ISA Technical Report

Technical Report of Control Protocols for LED Smart Home Connected Lighting

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International Solid State Lighting Alliance

Technical Committee on Standardization

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This ISA Technical Report was prepared by ISA Technical Committee on Standardization, Working Group 10: Technical report of control protocols for LED smart home connected lighting

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Foreword

International Solid-State Alliance (ISA) is an international, not-for-profit organization aiming to promote the sustainable development and application of Solid State Lighting (SSL) worldwide, consisting of numerous cooperate members in the SSL industry as well as research organizations worldwide.

ISA Technical Reports provide latest knowledge in LED light source technologies and lighting practice in specific topics useful for the developments of solid-state lighting sources and systems, especially for the new application areas where guidance and standardization are needed.

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1 Introduction

With the involvement of internet companies, smart home industry become prosperous in 2015. The industry claimed that 2014 was the first year of smart home era, from year 2015, smart home developed rapidly. There are many SDOs in industry to push smart home, in addition to relevant enterprises, such as lighting companies and home appliance enterprises, there are also Internet companies, telecommunications operators, as well as chip companies, all are eager to occupy a favorable position in the smart home market with revenue of hundreds of billion. LED smart home connected lighting is one of the important functions in smart home. And the lighting enterprises focus on considering how to choose the appropriate control protocols and how to connect the lighting.

2 Scope

This technical report cover architecture, control protocol of smart home connected lighting system. comparison among protocols is given and a recommendation is provided.

3 Terms and Definitions

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4 LED smart home connected lighting control system architecture

4.1 Lighting control system architecture

Smart home connected lighting control system architecture is shown in Fig.1.

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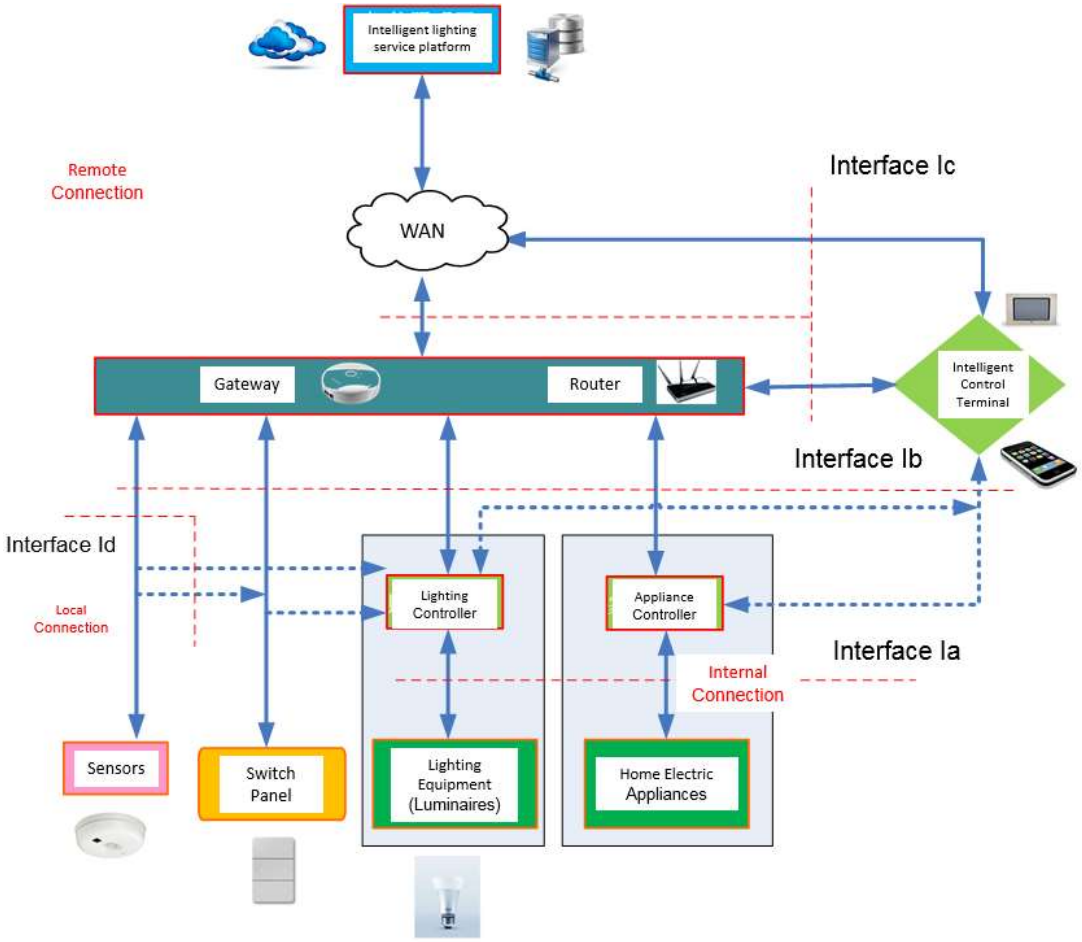

Figure 1 Smart home connected lighting control system architecture schematic diagram

Smart home connected lighting control system consists of following parts:

- Objects to be controlled

The objects include household appliances and lighting appliances. Household appliances may be include white appliances (refrigerators, washing machines, air conditioners), black appliances (TV set), small household appliances (water fountains, air purifiers, electric kettles, coffee machines, soya-bean milk maker, etc.) and kitchen appliances (stove, smoke exhaust ventilators, water heaters).

Lighting appliances are normally switch panels and all kinds of luminaires (celling light, floor light, wall light and desk light etc.).

This report focuses on the control of lighting appliances.

- Controller (Actuator) (Lighting Controller / Appliance Controller)

The controller controls the objects according to control command onsite, the pre-configurated program command or sensor signal, which is integrated in the object, and may locate outside the object. In the lighting control system, it is called a lighting controller or a single lamp controller.

- Gateway / Router

Gateway, as the transfer, aggregation and processing equipment between controller and intelligent lighting service management platform, its functions should be conversion of communication protocol, processing, transfer or aggregation of controller's local control signals and sensor signals to the intelligent lighting service platform or other intelligence controller in the system.

- Intelligent lighting service management platform

The server stores and processes control system data, analyzes control system data, and provides remote control functions.

Intelligent lighting control terminal

Intelligent lighting control terminal includes intelligent control panel, smart mobile phone or smart tablet PC. By operating the control software (such as APP) installed in them, these control terminals can configure or control the object on-site or remotely.

- Switch panel

Switch panel can control the system on-site, such as switch on/off, dim lighting appliances individually or by group. The switch panel can be mounted on a wall or placed in a room as a mobile remote control.

- Sensors

The sensor senses ambient conditions such as lighting, human presence, opening/closing of door and window, provides input to the control system, and can be connected to a gateway / router, and also to a controller (actuator). The system can automatically control according to environmental conditions.

4.2 Connection interfaces of lighting control system

In smart home connected lighting control system, various parts are to be connected via communication to transmit and process the info. There are three types of communication interfaces:

- Internal connection inside the equipment

The lighting controller and the luminaires power supply are connected through Ia interface.

- Local area connections between equipment

The network among lighting controllers, sensors, switch panels, and gateways / routers, is connected via interface Ib. Intelligent lighting control terminal can also be connected to lighting controller by the Ib interface. The sensor can also be connected directly to an individual lighting controller or bypass to gateway / router using separate Id interface.

- Remote connections between equipment

The network among intelligent control terminals (APP), gateways / routers, and servers, is connected via interface Ic.

5 Control protocols for LED smart home connected lighting system

For internal connection interface (Ia)inside the equipment, which connects controller and lighting power supply, it should support the following functions: switching and dimming and meet the requirement of no flickering during dimming.

For the remote interface (Ic), which provides services through the Internet and meet the requirements of IoT, it should support IP protocol and web-based language (XML, JSON).

In smart home connected lighting system, the local connection interface (Ib) is the key control protocol, which is priority analysis in this document.

As regards control protocol for the local network interfaces, some requirements should be considered. And this requirement is closed link to different application scenes and objects to be controlled, here is considered requirements:

- Number of objects
- Topology of the object and networking support
- Information traffic bandwidth
- Coverage
- Installation and configuration
- Power consumption
- Cost
- Security
- OSI protocol layer
- Network reliability

In the smart home environment, most used application scenes include intelligent home lighting system, individual intelligent lighting product controlled, and extended lighting.

Table 1 shows the requirements of the control protocol for each application scene.

Table 1 Application scenes and requirements to control protocols in smart home system

Scenes	Smart home lighting system	Individual intelligent lighting product controlled	Extended lighting
Scene Description	Provide linkage lighting control for all the downlights, ceiling lamps, wall lamps, GLS lamps, switch panel, sensor system in the entire smart home system	Accent lighting by pendent lamp / chandeliers in living room, dining room, etc. Or illumination of the reading area with a table lamp or a bedside lamp	Luminaires are the nodes for comprehensive service, in addition to lighting, audio, video, wireless access communications and other functions are also provided
Number of objects	more than 50	One or several	One
Topology of the object and networking support	MESH	Point-to-point or a star	Point-to-point

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Information traffic bandwidth	Hundreds of kB (control information)	Hundreds of KB (control information)	a few MB (audio and video information included)
Coverage	> ~ 50m	1 ~ 10m	1 ~ 10m
Installation and configuration	Easy	Easy	Easy
Low power consumption	Low	No	No
Cost of chip / module	Low	No sensitive on cost	No sensitive on cost
Security	High	High	High
OSI protocol layer	Required	Required	Required
Network reliability	High	High	High

6 Analysis to control protocols for LED smart home connected lighting

6.1 Internal Connection interface Ia

This interface is located inside the luminaires of smart home connected lighting, generally, power supply and lighting controller are integrated. This connection between power supply and lighting controller is an internal interface, which can provide switching frequency changes or current or voltage change function, most of them are 0/1-10V or PWM protocols.

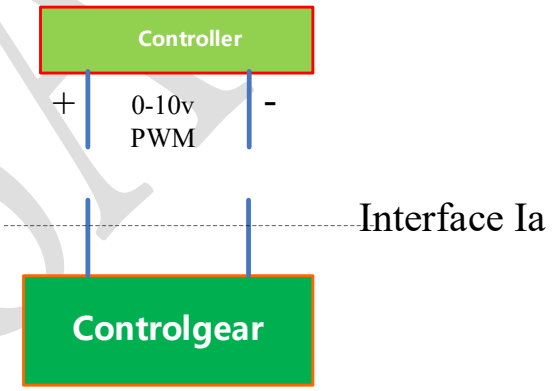


Fig.2 Ia Interface Protocols

Please refer to IEC 63128 - Lighting control interface for dimming – Analogue voltage dimming interface for electronic current sourcing controlgear.

0/1 ~ 10V is the mainstream dimming interface of the LED power supply, whose dimming is smooth and uniform.

PWM method is commonly used in digital control of LED luminous flux, color temperature and color, with the advantages of high precision, low cost, and no color deviation.

6.2 Local Connection Ib

Protocols of Ib interface is applied among lighting controllers, switch panels, and gateways / routers, lighting control terminal (mobile phone, PAD, etc.). The sensor can be also connected locally by the Ib interface, or it is connected by a different interface Id.

Ib interfaces generally use wireless short-range communication protocol, mainly ZigBee and Thread based on IEEE802.15.4, Wi-Fi based on IEEE802.11, and Bluetooth based on IEEE802.15.1.

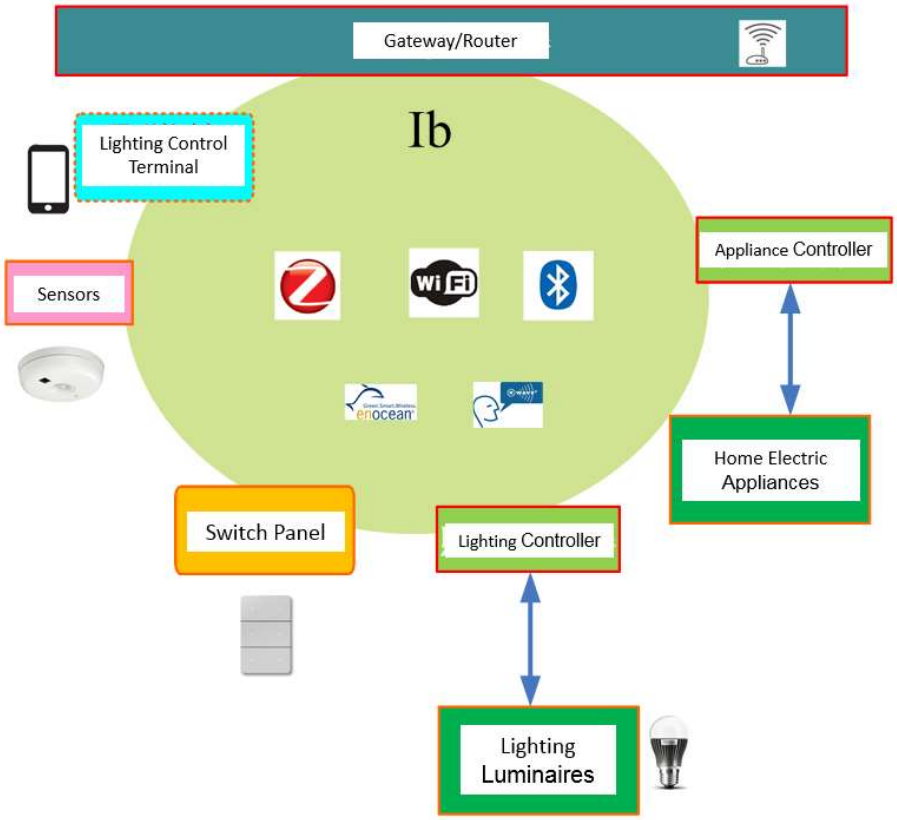


Fig.3 Schematic diagram of Ib interface protocols

The comparison of ZigBee, Wi-Fi and Bluetooth is shown in Table 2.

Table 2 wireless communication technology comparison

Requirements	ZigBee IEEE 802.15.4	Wi-Fi IEEE 802.11	Bluetooth IEEE 802.15.1
Number of objects	In theory, support 60k nodes; in fact, support hundreds of nodes	Theoretically supports 256 nodes. Actual number supported depending on routers, general router below 15, and intelligent router up to 64.	Theoretically supports 8 / Pico net, in fact, support 1 to 4
Topology of the object and networking support	Mesh connection	Point to point or star connection (Multi-AP-Easy mesh)	Point to point master-slave connection and

				point to multipoint (MESH)
Information traffic bandwidth		250 kbps	10/100Mbps	~1Mbps
Coverage		30-50m (2.4 GHz); 100m (Sub-GHz)	IEEE802.3b/n/ac/ah：30-50m；IEEE802.11ah：1000m (Sub-GHz)	~30m
Installation and configuration		Very convenient（touch Link）	Convenient (need to enter a password)	Convenient (some settings need codes)
Power consumption		~100mW	~1W	~100mW
Cost of purchasing chip / module		Very low	Low	Very low
Security		High（AES）	High（AES）	High（AES）
OSI protocol layer		ZLL-ZigBee Light Link ZHA-ZigBee Home Automation，integrated into ZigBee3.0	No application layer protocol	No application protocol on Bluetooth low energy-BLE Need to define by yourself and models are defined in Bluetooth MESH
Network reliability		High	High	High
Summary	Advantages	1. With special lighting technology agreement (ZLL) & home control protocol (ZHA) to ensure interoperability 2. Low cost, low power consumption 3.MESH network for complex control systems	1. Compatible with IP system 2. Mobile terminal support is good	1. Suitable for rapid development of point-to-point control system. 2. Low cost, low power consumption 3. Mobile terminal support is good
	Disadvantages	Cannot directly connect with intelligent mobile terminal, gateway needed for connection.	1. Higher cost 2. High power consumption, low-power chip being developed. 3 Restricted by star network topology, not suitable for complex control systems 4. No application layer technical standards, products of different manufacturers cannot interconnect	1. Restricted by master-slave network topology, not suitable for complex control systems 2. No application layer technology standards, products of different manufacturers cannot interconnect

Table 3 Analysis to Protocols for Smart home lighting system

Scene	Smart home lighting system			
Scene Description	All the downlights, ceiling lamps, wall lamps, switch panel, sensor system in the entire smart home system are controlled uniformly			
Requirements of the scene		Comparison of three protocols in meeting the requirements		
		ZigBee	Wi-Fi	Bluetooth
Number of objects	The number of devices is greater than 50	Y	N	Partial with MESH
Topology of the object and networking support	MESH connection	Y	N	N
Information traffic bandwidth	Hundreds of kB control information	Y	Y	Y
Coverage	> ~ 50m	Y	N	N
Installation and configuration	Convenient	Y	N	N
Power consumption	Low	Y	N	Y
Cost of purchasing chip / module	Low	Y	N	Y
Security	High	Y	Y	Y
OSI protocol layer	Required	Y	N	N
Network reliability	High	Y	Y	Y
Summary		Suitable	Not suitable, improvement needed	Not suitable, improvement needed

Table 4 Analysis to Protocols for control of Individual intelligent lighting product

Scene	Individual intelligent lighting product Lighting control for a few general-purpose lighting products, pendent lamp / chandeliers, table lamps			
Scene Description	Accent lighting by pendent lamp / chandeliers in living room, dining room, etc. Illumination of the reading area with a table lamp or a bedside lamp			
Requirements of the scene		Comparison of three protocols in meeting the requirements		
		ZigBee	Wi-Fi	Bluetooth
Number of objects	One or several	Y	Y	Y
Topology of the object and networking support	Point-to-point connection or a star connection	Y	Y	Y
Information traffic bandwidth	Hundreds of KB (Control information)	Y	Y	Y
Coverage	1 ~ 10m	Y	Y	Y

Installation and configuration	Convenient	Y	Y	Y
Power consumption	No requirement	Y	Y	Y
Cost of purchasing chip / module	No requirement	Y	Y	Y
Security	High	Y	Y	Y
OSI protocol layer	Required	Y	N	N
Network reliability	High	Y	Y	Y
Summary		Suitable	Suitable	Suitable

Table 5 Analysis to Protocols for scene of extended lighting

Scene	Extended lighting			
Scene Description	Luminaires are the nodes for comprehensive service, in addition to lighting, audio, video monitoring, wireless access communications and other functions are also provided			
Requirements of the scene		Comparison of three protocols in meeting the requirements		
		ZigBee	Wi-Fi	Bluetooth
Number of objects	One	Y	Y	Y
Topology of the object and	Point-to-point connection	Y	Y	Y
Information traffic bandwidth	a few MB audio and video information	N	Y	Y
Coverage	1 ~ 10m	Y	Y	Y
Installation and configuration	Convenient	Y	Y	Y
Power consumption	No requirement	Y	Y	Y
Cost of purchasing chip / module	No requirement	Y	Y	Y
Security	High	Y	Y	Y
OSI protocol layer	Required	Y	N	N
Network reliability	High	Y	Y	Y
Summary		Not suitable, improvement needed	Suitable if with improvement	Suitable if with improvement

6.3 Remote and local connections Ic

Local connection: The intelligent controller (APP) is connected to the gateway / router via Wi-Fi.

The remote connection consists of two types:

Connection 1: The gateway / router is connected to a remote server or cloud server via a wireless communication protocol, and its general network protocol is GPRS / 3G / LTE / Ethernet / DSL.

Connection 2: The intelligent controller (APP) is connected to a remote server or cloud server via a wireless communication protocol, and its general network protocol is GPRS / 3G / LTE or Wi-Fi.

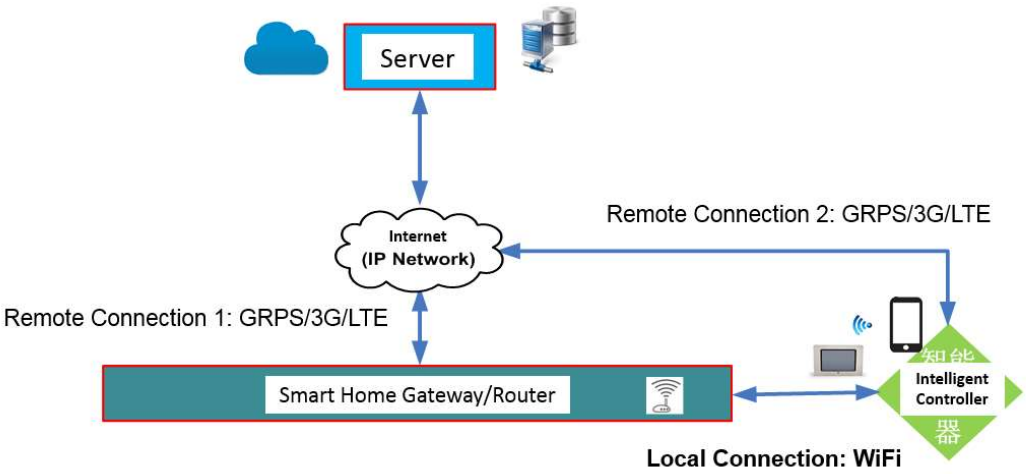


Fig.4 Schematic diagram of Ic interface protocols

In these three connections (including local connection and remote connection), GPRS / 3G / LTE and Wi-Fi provide the underlying communication protocol, but also need to combine with high-level application layer protocol to complete the control function.

- The basic protocols are IGRS, UPnP, CSHIA-FC-GW for smart home, but these protocols are designed for audio and video products at home but not for lighting control.
- Lighting control system in the market are basically based on XML/JSON, JD, Mi, ALI, Baidu and other internet enterprises basically adopt this idea.
- There are also extensions to industrial IoT control protocol based on the MQTT protocol.
- There are also application protocols based on enterprise-defined ecosystems, such as Apple's HomeKit.

They are listed in table below.

Table 6 List of local and remote communication and control protocols

Application Layer	IGRS	UPnP	CSHIA-FC-GW	XML/JSON	Enterprise HomeKit	Enterprise (OceanConnect/OneNET)	AllJoyn (OCF)
Transmission layer	HTTP/COAP TCP/UDP IP	HTTP/COAP TCP/UDP IP	HTTP/COAP TCP/UDP IP	HTTP/COAP TCP/UDP IP	HTTP/COAP TCP/UDP IP	MQTT TCP IP	

Physical Layer	GPRS/3G/LTE/Wi-Fi/DSL	GPRS/3G/LTE/Wi-Fi/DSL	GPRS/3G/LTE/Wi-Fi/DSL	GPRS/3G/LTE/Wi-Fi/DSL	NA	NA	Wi-Fi /Bluetooth
Remarks	IGRS	DLNA	CSHIA	Private	Apple	IBM	OCF

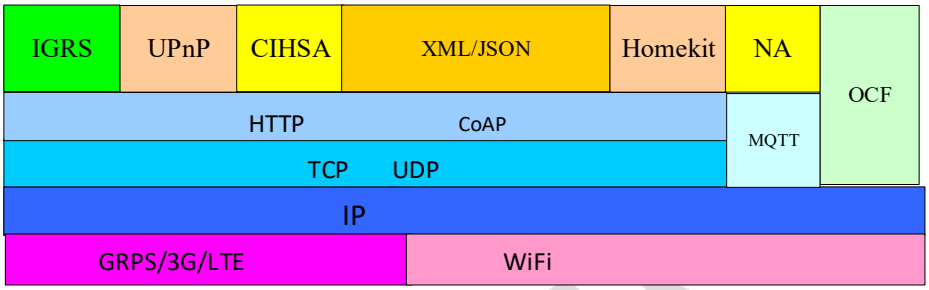


Fig.5 Schematic diagram of Ic Interface protocol stack

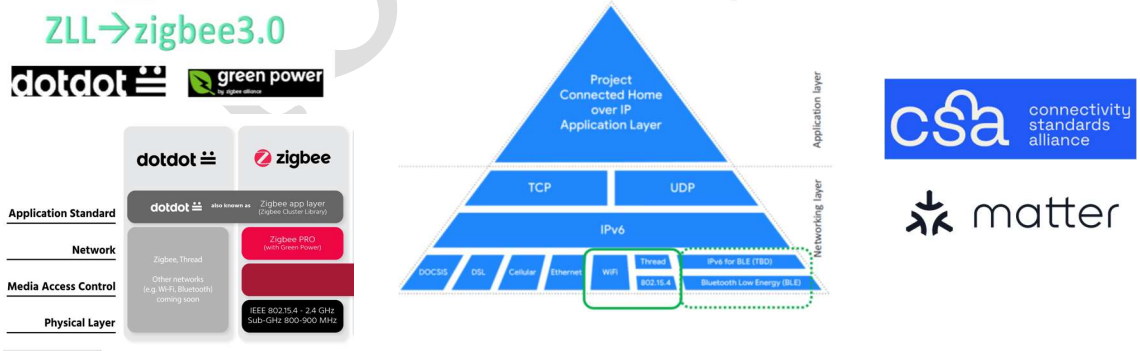
7 The evolution of wireless connection

7.1 ZigBee technology development

ZigBee has completed standardization of ZigBee light link and ZigBee home automation and integrate the two protocol stacks into ZigBee3.0 to have better support for home lighting and sensor devices.

On the other hand, the ZigBee application protocol dotdot decoupled with IEEE802.15.4 is defined. And green power is also supported.

In 2020, Zigbee Alliance is working on CHIP, which is IP-based protocol stack is release as matter1.0 in CSA (connectivity standard alliance).



ZigBee CHIP Matter

Fig.6 Zigbee evolution

7.2 Wi-Fi technology development

Wi-Fi technology is defined based on the IEEE802.11 and was originally used for wireless LAN interconnection of communication products, the number of connected nodes is limited, and they do not consider the power consumption at home environment.

In the lighting control and networking applications, these need to be considered low power, Qualcomm and other chip companies develop low-power Wi-Fi chips, which is head to be used for Internet of things. The IEEE 802.11ah (Wi-Fi Halow) standard also attempts to standardize low-power Wi-Fi, which optimizes access control, increases the number of access points, and deployed in sub-GHz. It also defines low-power mechanisms, such as sleep and wake-up, to bring power consumption to level of 100mW in IEEE802.11ah and IEEE802.11ax (Wi-Fi 6). IEEE802.11ah is intended to cover outdoor and Wi-Fi 6 is still not widely deployed.

WFA defines EasyMesh, which is relay-based connections to support tree topology and increases the number of simultaneous connections by multi-AP supported.

7.3 Bluetooth technology development

Bluetooth has been standardized Bluetooth low power in 4.0 and the present version is 5.1.

CSR has launched MESH Bluetooth chipset to support mesh networking, and SIG is defining Bluetooth technology for MESH. Seven companies have provided technical solutions. On this basis, Version 0.7 and supplementary documents (Definition of application layer protocol) had been completed by May 2016, with plan to complete the standardization by December 2016. Now Bluetooth published Bluetooth MESH1.0 based on flooding and defined models (application layer) for lighting. Bluetooth MESH1.1 based on routing is under discussion.

Fig7 Bluetooth roadmap

8 Summary

Interface between lighting controller and luminaires power supply——in general is an internal interface in smart home connected lighting system ——Ia: use 0-10V or PWM.

Interconnection interface between intelligent controller (APP), gateway / router, remote server Ic.

The underlying communication and interconnection technology can use Wi-Fi or GRPS/3G/LTE and other communication technology. Application layer protocol can be protocol based on IP. There are IGRS, UPnP, CSHIA-FC-GW in smart home areas, these protocols are for audio and video service at home but not for lighting. One can also use Alljoyn extension or HomeKit, etc. The reality is that all companies use customized protocol based on HTTP or MQTT, COAP and other application protocols.

Lighting controller, sensor, switch panel, gateway / router local connection interface Ib.

- ZigBee is appropriate for control protocols for smart home lighting system and individual intelligent lighting product, but gateway supporting ZigBee protocols is to be developed.
- Wi-Fi is appropriate for control protocols for individual intelligent lighting product with a few control nodes and extended lighting only if having defined application layer protocols. Wi-Fi is not suitable to the home lighting system unless improvements are made, such as increasing limit in quantity of access nodes, reducing power consumption, and defining application layer protocols. Low-power-consumption Wi-Fi-IEEE 802.3ah is being developed, which supports more nodes via relay, optimizes sleep and wake-up mechanisms to lower power consumption, and can also provide greater coverage with frequencies less than GHz.
- Bluetooth is appropriate for control protocols for individual intelligent lighting product with a few control nodes and extended lighting only if having defined application layer protocols. Bluetooth is partial suitable to the home lighting system unless improvements are made on increasing limit in quantity of access nodes (supporting MESH network) and defining application layer (model in MESH) protocols. MESH's Bluetooth standardization efforts are under way to support more nodes and IP protocol.

Table 7 shows the protocols appropriate for the scenes.

Table 7 ZigBee, Wi-Fi, Bluetooth: Applicability for different scenes

Technology	Intelligent home lighting system	Individual intelligent lighting product	Extended lighting
ZigBee	Yes	Yes (Gateway support required)	No cannot provide high-bandwidth transmission
Wi-Fi	No Improvements needed: 1. Increase the number of access nodes by EasyMesh (Multi-AP) 2. Reduce power consumption 3. Define the application layer protocol	Yes/but Improvements needed: Define the application layer protocol	Yes/but Improvements needed: Define the application layer protocol
Bluetooth	No/Partial Improvements needed:	Yes/but Improvements needed: Define the application layer protocol	Yes/but Improvements needed: Define the application layer protocol

	1. Increase the number of access nodes by Bluetooth MESH 2. Define the application layer protocol		

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