of operation in a domain, which includes centralized mode (CM) and unified mode (UM). In a centralized mode, the direct communication between DM and end-point (EP) node is allowed, while the direct communication among end-point nodes is not allowed. The CM supports three types of operation modes: a) bi-directional communication, b) broadcast-only, and c) hybrid communication. In the unified mode, the direct or indirect communication among nodes is allowed.

[b-IEEE 802.15.7] specifies PHY and medium access control (MAC) sublayer for VLC. In [b-IEEE 802.15.7], it uses the term optical wireless communications (OWC) rather than VLC because the Standard explicitly considers the wavelength from 10,000 nm to 190 nm, which includes visible light, IR, and UV. The Standard also introduces the term optical wireless personal area network (OWPAN) specifying a network topology, addressing, collision avoidance, acknowledgement, performance quality indication, dimming support, visibility support, coloured status indication, and colour stabilization.

[b-IEEE 802.15.7] classifies three types of devices in OWC: a) infrastructure, b) mobile, and c) vehicle. It also specifies three network topologies: a) peer-to-peer, b) star, and c) broadcast. In the network, one of the devices gets the role of coordinator, which is determined by applications. The Standard also specifies the visibility support across all topologies with flicker mitigation.

6.2 IoT services based on VLC

In this Recommendation, IoT services based on VLC are composed of two parts: a) device management of VLC light (VL) and user terminal (UT) and b) supporting capabilities for IoT applications which run in the UT. In particular, IoT services that need high accuracy positioning are the typical case.

NOTE – An example of IoT services based on VLC is given in Appendix I.

IoT services based on VLC can be realized with the following functionalities:

– Device initialization, including device discovery and device registration;
– Data transport using VLC for the downlink channel from a lighting device to a UT;
– Data transport using VLC for the uplink from a UT to a lighting device or using radio frequency (RF) for the uplink channel from a UT to the VLC agent device;
– Light control;
– Device monitoring;
– Roaming support for the mobile UT.

Figure 1 shows the network configuration, which describes the functional nodes in the IoT services based on VLC: IoT server (IS), VLC agent (VA), VLC lights (VL) and user terminal (UT):

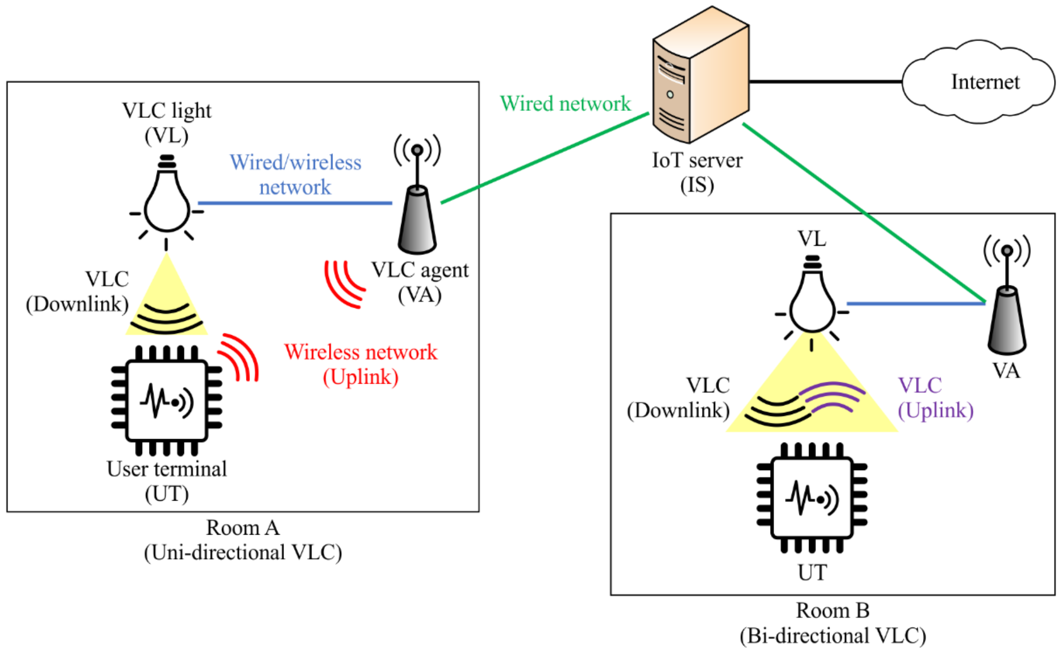

Figure 1 – Network configuration for IoT services based on VLC

As shown in Figure 1, it is noted that there are two kinds of VLC between UT and VL/VA: a) uni-directional VLC and b) bi-directional VLC. In the bi-directional VLC case, VLC is performed between UT 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 RF-based wireless communication technologies (e.g., wireless local area network (WLAN) or wireless personal area network (WPAN)). In the viewpoint of VLC deployment in real-world networks, the bi-directional VLC is suggested, but the uni-directional VLC may be used in a particular network.

6.3 Functional nodes

6.3.1 IoT server

IoT server (IS) is responsible for the overall management for VA, VL, and UT in the network. IS performs IP-based protocol operations including the device initialization, device registration, device monitoring, light control, and device roaming. Also, IS transmits data to VL and UT in the data transport operation. The IoT server is connected to the Internet.

6.3.2 VLC agent

For effective management of VL and UT in the network, one or more VAs can be deployed in the network. VA is purposed to perform IP-based protocol operations and to manage its associated VLs and UTs locally. 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 the responsibility to relay data between IS and VL/UT. In particular cases, IS and VA can be combined.

NOTE – For example, IoT services based on VLC may be deployed in a building with many floors and rooms. In this case, an IS may be deployed in the building, and a VA may be installed on a floor or room. Each room may have many VLC lights that are managed by a VA.

6.3.3 VLC light

VL can be installed or embedded in an LED light. In the initialization, VL is registered to IS. Subsequently, VL advertises itself to UTs in the VLC network by using VLC. VL has the responsibility to translate non-VLC frames to VLC frames and vice versa.

6.3.4 User terminal

UT represents the IoT service device with the VLC functionality. All UTs can be registered to and managed by IS via its associated VL or VA using the device initialization and monitoring operations. IoT service data (ISD) are also exchanged between UT and IS by way of VL or VA.

7 Requirements for IoT services based on VLC

To provide IoT services based on VLC, the following functionalities should be required.

NOTE 1 – In this clause, the term "device" means the functional nodes.

NOTE 2 – In this clause, the term "uplink device" means that the device is registered and the term "downlink device" means that the opposite-side of the device of the uplink ones.

7.1 Device initialization capability

To enable IoT services based on VLC, IS, VA, VL, and UT that need to discover an uplink device, it is necessary to join the network, and make them discoverable in the network. The following are the requirements for device initialization:

– IS, VA, VL, and UT are required to have capabilities of device advertisement and device discovery in the network;
– IS, VA, VL, and UT are required to generate its unique identifier (ID) and to request registration to its uplink device;
– IS, VA, VL, and UT are recommended to use device control data (DCD) for the device initialization process.

7.2 Device monitoring capability

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

– VA, VL, and UT are required to generate its status information;
– VA, VL, and UT are required to send its status information to its uplink device periodically;
– VA, VL, and UT are required to receive the request of status information from its uplink device and to send its up-to-date status information to the uplink device;
– IS, VA, VL, and UT are recommended to use DCD for the device monitoring process.

7.3 Provision of uplink channel for UT in the uni-directional VLC

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

– VA is required to create an RF-based uplink channel as an uplink channel;
– VA is required to configure the uplink channel with the parameters received from its uplink device;
– VA is required to send the information of the uplink channel to the downlink device;
– VA is required to forward data packets to the uplink and downlink channel;
– VL is required to generate a VLC frame which includes the information of the uplink channel and to broadcast the VLC frame to the downlink device periodically;
– UT is required to receive a VLC frame from the uplink device and to extract the information of the uplink channel;
– UT is required to establish the uplink channel with the VA;
– IS, VA, VL, and UT are recommended to use DCD for the information of the uplink channel.

7.4 Data transport capability

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

– IS, VA, VL, and UT are required to handle IP-based data packets in the network;
– VL and UT are required to translate non-VLC frames to VLC frames, and vice versa;
– IS, VA, VL, and UT are recommended to use ISD for IoT applications.

7.5 Light control capability

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

– VL is required to handle the request of IS for the configuration of a LED light;
– VL is required to change the physical characteristics of a LED light, as per the request of the IS;
– IS, VA, and VL are recommended to use light control data (LCD) for the light control process.

7.6 Device roaming capability

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

– UT is required to discover the neighbouring VLs in the roaming case;
– UT is required to generate and exchange the roaming data with its neighbouring VL;
– VL is required to detect the roaming event from the association request with the roaming data;
– VL is required to notify the roaming event to the uplink device;
– IS and VL are required to handle the roaming request appropriately;
– IS, VA, VL, and UT are recommended to use DCD for the device roaming process.

8 Reference model for IoT services based on VLC

8.1 Generic reference model

[ITU-T Y.4000] provides the IoT reference model with four layers (application layer, service support and application support layer, network layer, and device layer) and two additional capabilities (management capabilities and security capabilities).

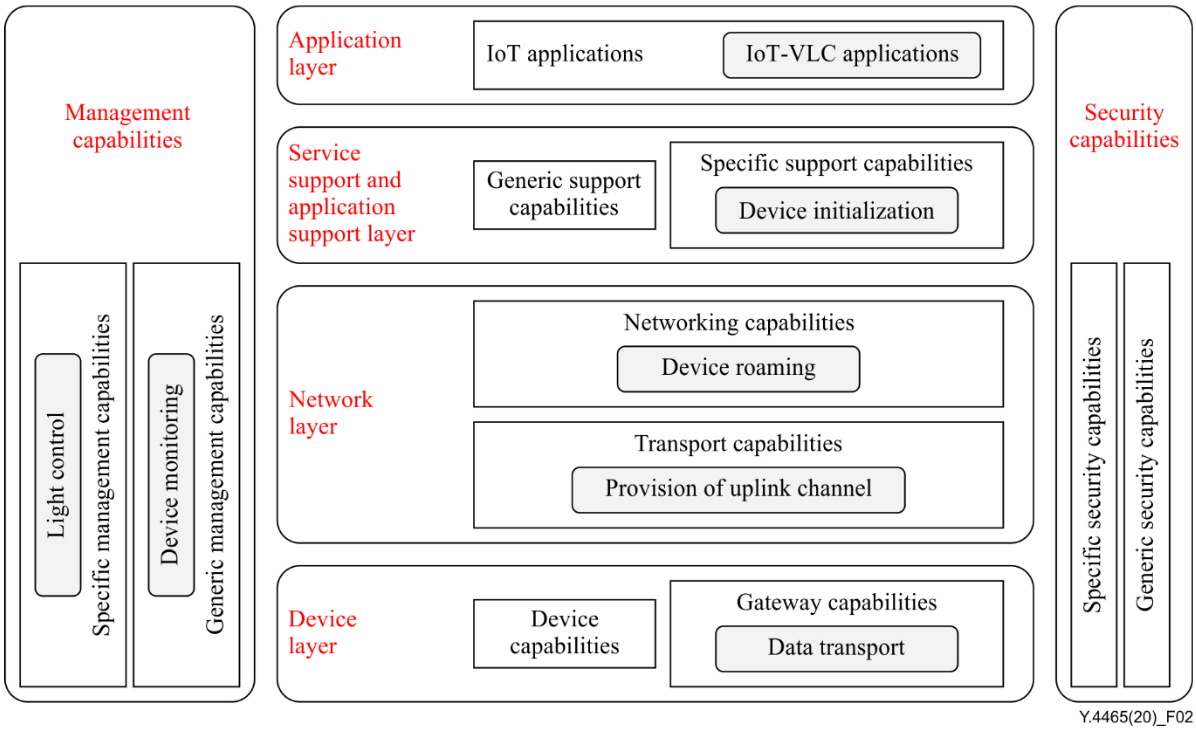

Figure 2 – Reference model for IoT services based on VLC [ITU-T Y.4000]

From the requirements and the IoT reference model, Figure 2 shows the relationship of requirements and capabilities with the IoT services based on VLC. Each functional capability is described as follows:

– Data transport extracts data from IP-based packets and VLC frames. It also converts from IP-based packets to VLC frames and from VLC frames to IP-based packets;
– Provision of uplink channel is responsible for the configuration of the uplink channel for the UT with uni-directional VLC capability;
– Device roaming is used for seamless IoT services when the mobile UT detects its movement by capturing the VL around it;
– Device initialization helps devices to discover uplink devices, join the network of the uplink device, and advertise the joined devices to the network;
– Light control is used to configure the physical characteristics of LED light by the command of IS;
– Device monitoring is used to report the status information of a device to the uplink device periodically. It is also used to report the up-to-date status information by the request of uplink devices.

8.2 Network models for VLC

There are two possible VLC scenarios between VL/VA and UT, as shown in Figure 3. Figure 3(a) depicts a network with a bi-directional VLC between VL and UT, in which both uplink and downlink use VLC. On the other hand, Figure 3(b) shows a network with a uni-directional VLC, in which only downlink VLC is allowed, whereas the uplink transmission is performed between UT and VA (instead of VL) by using the RF-based wireless channel, such as WLAN or WPAN.

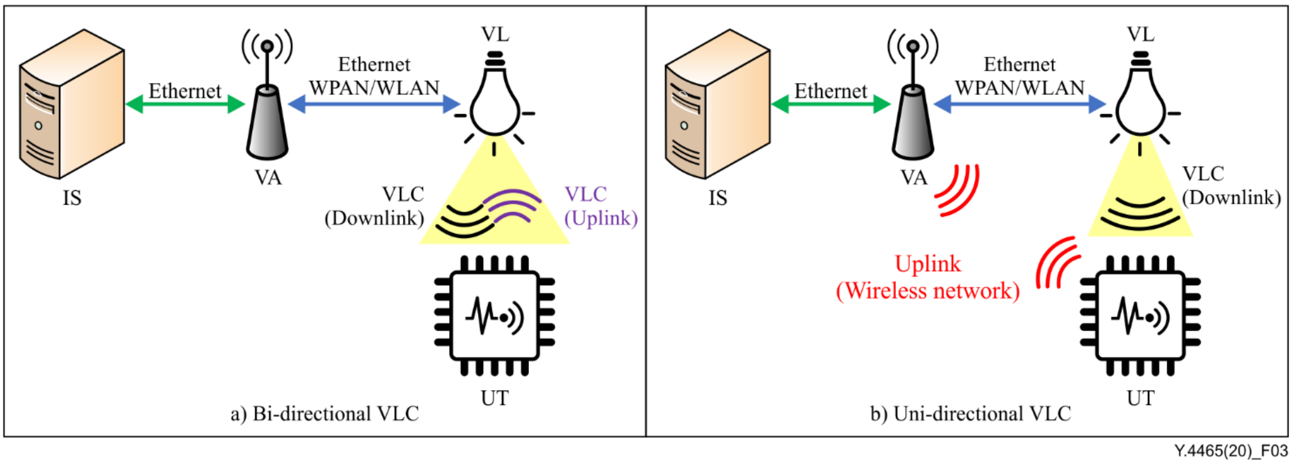

Figure 3 – Network models for VLC

It is noted that [b-IEEE 802.15.7] defines multiple network topologies (e.g., peer-to-peer, star, broadcast). The peer-to-peer and star topologies are suitable for bi-directional VLC, which uses two light sources for the uplink and downlink. In the meantime, the broadcast topology is suitable for uni-directional VLC, which uses one light source.

8.3 Data types

The following three types of data packets can be used for providing IoT services based on VLC:

– Device control data (DCD) is used for device initialization, device monitoring, and device roaming operations among all network nodes;

– Light control data (LCD) is used for the light control operation to control the LED light installed on VL;

– IoT service data (ISD) is used for the data transport operation associated with IoT applications.

NOTE 1 – For example, using the light control, IS requests VL to turn on or off the LED light and VLC, or to change the parameters used in VLC, dimming level, or colour of the LED light.

NOTE 2 – ISD can be delivered by using the IP packets among IS, VA, and VL, whereas it can be translated to VLC frames and delivered by using the VLC between VL and UT.

Appendix I

An example of IoT services based on VLC

(This appendix does not form an integral part of this Recommendation.)

One of the examples of IoT services based on VLC is the *virtual museum* service. In this scenario a museum in which there are lots of exhibition rooms is considered. Each room has many exhibition items (e.g., pictures). Each exhibition item is associated with an LED light with the corresponding VL. Figure I.1 shows a network configuration for this virtual museum service. A set of VLs (exhibition items) are connected to a VA and further to the IS through the Ethernet in the exhibition room. The IS is connected to the Internet for museum administrators. A museum visitor (user), who is equipped with a UT, will move across different VLs within the room in order to enjoy many kinds of exhibition items. For VLC, the downlink channel from VL to UT is used to provide the specific information on the exhibition item for the users, and the upstream channel from UT to VA (uni-directional VLC) or VL (bi-directional VLC) is used to give a feedback or a user request to the IS, as shown in the Figure I.1. VLC from VL to UT may be used for the downlink channel. In the meantime, VLC or Wi-Fi may be used for the uplink channel from the UT. In the bi-directional VLC case, VLC is used, whereas Wi-Fi may be used in the uni-directional VLC case.

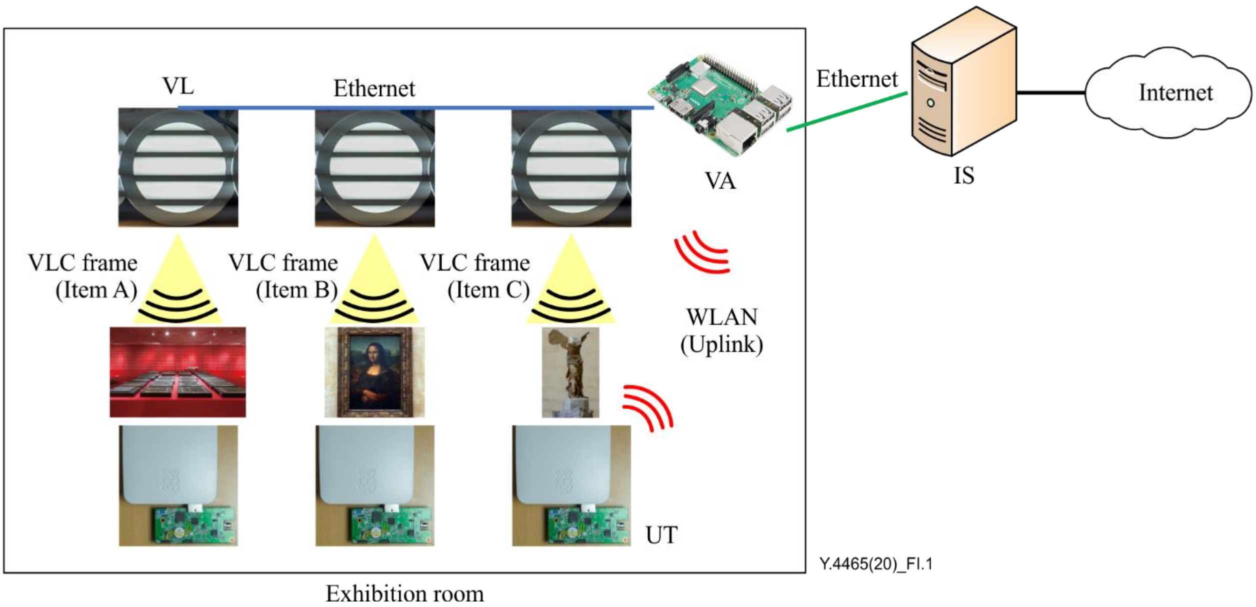

Figure I.1 – Network configuration for a virtual museum service

A traditional personal computer (PC) performs the IS, a microcontroller unit (MCU) device (e.g., Raspberry Pi, Arduino) performs VA. An MCU based device or other embedded device is installed on an LED light and perform VL. A smartphone or other embedded device is equipped with an image sensor or PD and performs the role of UT.

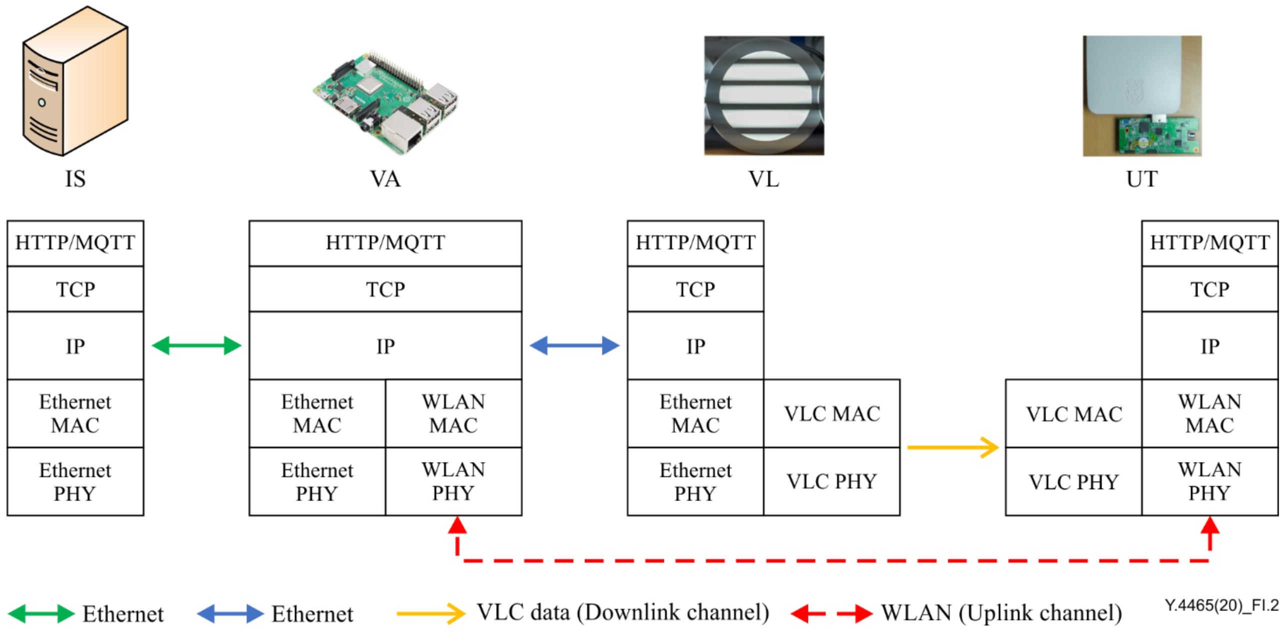

Figure I.2 – Protocol stacks for a virtual museum service

Figure I.2 illustrates the protocol stacks possibly used for the implementation of a virtual museum service. IS and VA are connected to the Ethernet. The VA and VL are connected to the Ethernet which is isolated from the connection between IS and VA. UT is equipped with PD-based VLC and WLAN because the UT only supports the uni-directional VLC case. In this regard, VA configures the uplink channel for the UT and the UT uses WLAN as the uplink channel.

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[b-IEEE P802.15.13] IEEE P802.15.13 (work in progress), *Standard for Multi-Gigabit per Second Optical Wireless Communications (OWC) with Ranges up to 200 meters.* <http://www.ieee802.org/15/pub/TG13.html>

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