ISA Technical Report

Overview on Standardization of the LED Lighting Control System

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International Solid State Lighting Alliance

Technical Committee on Standardization

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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

This technical report is informative only, other than standard document (normative document). The purpose of this technical report is to sort out the architecture, composition and interfacing and standardization statuses of LED lighting control system, analyze the problems existing in LED lighting control system standardization, present the standardization architecture of LED lighting control system and provide technical support for the standardization work in the future.

2 Scope

This technical report covers architecture of LED lighting control system, light control protocol in smart home, smart building and smart city are introduced. Standardization proposal of LED lighting control system is proposed.

3 Terms and Definitions

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4 LED Lighting Control System

4.1 Introduction of LED lighting control system

LED lighting control system, whose main functions are to achieve overall control and management of LED lighting system, is one set of control system for lighting device and related auxiliary device. LED lighting control system can make lighting device more energy-efficient and lighting design more flexible, with more functions provided. As intellectualization becomes the development trend of LED lighting control system, it provides support for the future smart home & smart building and even smart city.

LED lighting control system mainly consists of system software and hardware. The system software is used as a control means for communication between LED lighting device and control device as well as a human-machine interaction window of LED lighting system to achieve centralized control and management of lighting system. The system hardware consists of CMS, optional segment controller (gateway), light controller, LED driver, LED source and related auxiliary device. CMS is a central platform for lighting system control and management; optional segment controller (gateway) is a network coordinator and protocol converter to control multiple light control device, communicate with CMS and convert different lighting control protocols and network communication protocols; light controller is used to receive control signal from the control system or process signal of sensor in auxiliary device, so as to configure & control lighting source and monitor operations of lighting source and lighting luminaires; LED diver is used to receive control and configuration signal from the lighting controller and perform corresponding actions such as switching-on & switching-off, dimming and light color adjustment; LED source is an important part of luminous lighting; related auxiliary device can be sensors to detect lighting luminaires and environment.

In order to achieve user-friendly and intelligent management of lighting system, the key point for connection of various components of LED lighting control system lies in various components of control system: communication between CMS, segment controller (gateway) and light controller. For different network communication modes, communication media, topological structures and communication protocols are different, so for communication mode of LED lighting control system, different application scenarios and different user demands, e.g. home lighting, professional lighting and outdoor road lighting, shall be considered to determine a proper communication mode.

4.2 Architecture of LED lighting control system

The architecture of LED lighting control system is shown in Figure 1. The lighting luminaire system is composed of control device hardware and management software, e.g. CMS, commissioner (Pad, telephone and computer, etc. that can control lighting system by WAN or by local access), segment controller (gateway-optional, which can control multiple light controllers), light controller, sensor, driver and LED source, driver and LED source module from the left to the right.

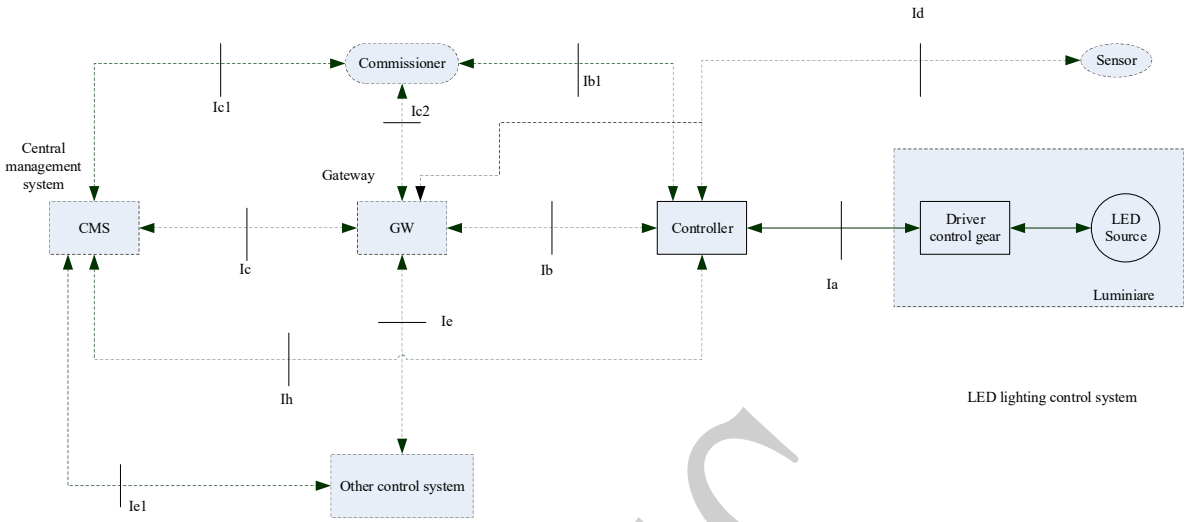


Figure 1 Overview of architecture of LED lighting control system

4.3 Composition of LED lighting control system

4.3.1 Central Management System-CMS

Central Management System (CMS) can manage lighting device, service and network. The main functions of CMS: device control, scenario programming, timing schedule, device connection, strategy development, data acquisition and storage, data analysis, failure alarming and visual interface, etc.

CMS can find and manage multiple segment controllers (gateways) for registration, address assignment and service management. CMS can control and manage internal device terminals of intelligent lighting system in a centralized manner by a segment controller.

CMS can also directly manage light controller with no gateway device required.

CMS can manage communication access, define data model and fulfillment process for various terminals and operations, and achieve the functions of centralized management, interactive software upgrading, service configuration and troubleshooting of various terminals in intelligent lighting system.

CMS can be built on a standalone server or cloud server.

4.3.2 Field Controller-Commissioner

Consisting of onsite commissioning tool, telephone/pad APP, panel switch or remote control, the commissioner can perform lighting system commissioning and control on site or remotely. The commissioner can relate to the segment controller or CMS by on site or remotely and can control lighting luminaires by a light controller.

4.3.3 Segment controller-Gateway

As an internal network of internal lighting management system, the segment controller (gateway) performs the task of connecting CMS. Its functions are shown below:

The segment controller (gateway) finds and records various service resources of luminaire, maintains the availability of these resources, and provides access control for these resources. The segment controller (gateway) views service resource statuses of lighting system and performs functional control by a system software connecting with it.

CMS or commissioner relates to the segment controller (gateway) via remote or onsite access of public network to control luminaires. The segment controller (gateway) ensures the safety of the external network access by access control technology.

4.3.4 Light Controller

The light controller receives command from CMS or segment controller (gateway), controls the luminaires, or receives information from the sensor, feeds back luminaire operation conditions, reports luminaire failures and gives alarm information.

4.3.5 LED Driver (control gear)

The LED driver receives control signal from the light controller and controls switching-on & switching-off, dimming and color adjustment of LED source by adjusting driver current or switching-on & switching-off period.

4.3.6 LED light source

LED source is a luminous lighting module.

4.3.7 Sensor

The sensor is used to detect environmental information, e.g. illuminance, temperature, person/vehicle flow and CO/CO2 and feed them back to the control system, which controls the system based on the environment.

4.4 LED lighting control system interface

LED lighting control system defines following interfaces:

- Ia: Interface between light controller and LED driver.
- Ib: Interface between centralized controller (gateway) and light controller.
- Ib1: Interface between commissioner and light controller.
- Ic: Interface between segment controller (gateway) and CMS.
- Ic1: Interface between commissioner and CMS.
- Ic2: Interface between commissioner and segment controller (gateway).
- Id: Interface between sensor and light controller or segment controller (gateway).
- Ie: Interface between segment controller (gateway) and other control systems (systems for smart home, building control and smart city).
- Ie1: Interface between CMS and other control systems (systems for smart home, building control and smart city).
- Ih: Interface between light controller and CMS.

Different Ib and Ic protocols are used in different application scenarios. The following sections give interface protocols used in different application scenarios, of which, Ic, Ic1 and Ic2 (unless the commissioner is used as a panel switch and as remote control) application layer protocols are generally consistent and built on TCP/IP (transmission control protocol/Internet protocol). Only underlying transmission protocols are different, e.g. using radio communication GSM/3G/4G or Internet /Wi-Fi, which are distinguished in following sections.

If the commissioner is a panel switch, its interfaces (Ic2 and Ib) with the segment controller (gateway) are the same. If the commissioner is a remote control, its interface (Ic2) with the segment controller (gateway) is a private interface.

The interfaces (Ib1 and Ib) between commissioner and light controller are the same.

In road lighting control system, the light controller can directly be connected with CMS without segment controller (gateway), and the interface (Ih) between them is a GSM/3G/4G-based lightweight transmission protocol.

The interface Ie/Ie1 must be a protocol supported by other systems (e.g. smart home and building control system).

This report mainly studies standardization of interfaces Ia, Ib, Ic and Id.

5 Standardization of LED Lighting Control System

5.1 Standardization of international lighting control system

In different application scenarios, there are different protocols and models of communication between different control units, which is focused on by standardization of LED lighting control system.

International standardization and academic organizations having a great influence on lighting field include technical committee for IEC/TC34 lighting luminaire and related device, Commission Internationale de l'Eclairage (CIE) and Illuminating Engineering Society of North America (IESNA), which published in IEC 63128 (Lighting control interface for dimming – Analogue voltage dimming interface for electronic current sourcing controlgear) on Analogue voltage dimming interface-0-10V, and IEC 62386 on digital addressable lighting interface (DALI). DALI and 0-10V are mainly used for the interface between light controller and driver, or network as well as the interface between light controllers.

For stage lamp or landscape lighting, USITT defines standard digital interface control dimmer (DMX512) for control console.

For industrial building lighting, International Standardization Organization (ISO) also defines some control protocols, which can be used in lighting control filed, e.g. bus protocols: KNX, BACnet, Modbus, LonWorks and C-BUS.

For home lighting, Wi-Fi, Bluetooth, ZigBee, Z-Wave and EnOcean, etc. are widely applied, but the influential one in present market is ZigBee protocol-based ZigBee Light Link standard protocol, now it is ZigBee3.0, and is mainly initiated by international lighting giants, e.g. Signify, OSRAM and spread around the world. ISO/IEC JCTC1 also published UPnP protocol with an aim to make home network easier, and such protocol is popularized by DLNA (Digital Life Network Alliance).

For road lighting, communication between light controller and segment controller (gateway) is mainly using power line carrier (PLC)-based Lonworks and ZigBee -like RF communication, while the communication between segment controller (gateway) and CMS is achieved by GPRS/3G/4G. In a segment controller (gateway)-free system, the light controller is directly connected with CMS via GPRS/3G/4G or NB-IoT or LoRa. In terms of road lighting control protocol, TALQ Consortium is developing TALQ protocol, which is used between CMS and segment controller (gateway).

As basic standards, protocols in communication layer, e.g. Wi-Fi, Bluetooth, 6LoWPAN and POE can be used as underlying protocols for lighting control (e.g. ZigBee, Z-Wave and EnOcean) due to the flexibility, convenience and extensive application to facilitate control protocol development by professional international standardization forum organization. These protocols are widely applied in lighting control field.

For sensor used as a part of Internet of Things in lighting control system, Zigbee Alliance is developing corresponding IEEE802.15.4-based protocol, and IPSO is also actively promoting IPv6-based protocol.

As lighting control is a typical use case of Internet of Things in smart home, international giants are developing protocols for Internet of Things, including protocols for lighting control, e.g. Thread mainly developed by Google-NEST, OCF which is merged AllJoyn protocol developed by Qualcomm in Allseen organization with protocol developed by OIC Consortium consisting of Samsung, HomeKit published by APPLE, Oceanconnect by Huawei, and others protocol by Alibaba, JD, Xiaomi.

5.2 Standardization of China's lighting control system

The domestic intelligent lighting industry has been developed for many years, but industrialized development has been slow for many reasons. On one hand, low demand for intelligent lighting in China, no compulsory standard and marginalization of industrialized development make impossible inspection by market and improvement of technology; on the other hand, many industries started to involve lighting control, e.g. involving lighting control from building control filed and communication control field, and various solutions & standards are available. For domestic lighting industry, the early-stage development mainly focuses on LED lighting luminaires, instead of large-scale intelligent lighting system development. So far, a set of competitive systems for large-scale application or complete national standards are unavailable in domestic intelligent lighting industry.

For lighting control protocol, SAC/TC224 (National Lighting Standardization Technical Committee) has published DALI national standards. Some published control protocol standards, e.g. national DMX512 standard published by the Ministry of Culture, national KNX and Modbus standards published by SAC/TC124 (National Technical Committee on Industrial Process Measurement and Control of Standardization Administration of China) and national BACnet standard published by SAC/TC246 (National Technical Committee on Electromagnetic Compatibility Standardization), can be used for reference.

As home lighting is a part of the smart home, IGRS has published IGRS protocol, while I Top Home is going to publish Itophome protocol. China Smart Home Industry Alliance (CSHIA) and SAC/TC426 (National Technical Committee on Digital

Technique of Intelligent Building and Residence Community of Standardization Administration of China) are also carrying out work of smart home standardization. Haier also makes its efforts to carry out U+ promotion and JD, Alibaba, Xiaomi and Huawei are carrying super APP promotion.

To meet the market demands of urban road control system, 433M-based wireless protocol has been extensively applied but not been standardized. In 2012, the Ministry of Housing and Urban-Rural Development started to develop standards for urban road lighting control system, which is to be published as CJJT227-2014. In April 2013, CSA published Application Layer Communication Protocols for the Interface in Intelligent Public LED Lighting Systems (CSA018), which was listed as a national standard planning program of SAC in December 2013, and it is published as GB/T 35255 (2017). Technical Evaluation Alliance for Solid State Lighting (TEAS) is trying to develop protocols, and some local government (e.g. Shanghai and Guangdong) road lighting control standards are being developed. Meanwhile, China State grid edited another national standard published as GB/T 34923.1~6 (2017)

For standard of sensor as a part of Internet of Things in lighting control system, WGSN of SAC/TC28 (National Technical Committee on Information Technology Standardization) is developing corresponding protocols, and SAC/TC124 (National Technical Committee on Industrial Process Measurement and Control of Standardization Administration of China) is also carrying out standardization work.

With the development of LED lighting industry, intelligent LED lighting control system will become the development trend of lighting industry in future. In the face of this new market opportunity, neither the lighting luminaire manufacturer nor the intelligent control enterprise shall work alone in a state of disunity but should unite together to achieve true interconnection and compatibility between systems and products of each manufacturer and promote the efficient development of LED intelligent lighting industry together.

5.3 Summary of lighting control system standardization

A variety of protocols are applied in lighting control system, with different protocols used in different scenarios. Related system interface protocols are summarized in Table 1.

Table 1 Summary of interface protocol of intelligent lighting control system

Application	Ia	Ib	Ic	Id
home lighting	0-10V PWM	DALI Wi-Fi Bluetooth Zigbee3.0 Z-Wave Enocean	UPnP IGRS User-defined	Zigbee/BLE/Wi-Fi IEEE802.15.4-based IPv6/6LoWPAN RS485

		UPnP IGRS Itophome Thread OCF(AllSeen (AllJoyn)/ OIC)		Dry contact I/O ILB User-defined
Professional lighting	0-10V PWM DALI	DALI KNX BACnet PLC-Lonworks Wi-Fi Bluetooth 6 LoWPAN POE Zigbee Z-Wave Enocean	KNX BACnet Lonwork Dynet User-defined	Zigbee/BLE/Wi-Fi IEEE802.15.4-based IPv6/6LoWPAN RS485 DALI
Road lighting	0-10V PWM DALI	433M DALI PLC- Lonworks RF-Zigbee like GB/T 34923.x	XML/JSON Modbus CSA018/GB/T35255 User-defined	Zigbee/BLE IEEE802.15.4-based IPv6/6LoWPAN RS485 DALI User-defined
Landscape lighting	0-10V PWM	DMX512	DMX512 over TCP/IP Ki-Net ArtNet	NA

6 LED Lighting System Control Protocol

6.1 Introduction of LED lighting system control protocol

6.1.1 0-10V

0-10V is one analog light control standard. In fact, it controls lighting intensity by changing one 0/1-10V voltage signal. As stipulated in the standard, the driver output shall be 100% when control signal is of 10V. The controller is used to turn down 1-10V signal, light will be dimmed. Light is the lowest in case of signal<1V and some drivers may be turned off in case of 0V. The minimum level means minimum output of the driver, so it important to understand the minimum value of the driver. For the driver that can be turned off at lowest signal, it is necessary to provide one additional switch in AC circuit.

In addition, IEC 63128 ed 1.0 standard has considered current capacity of control system and stipulated current consumption of each driver at 0/1-10V signal input terminal<2mA, which means one 50mA can control 25 drivers.

0/1-10V analog control signal range of controlled lighting luminaire receiving controller must comply with following specification (IEC 63128):

- Maximum input voltage: 10-11V.
- Minimum input voltage: 0-1V.
- Input voltage range corresponding to minimum light output to maximum light output: 1 - 10V.
- Input voltage range corresponding to stable light output of lighting luminaire: 0 - 11V.
- Safety input voltage range: -20 - +20V.

The input terminal of controlled lighting luminaire must have reverse electrode protection function. That is to say, the controlled lighting luminaire can only produce minimum light output or be uncontrolled.

One light controller can control one or more lighting luminaires, provided 0 -10V (1 - 10V) analog control signal voltage input into these lighting luminaires complies with above specifications.

The voltage imposed on light controller by a controlled lighting luminaire cannot exceed -20 - +20V, and at the same time, the current shall be 10uA - 2mA.

The controlled lighting luminaire can be switched on under any allowable input voltage.

Advantages: 0/1 - 10V is currently a major dimming interface of LED power supply as dimming interface standard of control system, e.g. DALI due to smooth & uniform dimming performances.

Disadvantages: with poor reliability of voltage signal transmission, it is unsuitable for long-distance transmission. For LED application, 0 - 10V dimming means multiple weak power supplies are required. Except 3.3V or 5V power supplies, about 12V power supply shall be additionally provided, increasing the cost of dimmable LED lighting luminaire.

6.1.2 PWM

Pulse width modulation (PWM) is one method for digital coding of analog signal level. One advantage of PWM is to ensure signal from the processor to controlled signal is digital and shall not be subject to digital-to-analogue conversion, which can minimize noise.

Digital dimming signal range of controlled lighting luminaire receiving controller must comply with following specification (IEC 63128):

- High level of signal: 5V - 100V.
- Low level of signal: 0 - 1.5V.
- Signal cycle: 1-10ms; The input terminal of controlled lighting luminaire must have reverse electrode protection function. That is to say, the controlled lighting luminaire is uncontrolled under reverse voltage output.

The resistance range of controlled lighting luminaire is 1k - 10k Ohms.

The percentage of the light output of the controlled lighting luminaire is determined by the proportion of the duration of the high level in the entire signal cycle. The corresponding proportion of the duration of the high level in the entire signal cycle is 0%- 6% for the lighting luminaire realizing 100% light output; the corresponding proportion of the duration of the high level in the entire signal cycle is 94% - 96% for the lighting luminaire realizing 1% light output or minimum light output. When the corresponding proportion of the duration of the high level in the entire signal cycle is more than 95%, the lighting luminaire shall be turned off.

With the scope of current carrying capacity, one light controller can control one or more lighting luminaires, provided PWM control signal voltage input into these lighting luminaires complies with above specifications;

Advantages: it 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.

Disadvantages: stroboflash may be caused. The output voltage of LED driving power shall not be changed suddenly, otherwise having an adverse impact on reliability of LED source. PWM signal reliability may be affected during one-to-multiple dimming.

6.1.3 DALI

Digital addressable lighting interface (DALI) is originally defined in international standard IEC60929, which was supplemented in 2009 as IEC62386 to define DALIv1. Now, this standard is being modified to define DALIv2. And now DiiA work to extension DALI for IoT industry on D4i.

DALI has defined the way of communication between electronic ballast and device controller and can ensure compatibility between DALI-compliant LED lighting and ballast lighting equipment from different manufacturers.

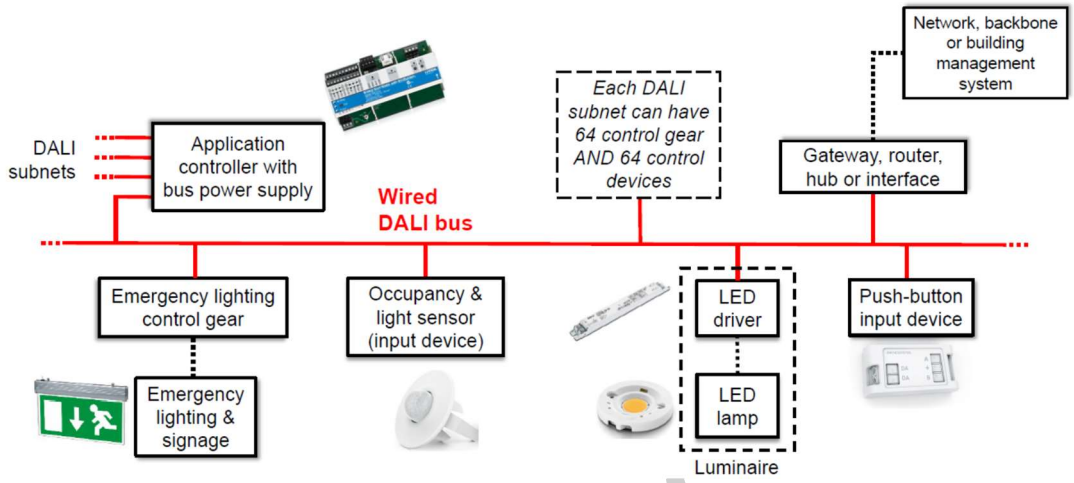


Figure 2 Architecture of DALI system

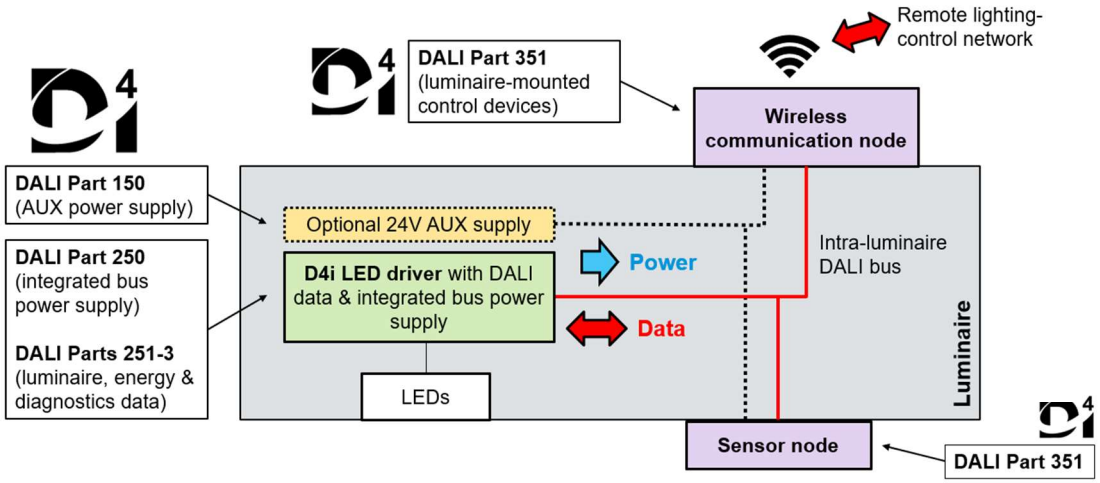


Figure 3 Overview of DALI control system indoor and outdoor (D4i)

The typical structure of DALI is master-slave structure. One master can address up to 64 slaves. DALI bandwidth is 1200bps and maximum transmission distance is 300m. In intelligent lighting system, the product can store data separately. Each luminaire or control node has corresponding addresses so that they can judge their own data to achieve to-way communication. DALI system is only used as one lighting control subsystem application as well as an important make-up system of KNX, which is supported by corresponding DALI gateways.

Table 2 Analysis on DALI protocol

Type	DALI protocol

Application range	Between controllers as well as controller and gateway
OSI protocol layer	Physical layer and application layer
Topological structure	Bus and star
Network type	Master-slave
Communication protocol	For physical layer and application layer, low-voltage carrier is used as communication bus, which can supply at most 250mA current for DALI device.
Device type	Driver, controller and master
Channel access mechanism	None (to be defined by user)
Number of network nodes	64
Transmission media	Twisted pair
Transmission rate	1200 bit/s
Transmission distance	The longest distance is 300, and bus voltage drop between farthest ends shall not exceed 2V.
System power consumption	Low power consumption, high long-distance communication power consumption
Development difficulty	Easy
Reference module cost	low
Advantages	1. The wiring of the control circuit is simple. 2. The control of a single device (a single address) or class group (group address) is possible. 3. It is possible to control the all-broadcast addresses simultaneously at any time (built-in initial running function. 4. The data communication is undisturbed due to simple data structure. 5. The DALI application features no stroboflash and small electromagnetic interference. 6. DALI protocol is digital signal, with large difference between high level (>9V) corresponding to 1 and low level (<6.5V) corresponding to 0. With strong anti-interference capability, it is suitable for use at the place with large interferences, with wide adaptability.
Disadvantages	1. There are totally 200 complex protocols, and different lighting luminaires also have extension protocols with special functions. 2. There are fewer system support nodes (only 64).
Development trend	DALI has defined very professional lighting control system from the level of design orientation at the beginning and is a supplement of large system such as KNX/EIB and Lonworks. Its large bus, e.g. EIB has its unique advantages in supporting light controller and can effectively use existing control wiring. It is a good solution for previous analog ballast upgrading.
Application	Dimming lighting

6.1.4 DMX512/RDM

Figure 4 Schematic diagram of DMX512 control system

DMX512 data protocol is one standard issued by USITT in 1990 for data transmission of lighting controller and lighting luminaire. It covers electrical characteristics, data protocols and data format, etc. In terms of electrical characteristics, DMX512 is fully compatible with RS-485, with the same requirements in driver/receiver selection, line loading and multi-station configuration. DMX512 data protocol has specified use of baud rate 250kbps. Adopting one-way communication, DMX512 cannot feedback execution status, but currently can achieve full-duplex (two-way communication and simultaneous transmission) transmission of information through a pair of extended signal lines.

RDM is an extension of USITT DMX512 that describes a method of bidirectional communication over a DMX512/1990 or DMX512-A network. RDM permits a console or other controlling device to discover and then configure, monitor, and manage intermediate and end-devices connected through a DMX512 network, providing for improved control of the devices. RDM is a half-duplex bidirectional serial protocol. Since DMX512 is unidirectional and RDM is bidirectional, there are some hardware differences that should be examined when retrofitting RDM into an existing DMX512 system.

Table 3 Analysis on DMX512 protocol

Type	DMX512 protocol
Application range	Between controllers as well as controller and gateway
OSI protocol layer	1-2 layer + application layer
Topological structure	Bus and star
Network type	Master-slave
Communication protocol	For physical layer and application layer, use RS485 as communication bus.
Device type	Driver and master
Channel access mechanism	None (to be defined by user)
Number of network nodes	512
Transmission media	Twisted pair
Transmission rate	250kbps
Transmission distance	500m
System power consumption	Low power consumption, high long-distance communication power consumption
Development difficulty	Easy
Reference module cost	High
Advantages	1. Maximum refresh rate is 44 frames/second (dynamic effect). The grouping, scene, and fade time parameters are stored in the master, which has a large storage capacity. 2. It is applicable to dynamic lighting fields such as stage lighting and landscape lighting.
Disadvantages	Low signal transmission rate, high transmission signal error rate, one-way transmission (DMX512-A standard allows two-way transmission), limited number of single control systems (only 512) and trivial address code setting.
Development trend	It is developed rapidly in landscape lighting field.
Application	Stage lighting and landscape lighting.

6.1.5 KNX/EIB

KNX/EIB (Konnex/European Installing Bus) can be applied in all possible functions/applications in residence and building control, including lighting, closing control of multiple security systems, heating, ventilation, air-conditioning, monitoring, alarm, water consumption control, energy management and measurement, home appliances, acoustic devices and many other fields. KNX can be used in both small apartments and large buildings (office building, hotel, conference center, hospital, school, apartment block, warehouse, airport, etc.).

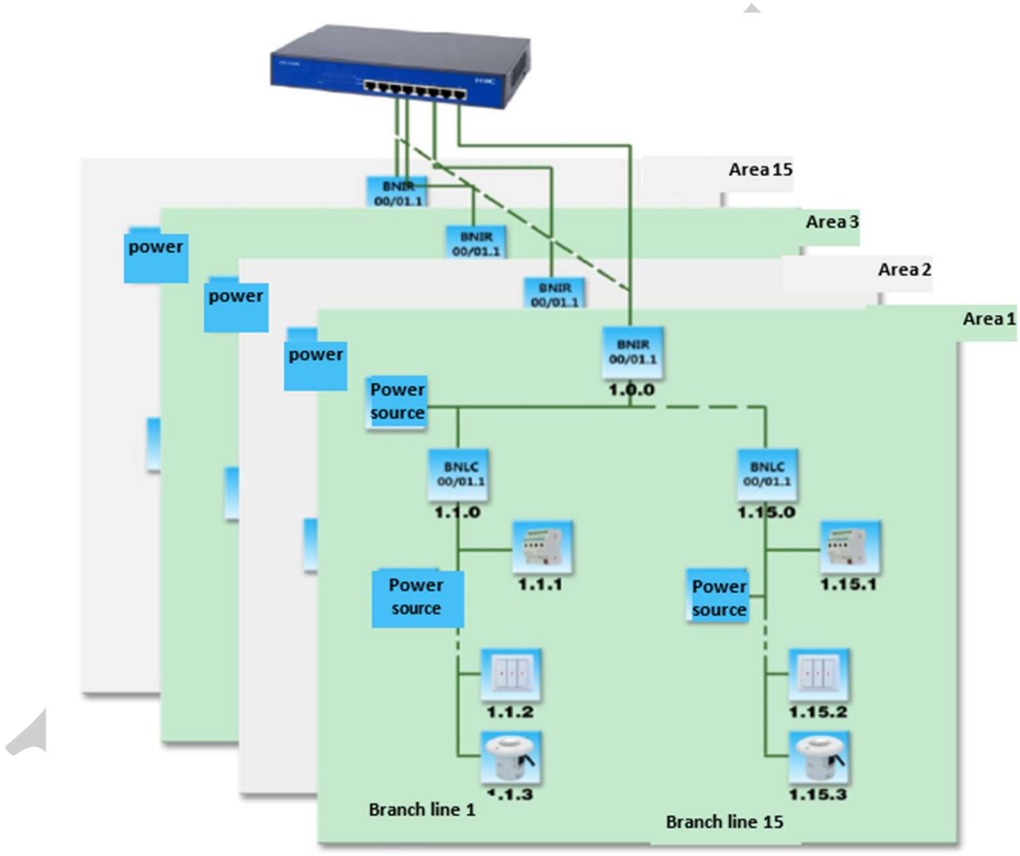


Figure 5 Architecture diagram of KNX/EIB system

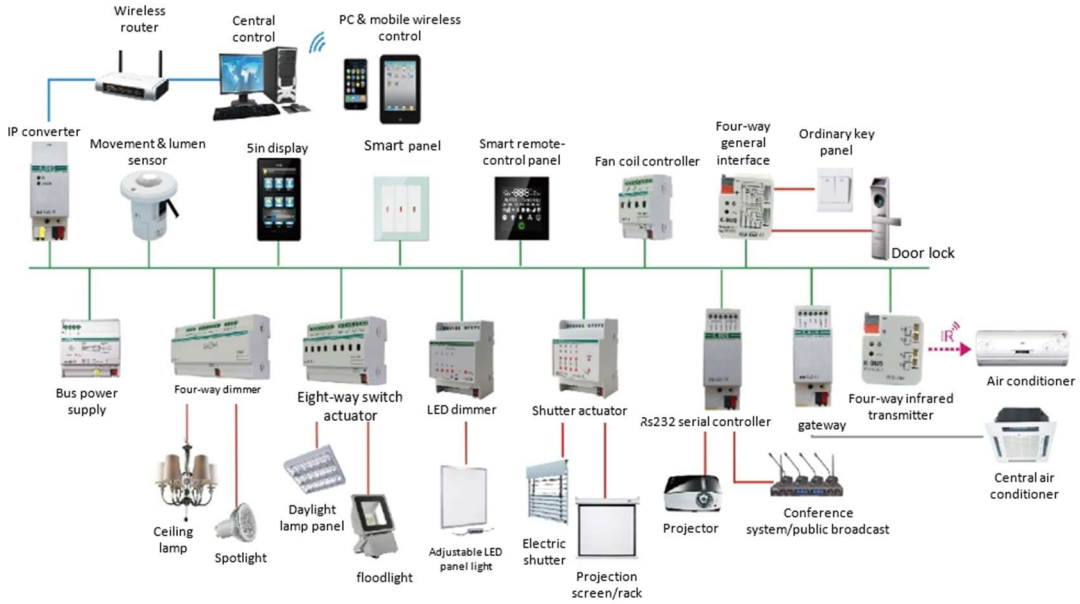


Figure 6 Schematic diagram of KNX/EIB control system

KNX/EIB supports several configuration modes:

Easy installation (E-mode): configuration can be completed by using one central controller, coding wheel or push button instead of using PC. Generally, E-mode compatible products are limited in functions and prone to minimal installation.

System installation (S-mode): installation and configuration plan can be completed through one PC and installed ETS software, with manufacturer product data included in ETS database. S-mode is prone to KNX/EIB certification planner, contractor and large plants.

KNX/EIB supports multiple communication media and each one can be connected through one or more configuration modes. Manufacturers can select suitable connection according to their target markets and applications.

- Twisted pair (KNX TP): can transmit KNX with independent bus cable in a crossing manner; an architectural system is formed in the line and the area.
- Power line (KNX PL): can transmit KNX through existing main network.
- Radio frequency (KNX RF): transmit by radio signal; either one-way device or two-way device is available.
- IP/Ethernet (KNX IP): the widely distributed communication medium can be applied in the network complying with KNXnet/IP specifications.

Table 4 Analysis on KNX/EIB protocol

Type	KNX/EIB protocol
Application range	Systems between controllers, control and gateway, and gateway and management control
OSI protocol layer	Layers 1 - 7
Topological structure	Bus, star and tree
Network type	Acentric, peer-peer control
Communication protocol	EIB communication protocol conforms to OSI model (open system interconnection reference model)
Device type	Driver, sensor, system device
Channel access mechanism	CSMA/CA (with carrier sense multiple access for collision detection)
Number of network nodes	A branch line can relate to 64 elements, an area can be formed with at most 15 branch lines via line coupler, and a largest system can be formed based on the 15 areas through backbone line coupler, so the maximum number of elements that a system can accommodate is 14,400.
Transmission media	Twisted pair, radio frequency, power line or IP/Ethernet
Transmission rate	9.6kbps
Transmission distance	<1000m
System power consumption	Low
Development difficulty	Difficult
Reference module cost	High
Advantages	1. The line is easy to install and maintain. 2. The system is of openness and can be combined with other building management system (BMS), building automation (BA) system, security and fire protection system. 3. Several control tasks such as single point, double point, multiple point, area, group control, scene setting, timing switch, manual/automatic brightness control, infrared detection, centralized monitoring and remote control can be realized. 4. Network topology is diverse. 5. The system scale is large, suitable for large-scale public construction projects.
Disadvantages	1. Great development difficulty. 2. High certification cost. 3. High cost.
Development trend	European Installing Bus (EIB) plays a predominant role in European building/family automation standards. There are over 5,000 EIB compatible products from more than 300 manufacturers in the world,

	accounting for 80% sales amount of European building/family automation devices.
Applications	Its control applications include building management devices, such as lighting, shading/louver, security system, energy management, heating, ventilation, air conditioning, signaling and monitoring system, service interface and building control system, remote control, metering, video/audio control and large appliances; industrial control is unavailable.

6.1.6 BACnet

A Data Communication Protocol for Building Automation and Control Networks (hereinafter referred as BACnet Protocol) was developed by Stand Project Committee 135P (i.e. SPC 135P) organized by the American Society of Heating Refrigerating and Air Conditioning Engineer (ASHRAE) over the course of eight and half years. This protocol is designed for heating, ventilating, and refrigerating control devices and also provides basic principles for integration of other building control system (such as lighting, security and fire protection systems).

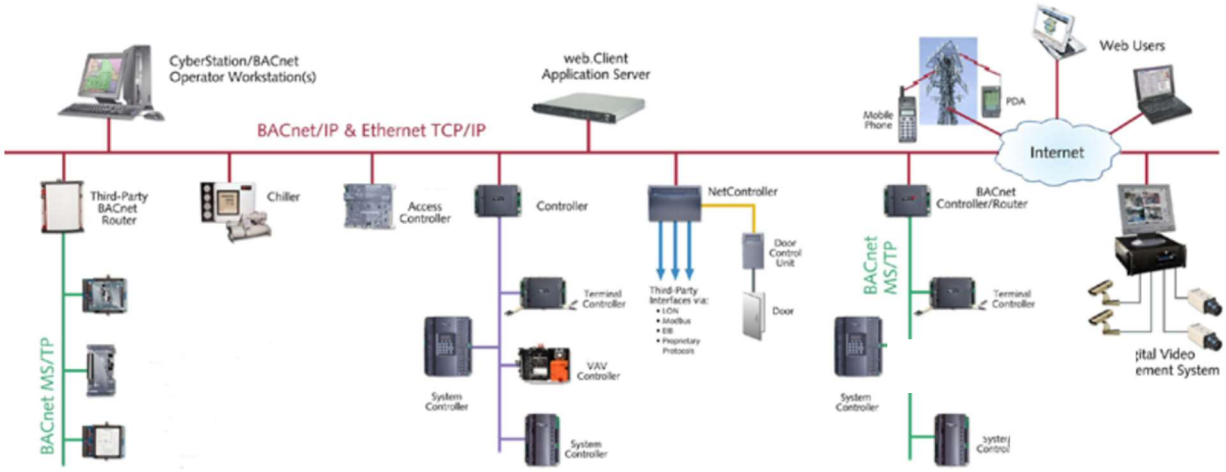


Figure 7 BACnet system architecture

Table 5 Analysis on BACnet protocol

Type	BACnet protocol
Application range	Systems between controllers, control and gateway, and gateway and management control
OSI protocol layer	Application layer, network layer, data link layer, physical layer
Topological structure	Bus, star and tree
Network type	Except ***MS/TP slaves: master-slave/token-passing slaves, all of them are peer.***
Communication protocol	BACnet Protocol
Device type	Network bridge, router, relay, half router
Channel access mechanism	
Number of network nodes	Unlimited
Transmission media	ARCNET, Ethernet, BACnet/IP, Point-to-point_(telecommunications) on RS-232, Master-Slave/Token-Passing (hereinafter referred as MS/TP) communication on RS-485, LonTalk
Transmission rate	2.5Mbps coaxial cable, 100Mbps Ethernet
Transmission distance	/
System power consumption	Low
Development difficulty	Difficult
Reference module cost	/
Advantages	1. It is a fully open protocol developed by a non-profit organization. 2. It is dedicated to building automation network. 3. It is of sound interconnection and expansibility. 4. It is of good elasticity, without limits in the number of system node.
Disadvantages	1. In addition to common mandatory use attributes, alternative attributes are also defined by BACnet. That is because the manufacturers are devoted to developing their own alternative attributes to lock users in their products, thus making these attributes keep consistent. In this case, common object attributes can be shared by products from different manufacturers while dedicated attributes cannot be shared, which brings negative impact for the openness. 2. In addition, huge and complex objects and attributes are defined by BACnet, which makes users difficult in configuring control system. In this way, the system must obtain maintenance from the supplier and the user must keep investing to ensure system update and extension.
Development trend	It is not so developed as KNX in recent years.
Applications	It is applied building system design for air conditioning, water supply and drainage, fire protection and security, and also provides various building

	device models, enabling interoperation and coordination among all kinds of devices.

6.1.7 ModBus

Modbus was invented by Modicon (now one brand of Schneider Electric) in 1979, which is the first bus protocol used in industrial field. Standard Modbus interface utilizes RS-232-C compatible serial interface and defines the pin, cable, signal bit, transmission baud rate and odd-even check of connector. Controller networking can be directly completed or completed via Modem.

Master-slave technology is adopted in controller communication, i.e. transmission (query) is initialized by one device (master device). Other devices (slave devices) will make corresponding responses according to the data inquired and provided by master device. Typical master devices: master computer and programmable instrument; typical slave devices: programmable controller.

Master device can separately communicate with slave device and can also communicate with all slave devices in broadcasting. In case separate communication is adopted, one message will be returned from the device as response; in case broadcast query is adopted, no response will be made. Modbus protocol establishes query format by master device: device (or broadcast) address, function code, all data to be sent, and error detection domain.

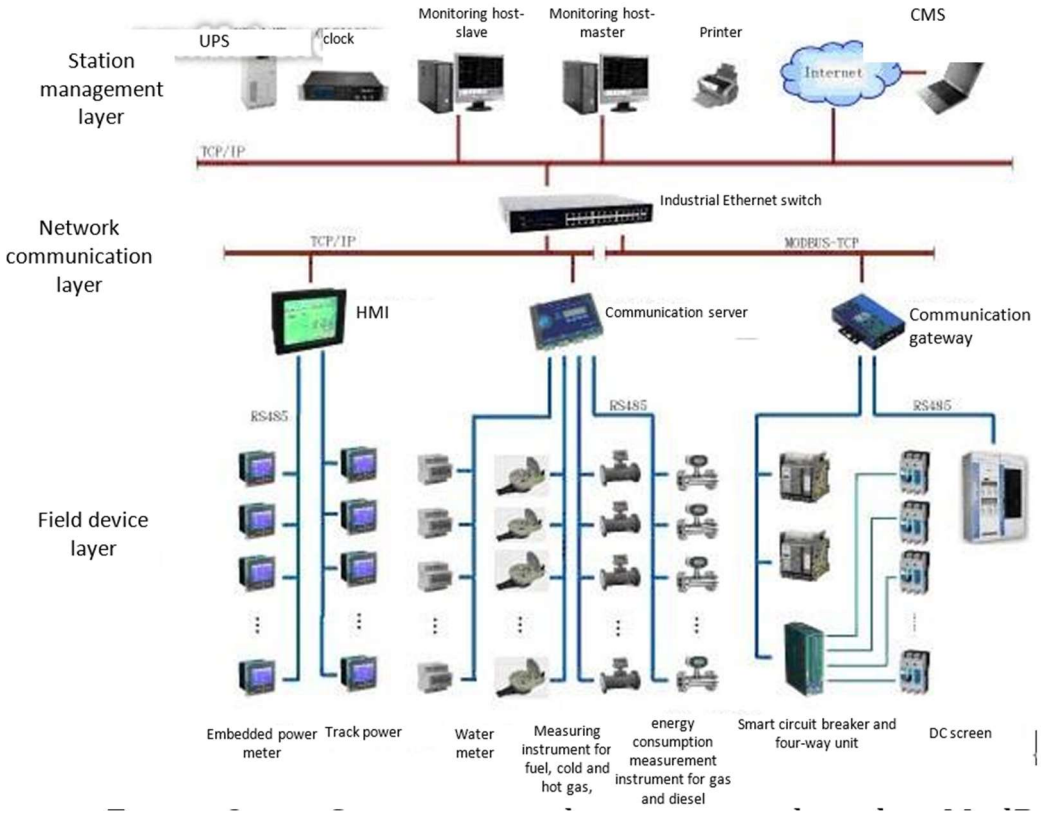


Figure 8 System network architecture based on Modbus protocol

Message responding from device is also a part of Modbus protocol, including confirming the domain to act on, any data to be returned, and error detection domain. In case there is any error occurred in message receiving or the command cannot be executed by slave device, the slave device will establish an error message and send it out as response.

Table 6 Analysis on ModBus protocol

Type	Modbus protocol
Application range	Systems between controllers, control and gateway, and gateway and management control
OSI protocol layer	Physical layer, link layer, application layer
Topological structure	Bus
Network type	Master-slave
Communication protocol	Modbus built on RS485, and Modbus built on TCP/IP
Device type	Electric node ECU, matched terminal
Channel access mechanism	None (to be defined by user)
Number of network nodes	32
Transmission media	Twisted pair
Transmission rate	300 - 115.2kbps
Transmission distance	<1.2km
System power consumption	Low power consumption, high long-distance communication power consumption
Development difficulty	Easy
Reference module cost	low
Advantages	1. It is designed to detect communication between instruments, based on baseband differential mode, with simple routing and low cost, suitable for near field communication. 2. Simple master-slave control mode is adopted, suitable for controlling and monitoring industrial devices in a centralized area. The protocol is available for many industrial devices.
Disadvantages	1. Master station polling is adopted, and the system has poor timeliness and reliability; 2. There are only 32 network nodes. 3. Small signal amplitude, a fraction of peak volt, poor antijamming capability.

	4. In case data is sent to the bus from multiple nodes due to system error, the bus will be crashed. 5. Connection to tree bus is unavailable.
Development trend	With development of computer network, RS-485 network bus will be completely replaced by CAN-bus.
Applications	All control fields

6.1.8 PLC-Lonworks

Power line Communication (PLC) is a communication mode peculiar to electric power system. It refers to technology that can transmit simulate or digital signals at high speed by using existing power line in carrier mode.

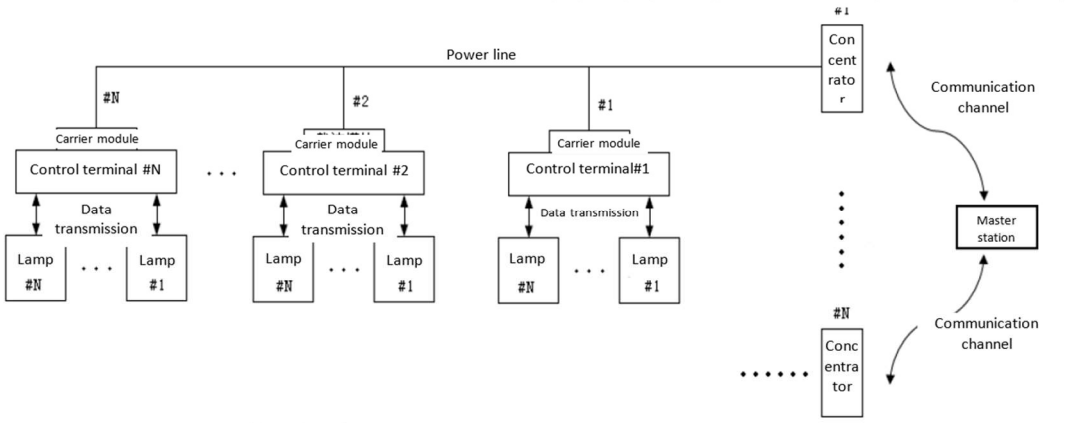


Figure 9 Architecture diagram of PLC road control system

The most important feature of PLC is that data transmission is available as long as there is electric wire, instead of requiring building network, which definitely becomes one of the best schemes to complete smart home data transmission. Meanwhile, due to data transmission limited in the family only, 5 troubles restraining PLC application will be greatly weakened and remote control to appliances will also be achieved in the manner traditional network connecting to PC first and controlling appliances.

Table 7 Analysis on PLC protocol

Type	PLC protocol
Application range	Between controllers, controllers and gateways
OSI protocol layer	Lonworks: layers 1 - 7
Topological structure	Unlimited
Network type	Multiple-master
Communication protocol	PLC-BUS communication protocol Lonworks-ISOIEC14908-x based on chips

Device type	Emitter, receiver and system supporting devices
Channel access mechanism	CSMA-CA
Number of network nodes	9,999 segment controllers, 2.56 million lamps
Transmission media	Power line, 4 - 60Hz frequency hopping, co-phase conductor
Transmission rate	5500bps, carrier frequency 132kHz
Transmission distance	<500m
System power consumption	Low
Development difficulty	Difficult
Reference module cost	High
Advantages	Power line is reused for data transmission, re-laying of communication line is not requirement, easy to construction.
Disadvantages	It will be greatly disturbed by the grid and pollute the grid at the same time. Data transmission within the same transformer in the grid is required and special devices are required to pass through the transformer.
Development trend	Tendency of application in road control system is obvious.
Applications	Road control and other lighting control systems

6.1.9 Wi-Fi

Wireless network refers to technology that can wirelessly interconnect personal computer, handheld devices (e.g. PDA, mobile phone) and other terminals. Wi-Fi is a brand of wireless network communication technology held by Wi-Fi Alliance. It is designed to improve interconnectivity among wireless network products based on IEEE802.11 standards. Some call the local area network using IEEE 802.11 series protocol wireless fidelity and even equate that to wireless network (Wi-Fi is an important part of WLAN).

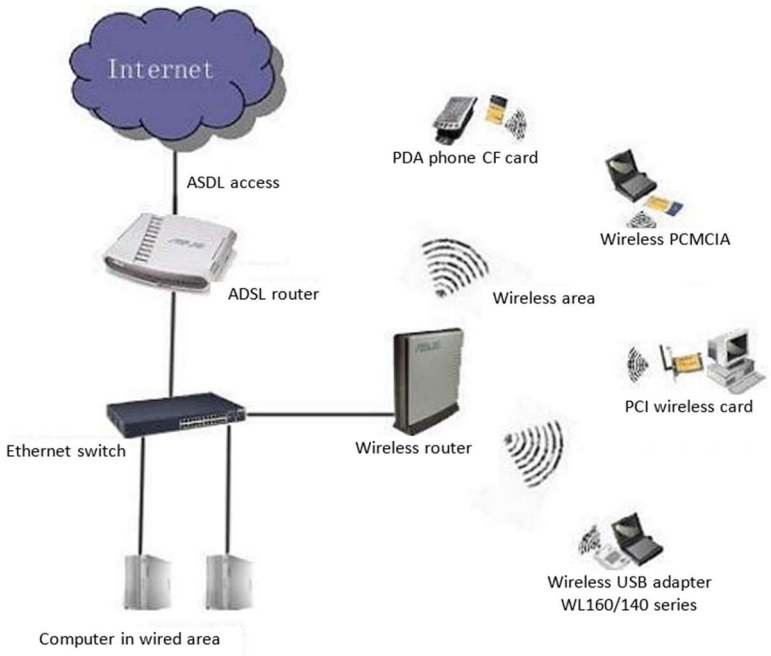


Figure 10 Schematic diagram of Wi-Fi network

Generally, basic outfit for building wireless network includes wireless card and one AP, then existing wired architecture can be used to share network resources in wireless mode. The building cost and complexity are much lower than that of traditional wired network. If just for peer-to-peer network of several computers, wireless card is required for each computer only, and AP is not a necessity. AP, short for Access Point, is generally translated into “wireless access point” or “bridge”. It is the bridge of wireless station and wired LAN in media access control (MAC) layer. Thanks to AP, wireless station can quickly and easily connect to the network just like a Hub for general wired network. Wireless fidelity is especially advantageous in broadband use. After cable broadband network (ADSL, community LAN, etc.) is accessed, connect to one AP and then install a wireless card in the computer. One AP is enough for one ordinary family and the neighbors can surf the Internet by sharing after approval obtained from the user, while additional interface is not required.

IEEE802.11 workgroup is working on wi-fi basic technology including PHY/MAC layer and WFA working to extend it suitable for application and certification and using new generation name such as wi-fi 4/5/6.

Table 8 Analysis on **Wi-Fi** protocol

Type	Wi-Fi protocol
Application range	Between controllers, controllers and gateways
OSI protocol layer	Physical layer, link layer

Topological structure	Star, Adhoc networking
Network type	Master-slave
Communication protocol	IEEE 802.11a/b/g/n/ac/ah
Device type	AP, P2P
Channel access mechanism	CSMA/CD
Number of network nodes	Each router can support dozens of nodes.
Transmission media	2.4 GHz/5.8Ghz
Transmission rate	Dozens of M – hundreds of Mbps, Gbps
Transmission distance	10 - 75m
System power consumption	High power consumption but low Wi-Fi power consumption in currently applied control fields
Development difficulty	Medium
Reference module cost	Low
Advantages	1. Global wireless broadband network standards are adopted. 2. Wi-Fi communication is supported by almost all smart terminal devices. 3. No addition gateway is required accessing to the network.
Disadvantages	1. Wi-Fi transmission security is low. 2. Number of nodes supported by wireless AP is limited. 3. Wi-Fi power consumption is high, needing to be improved; standby time of handheld device is short.
Development trend	With continuous reduction of price and power consumption of Wi-Fi chips, Wi-Fi gets a rather rapid development in smart home.
Applications	Smart items, smart home

6.1.10 Bluetooth

Bluetooth system adopts a flexible networking mode without base station so that a Bluetooth device can connect 7 other Bluetooth devices at the same time. The wireless access based on Bluetooth technology is called Bluetooth Public Access (BLUEPAC). The Bluetooth system network has two topological structures: Piconet and Scatternet.

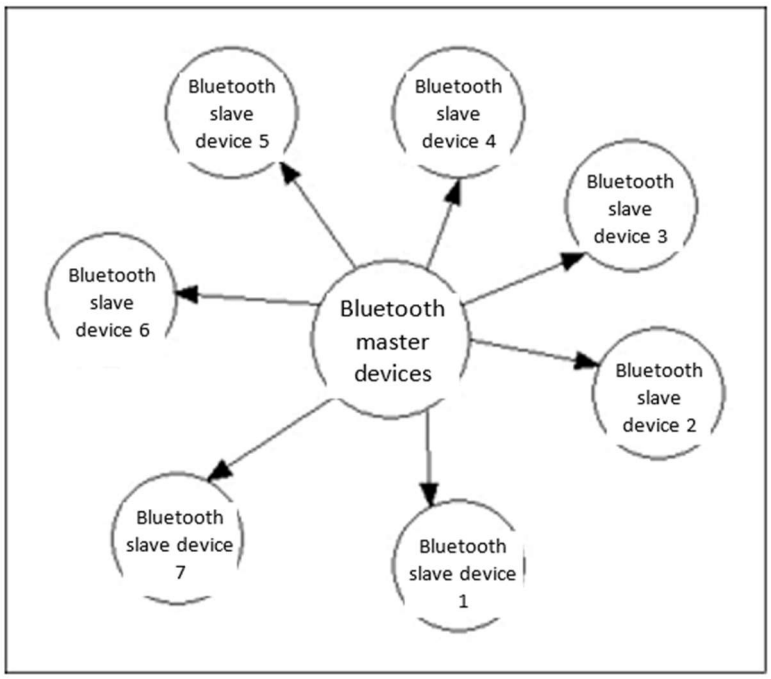


Figure 11 Architecture diagram of Bluetooth system

Piconet refers to micro network connected in a particular manner through Bluetooth technology. One Piconet can be formed by two connected devices only (e.g. one portable computer and one mobile phone) or formed by 8 connected devices. All devices in a Piconet are of the same grade and access. Bluetooth belongs to ad hoc networks. Piconet consists of master device unit (initiating links) and slave device unit, including one master device unit and 7 slave device unit at most. The master device unit is responsible for providing clock synchronization signal and hopping sequence while slave device unit is the controlled synchronous device unit to accept control from master device unit.

Scatternet consists of multiple separate asynchronous Piconets connected in a particular manner. One master device unit in a Piconet can also work as a slave device unit in another Piconet, this is so-called compound device unit. Strong vitality is injected to it through wireless accessing of Bluetooth in a special networking mode and 7 mobile Bluetooth users can access the Internet through one network node at the same time. Each Piconet is recognized through hopping sequence. All users in the same Piconet are synchronous with the hopping sequence.

Bluetooth Scatternet is an exception for ad hoc networks. Its most outstanding characteristic is to be supported without base station. All mobile terminals are equal in status and can separately transmit the decision in groups. The flexible networking, multiple-hopping, dynamic change of topological structure, and distributed control are the basis of building Bluetooth Scatternet.

Bluetooth SIG has published Bluetooth4.0/5.1 to support low energy and Bluetooth MESH1.0 to support mesh network.

Table 9 Analysis on Bluetooth protocol

Type	Bluetooth protocol
Application range	Between controllers, controllers and gateways
OSI protocol layer	Physical layer, link layer
Topological structure	point-to-point, star
Network type	Multiple master network to communicate in mesh structure
Communication protocol	IEEE802.11.6, Bluetooth4.0
Device type	Master node, slave node
Channel access mechanism	/
Number of network nodes	7
Transmission media	2.4 GHz
Transmission rate	24Mbps
Transmission distance	10m
System power consumption	Low
Development difficulty	Medium
Reference module cost	Very Low
Advantages	1. Support audio and data transmission. 2. Adopt frequency-hopping spread spectrum technology, with strong antijamming capability, not easy to eavesdrop. 3. Low power consumption and cost.
Disadvantages	The support number of network node is small and routing function is not supported.
Development trend	Smart home such as smart bracelet, smart item and smart lighting are widely applied, and Bluetooth acoustic devices are especially developed at a rapid speed.
Applications	Mobile phone, games machine, watch, PC, medical insurance, car, household appliances, automation and industry.

6.1.11 6LoWPAN

6LoWPAN is defined by IETF to support IPv6 protocol on wireless micropower IEEE802.15.4. It defines the encapsulation protocol of IPv6 to IEEE802.15.4, routing protocol Roll on IPv6 and application layer protocol language COAP.

Although some technical standards regarding 6LoWPANW network have been issued in succession, due to diversity and complexity of network demand of wireless sensor itself, there are still many key technical issues closely related to actual application demands to be solved, mainly including:

IPv6 adaptation layer protocol under low power and lossy environment. 6LoWPAN standard only enacts wireless link message transmission protocol of IPv6 message on IEEE 802.15.4, mainly consisting of message packaging format, compression, segmentation. However, it cannot support more demands about service quality and cover performance indicators such as real-time and deterministic indicators.

Router protocol under low power and lossy environment. Characteristics of node resource constraint, low power consumption and credibility, and resource dynamic change of wireless sensor network were taken into consideration by RPL router mechanism enacted by ROLL work group. However, more router protocol measurement indicators exist in MESH network, which are very important quality indicators under certain application environment.

IPv6 security technology under resource-constrained environment. It is worth studying and exploring deeply how to develop access method and how to implement encryption mechanism in wireless sensor network and considering the characteristic of IPv6 sensor node resource constraint.

Internet management protocol for IPv6 wireless sensor network. The application of IPv6 protocol enables wireless sensor node to use various internet management protocols based on IP, which have been verified and tested by the Internet for many years to own the characteristics of high maturity and good management effect. Some internet management protocols exercising well on the internet will be required to improve and expand to meet the management requirements of sensor node for its limited memory space and computing power, for which IPv6 management and optimization issues of wireless sensor internet is put out.

Internet of things adaptation layer protocol based on IPv6 technology. Communication and underlying communication employ socket interface on the internet while subnet requires internet performance management and device management services in IPv6 sensor internet. Therefore, it is necessary to establish a unified application sub-layer protocol for the application layer, as a unified service interface.

IPv6 portable support. On the Internet, the host is usually fixed, but in a wireless network, usually the wireless nodes are moved. Current IPv6 Mobility Support Protocol

is too complex to apply in resource-constrained sensor nodes. Therefore, the mobility support scheme of IPv6 sensor network should be studied.

IPv6 wireless sensor network, Internet connectivity framework and key technology. Interconnection and integration between Internet of things and Internet is the trend of network development. Heterogeneous network Intercommunication architecture and key technology based on IPv6 technology become the important issue to solve in order to realize this interconnection goal.

Table 10 Analysis on **6LoWPAN** protocol

Type	6LoWPAN protocol
Application range	Between controllers, controllers and gateways
OSI protocol layer	Layers 2 - 3
Topological structure	Star, tree, and line
Network type	Multiple master
Communication protocol	Backward compatibility with IPv4 based on the standard of 802.15.4 MAC, PHY, and 6LoWPAN IPv6 IETF
Device type	Coordinator, router, and terminal
Channel access mechanism	CSMA-CA (carrier sense multiple access with collision avoidance)
Number of network nodes	"Mesh-under" router can support over 500 nodes based on self-repair tree structure
Transmission media	2.4 GHz
Transmission rate	10 - 250kbp
Transmission distance	100m
System power consumption	The minimum power consumption can reach 18mA while working and 01.uA when falling into deep sleep (terminal can be switched to scheduled sleep while router device can be put to scheduled sleep by selection)
Development difficulty	Medium
Reference module cost	High
Advantages	1. Low power consumption, low cost, advanced internet management and self-repair mechanism 2. Designated for lighting and building optimization. 3. Supporting IPv6 and IPv4 based on standard internet protocol. 4. Supporting online OND and firmware upgrading via internet. 5. Coordinator switching mechanism and no single node fault.
Disadvantages	1. IPv6 does not enjoy a wide domestic application for which the part of IPv4 in JenNet-IP is mainly utilized.

	2. IPv6 has been in the market for a short time so that it gained inadequate domestic market verification
Development trend	It is considered to be the ideal next generation emerging wireless communication protocol of smart application to further achieve the Internet of Things (IOT)
Applications	Smart lighting, smart architecture, and smart home

6.1.12 POE

POE system transmits lighting control signals through Ethernet switch while powering the lighting with simple installment procedures and low cost. The schematic diagram is shown in Figure 12.

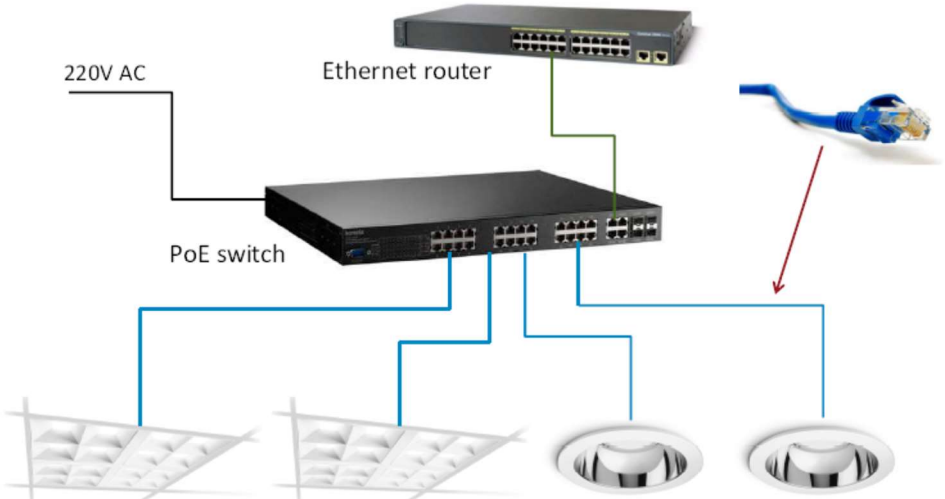


Figure 12 Schematic diagram of **POE** lighting control system

POE conforms to IEEE802.3af and IEEE802.3at. The detail parameters are shown in Figure 11.

Table11 POE standard

Class	802.3af(PoE)	802.3at (PoE Plus)	802.3bt
Classification	0 - 3	0~4	0~6
Valt	44 - 57V DC	50 - 57V DC	50 - 57V DC
Cable	Unstructured	CAT-5 or better	CAT-5 or better
The number of pairs of lines	2	2	4
Power of electrical equipment	13	30	100W

Current (0mA)	350	720	Type 3 (60W) Type 4 (100W)
Main application	Internet telephony (3 - 7W), WLAN access point (8 - 12W), etc.	LED lighting, video phone on internet(10－20W), PTZ video monitoring system(20W), WiMAX, 802.11n home router AP(8 - 45W), and personal computer(30W+), etc.	For most luminaire in office

6.1.13 ZigBee

ZigBee is an emerging wireless network technology with such characteristics as short range, low power consumption, low data rate, low cost and low complexity; ZigBee boasts all the advantages provided by the powerful wireless physical layer of IEEE 802.15.4: power saving, simpleness and low cost; logical networks, network security and application layer are added in ZigBee; ZigBee and 802.15.4 standards are suitable for low-rate data transfer with the maximum rate of 250kbps, and appropriate for the occasion where Transmission distance is relatively close contrasted with other wireless technologies.

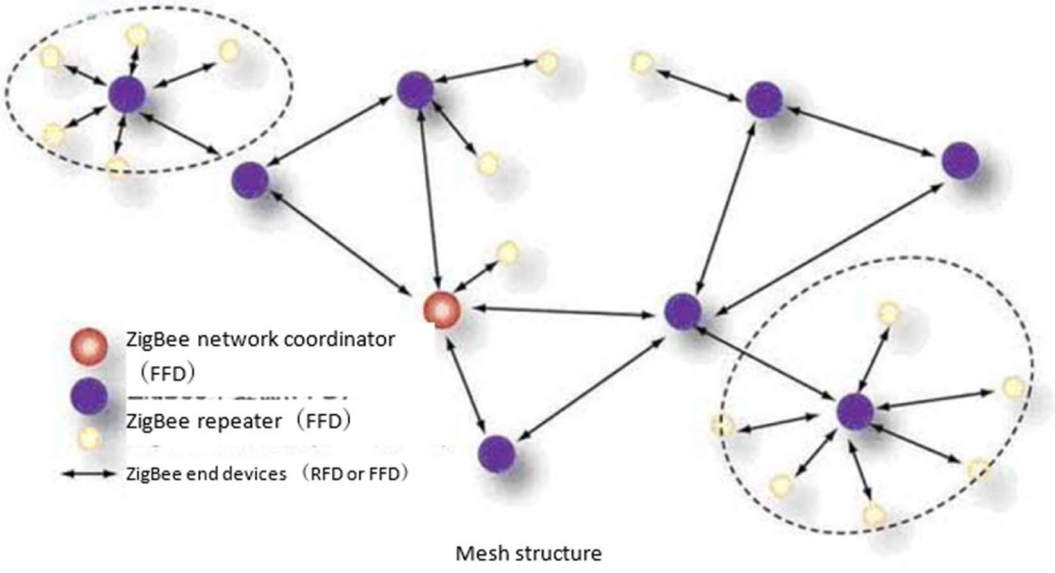


Figure 13 Topological structure of ZigBee wireless network

ZigBee wireless technology is suitable for the formation of WPAN network, i.e. the networking of wireless personal devices, so it performs well in data acquisition and control signal transmission.

ZigBee technology has strong networking capabilities, which can form star, tree and MESH networks, so the network structure can be selected appropriately according to the actual needs of projects. MESH network topology has a powerful function that it can communicate through "multi-hop"; the topology can also form a very complex network with the ability to self-organize and self-heal; star and family tree networks are suitable for multipoint-to-multipoint applications, or that with a relatively close range.

Now Zigbee Alliance working on zigbee3.0, green power, dotdot and CHIP.

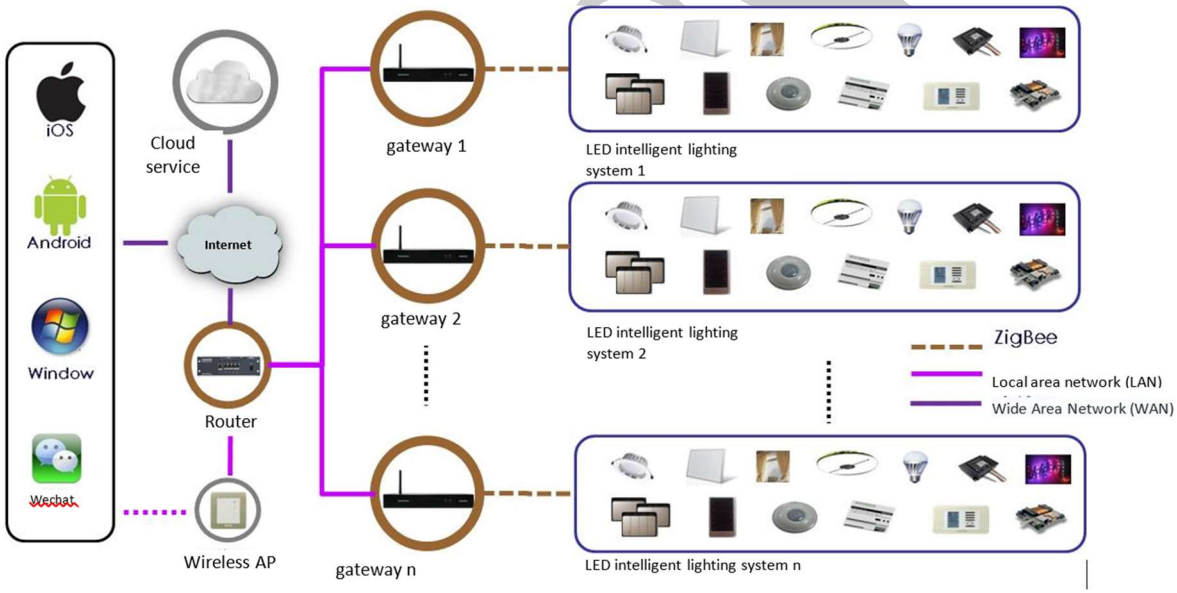


Figure 14 Schematic diagram of **ZigBee** lighting control system

Table 12 Analysis of **ZigBee** protocol

Type	ZigBee protocol
Application range	Between controllers, controllers and gateways
OSI protocol layer	Physical layer, link layer , network layer and application layer
Topological structure	Star-shape, tree-shape and mesh-shape
Network type	Multiple master network to communicate in mesh structure
Communication protocol	Short range wireless communication protocol based on 802.15.4, including physical layer, data link layer, network layer and application layer
Device type	A coordinator together with multiple routers and end devices

Channel access mechanism	CSMA-CA (carrier sense multiple access with collision avoidance)
Number of network nodes	Each router can support 256 nodes, while a coordinator supports 256 routers (with a total of 65536 nodes supported)
Transmission media	2.4GHz
Transmission rate	10 - 250 kbps
Transmission distance	10 - 75m
System power consumption	Very little power consumption (single node can work up to 6 months to 2 years with 2 No. 5 dry cells provided)
Development difficulty	Medium
Reference module cost	Very Low
Advantages	1. Low power consumption, low cost and large scale. 2. Data encryption provided resulting in high security. 3. Freely networking, with good expandability. 4. Multiple master communication with high efficiency. 5. Wireless communication with no needs of dedicated line; convenient installation and proper isolation of fault
Disadvantages	1. Power supply for single node required. 2. In contrast with other wire modes, wireless communication has high probability of being interfered and relatively low reliability. 3. Relatively short communication range (<100m). 4. Relatively low communication rate (<250Kbp/s).
Development trend	Chip solutions have been put into commercial use. In China, ZigBee technology may be initiatively applied in the field of smart home control.
Applications	Wireless sensor network, acquisition of various sensor information, intelligent building applications such as three meters (water, electricity and gas) remote reading

6.1.14 Z-Wave

Z-Wave is an emerging short-range wireless communication technology RF-based and network-compatible with such characteristics as low cost, low power and high reliability. The operating frequency range is 908.42MHz (USA) and 868.42MHz (Europe) respectively. The FSK (BFSK / GFSK) modulation mode is adopted. The data transfer rate is 9.6 kbps, with the effective signal coverage of 30m indoor and exceeding 100m outdoor, so it is suitable for narrow bandwidth applications. With the increase of communication range, the complexity of devices, power consumption and system cost are also augmenting. Compared with existing wireless communication technologies, Z-Wave will be the technology that has the lowest power consumption and the lowest cost,

which can effectively promote the development of low-rate wireless TKBHOME personal area network.

Figure 15 Architecture diagram of **Z-Wave** system

Figure 16 Schematic diagram of **Z-Wave** control system

Table 13 Analysis of **Z-Wave** protocol

Type	Z-Wave protocol
Application range	Between controllers, controllers and gateways
OSI protocol layer	Physical layer, link layer, network layer and application layer
Topological structure	Mesh type
Network type	Multiple master network to communicate in mesh structure

Communication protocol	Z-Wave protocol
Device type	Control node and slave node
Channel access mechanism	CSMA-CA (carrier sense multiple access with collision avoidance)
Number of network nodes	232 nodes (Slave)
Transmission media	908.42MHz (USA), 868.42MHz (Europe)
Transmission rate	Maximum 100kb/s
Transmission distance	30m indoor and more than 100m outdoor
System power consumption	Low
Development difficulty	Medium
Reference module cost	High
Advantages	1. Simple protocol favorable to a faster and easier development. 2. The protocol architecture is relatively simple as Z-Wave has clear applications such household applications. 3. Under a lower operating frequency, compared with ZigBee, Z-Wave possesses a longer transmission distance and more stable connection.
Disadvantages	1. Z-Wave chip can only be obtained from SigmaDesigns, the only source. 2. SigmaDesigns sells its products only to OEM, ODM and other main clients. 3. As Z-Wave is relatively closed and with high requirements, design manufacturers or manufacturers who adopt Z-Wave technology is much less than those employing Zigbee.
Development trend	Z-Wave is a kind of wireless communication technology with simple structure, low cost and reliable performance. The wireless network employing Z-Wave technology not only can realize the remote control of home appliances through the devices in this network, but also can control devices in Z-Wave network through Internet.
Applications	As Z-Wave technology has many advantages including low cost, secure networking and flexibility (address allocation), its commercialization has been accelerated with a view to occupying the household market. With the further development of the technology, it is expected to create a complete solution that meets the requirements of coverage, data rate and signal strength required by wireless home networks and related applications. It is believed that in the near future, more and more Z-Wave products will not only enter people's lives, but also play a role in the military industry, medical and other fields.

6.1.15 EnOcean

In March 2012, the EnOcean wireless standard was ratified as the international standard "ISO / IEC 14543-3-10" by the International Electrotechnical Commission (IEC), which is the only international wireless standard that uses energy harvesting technology in the world. The standard specifies the communication protocol for the bottom three layers of the protocol stack which are the physical, data link and networking layers. The EnOcean wireless energy harvesting module is manufactured and sold by EnOcean GmbH who also provides technical support to members of EnOcean Alliance. Based on this platform, OEMs (Original Equipment Manufacturer) can easily and quickly implement customized wireless switch sensing solutions based on wireless energy harvesting technology.

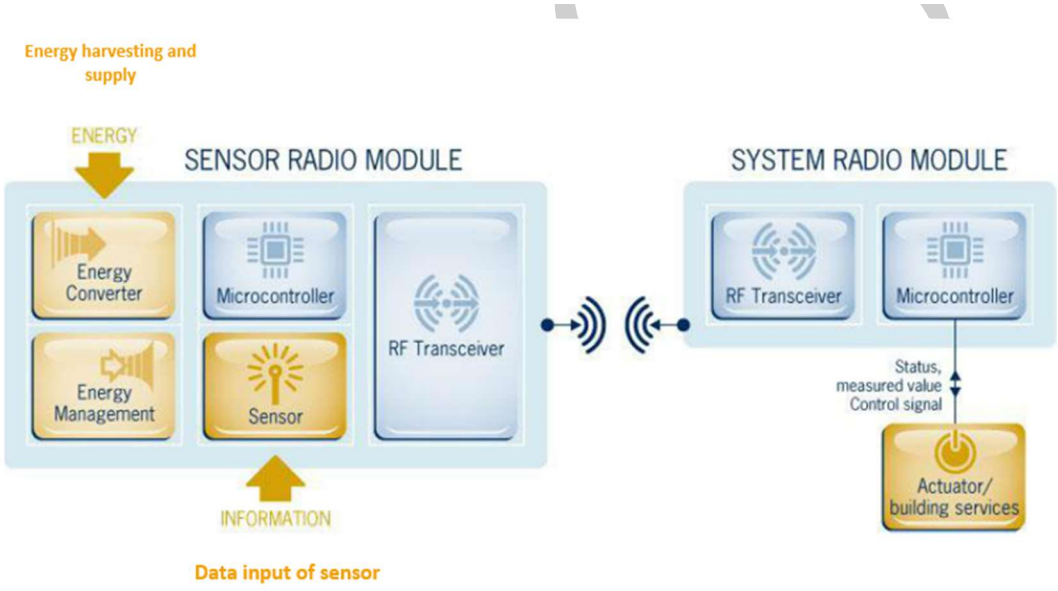


Figure 17 Architecture diagram of **EnOcean** system

Figure 18 Schematic diagram of **EnOcean** system products

6.1.16 UPnP

Universal Plug and Play (UPnP) is a structure that enables networked devices, such as smart devices, wireless devices, and personal computers to achieve peer-to-peer networking (P2P) all over the world. It is a distributed, open networking architecture. As it is an independent media, UPnP devices can be used in any programming language in any operating system.

UPnP defines the basic components of service, devices and control points. The module diagram is shown in Figure 19.

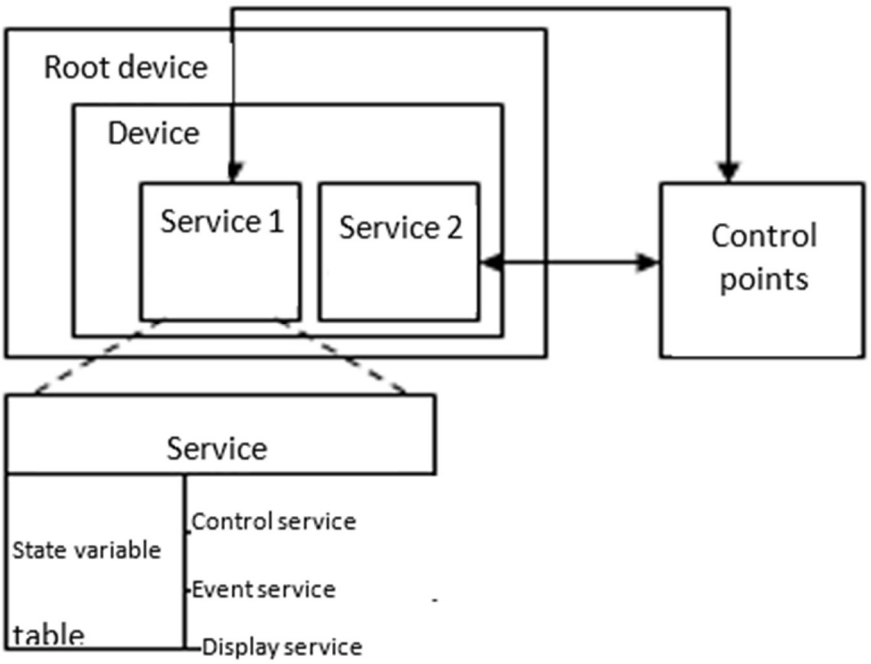


Figure 19 **UPnP** components

UPnP defines the protocol for communication between devices, devices and control points, and control points. The complete UPnP consists of device addressing, device discovery, device description, device control, event notification, and Html-based description interface. Figure 20 shows the protocol stack of UPnP device.

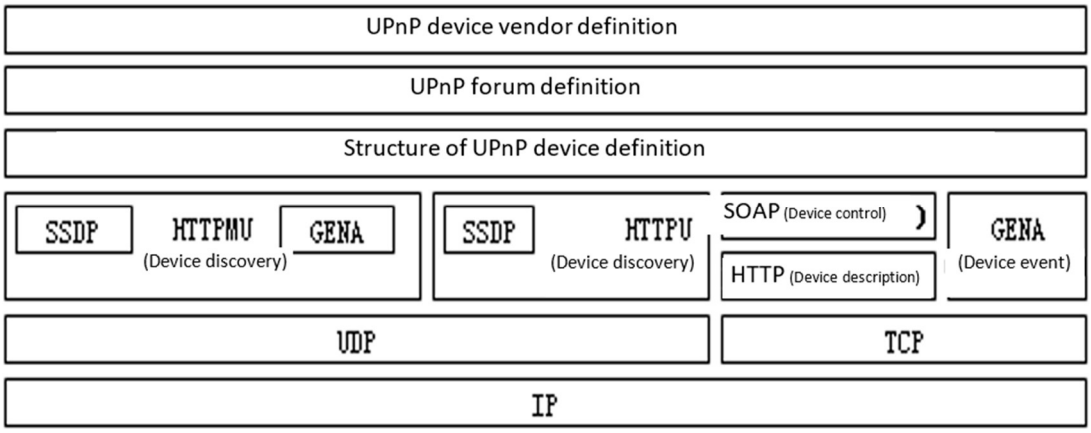


Figure 20 **UPnP** protocol stack

The TCP / IP protocol at the bottom layer is the basis of UPnP protocol architecture. IP layer is used for data transfer and reception. For information that needs reliable transmission, TCP is adopted, otherwise UDP is used. UPnP can run on many media including Ethernet, wireless network, IEEE1394 and IR (Infrared Ray). No special network physical device is necessary if the IP protocol can be supported. At the same time, it can also use other protocols in the TCP / IP protocol suite, such as ARP, IGMP, DHCP, and DNS.

Built on top of the TCP / IP protocol is the HTTP protocol and its variants, which are the core part of the UPnP protocol. All UPnP messages are encapsulated in the HTTP protocol and its variants that consist of HTTPU and HTTPMU. The format of these protocols follows that of the HTTP protocol, except that unlike the HTTP protocol, they send messages over UDP instead of TCP and can be used for multicast.

6.1.17 IGRS

On July 17, 2003, the "Intelligent Grouping and Resource Sharing" standard working group (referred to as IGRS standard working group), which was initiated by five companies including Lenovo, TCL, Konka, Hisense and CNC, and participated in by other seven entities together, was approved by the Science and Technology Division of Ministry of Industry and Information. The working group developed the IGRS1.0 protocol and is working on IGRS2.0. IGRS consists of three parts: the core, basic protocol suite, intelligent application framework and featured applications.

The IGRS standard is an application layer protocol based on the TCP / IP protocol. It is used to achieve the unification of different hardware and software systems at a higher

level. It can easily interconnect information devices with traditional appliances, automatically discover and find devices and service functions that can be utilized, using a simple way to install and use them.

The main controlled members are composed of household 3C devices (Internet-enabled TV, home storage NAS, digital photo frame, home control center, IP Camera), mobile 3C devices (MID / UMPC, mobile phones), and 3C devices in the office (network printer, laptop, VoIP phone). See Figure 21 for application scenarios.

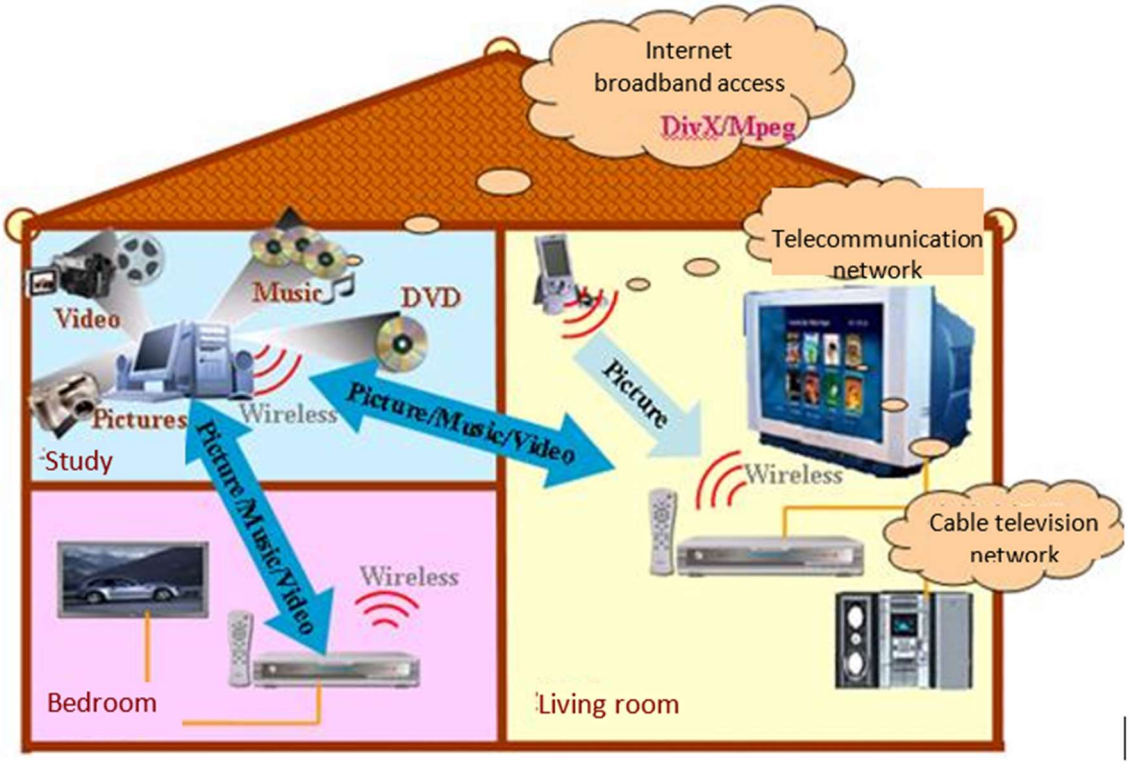


Figure 21 **IGRS** application scenarios

6.1.18 OCF

OCF-Open connect foundation is an industry consortium to optimize IoT standards.

- Dedicated and optimized protocols for IoT (e.g. CoAP)
- Standards and Open Source to allow flexibility creating solutions
- Certification testing for interoperability
- Certification and Logo program

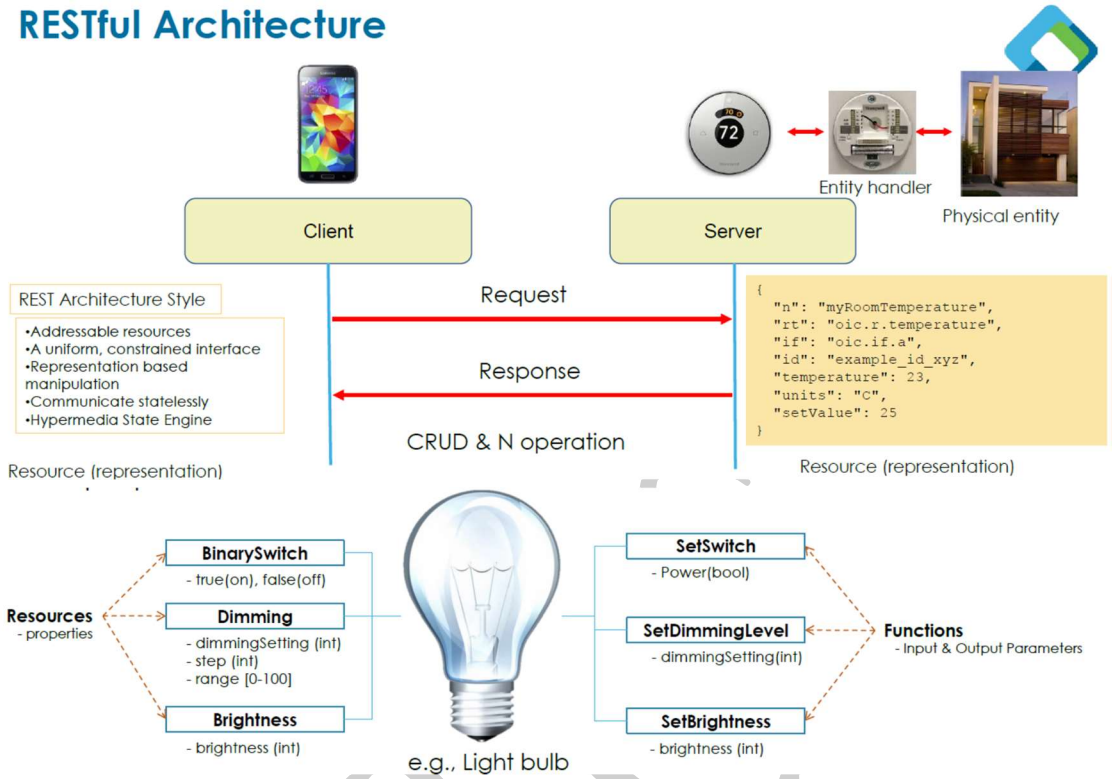


Figure 22 OCF architecture and smart light bulb

6.1.19 Thread

Thread defined A secure, wireless mesh networking protocol that:

- Supports IPv6 addresses and simple IP bridging
- Is built upon a foundation of existing standards
- Is optimized for low-power / battery-backed operation
- Is intended for control and automation (250kbps)
- Can support networks of 250 nodes or greater
- Supports low latency (less than 100 milliseconds)
- Offers simplified security and commissioning
- Runs on existing 802.15.4 wireless SoCs

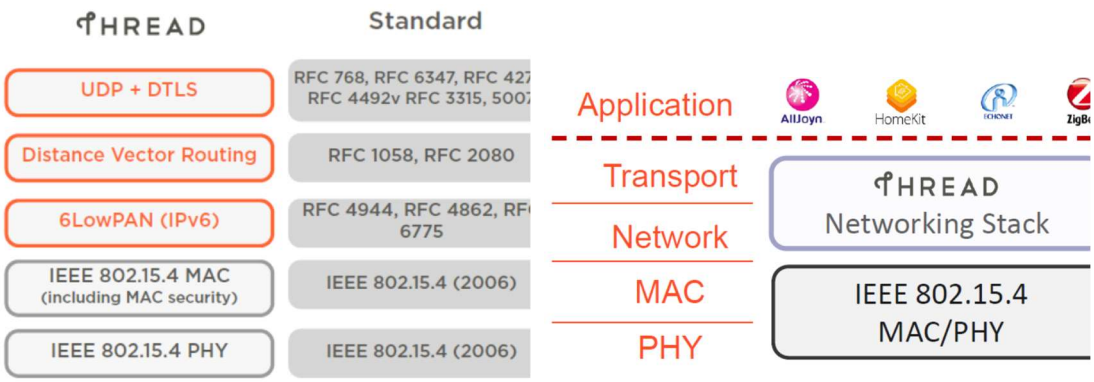


Figure 23 Thread OSI layers and standards

6.1.20 Oceanconnect

OceanConnect is defined by Huawei for IoT management platform. API for Smart light can be connected and management by this platform.

6.1.21 Road light system protocol-Application layer

TALQ is working on protocol between Gateway and CMS. And Chines national standard GB/T34923.6 and GB/T 35255 defined XML based, and APU based control protocol.

6.1.22 Wireless public connection

Wireless public connection is provided by telecom service provided for public wireless access, such as GPRS/3G/4G and now 5G.
And those connections are well organized and refer to 3GPP standards.

6.1.23 LPWAN

LPWAN is low power wide area network, which can provide long distance wireless access with low power, now NB-IoT, Lora, Sigfox and ZETA are LPWAN technology in market. But Lora and NB-IoT(Narrow-band Internet of Things) are widely used now.

LPWAN that leverage low power wide area networks mainly require deep / wide coverage, low power consumption, low device cost and massive connections. There are several inherent characteristics of the NB-IoT technology that makes it the best for LPWA deployment.

NB-IoT can refer to following relevant standards: 3GPP TS 36.201, 3GPP TS 36.211, 3GPP TS 36.212, 3GPP TS 36.213, 3GPP TS 36.214, 3GPP TS 36.300, 3GPP TS 36.321, 3GPP TS 36.322, 3GPP TS 36.323, 3GPP TS 36.331.

NB-IoT has 4 advantages:

Figure 24 NB-IoT advantages

6.2 OSI layer and protocol summary

The Open Systems Interconnection (OSI) model is often used to describe networks to help ensure compatibility between devices. Devices need to interoperate at the layers they support.

True interoperability may not be an issue in most lighting system specifications, but it is a worthwhile point to consider when collaborating with other component specialists who may be responsible for conforming to the OSI 7-layer model more thoroughly. It is useful to understand the OSI 7-layer model when researching a new system or determining whether a building system could properly control lighting. The OSI 7-layer system provides a framework for formulating questions that will help in determining whether the product is a viable solution for your project.

OSI has 7 layers, which is shown and compared with different protocols above in table 14.

Table 14: OSI layers and protocols

	Layer1 Physical	Layer 2 Data link	Layer3 Network	Layer4 transport	Layer5 Session	Layer 6 Presentation	Layer7 Application
DALI	y	y	y	y	y	y	y
Bluetooth-BLE	y	y	y	y			
Bluetooth-Mesh	y	y	y	y	y	y	y

Wi-Fi	y	y					
Zigbee	y	y	y	y	y	y	y
Z-wave	y	y	y	y	y	y	y
Enocean	y	y	y	y	y	y	y
OCF				y	y	y	y
Thread	y	y	y				
Oceanconnect				y	y	y	y
KNX	y	y	y	y	y	y	y
BACnet	y	y	y	y	y	y	y
Lonworks	y	y	y	y	y	y	y
ModBus	y	y	y	y	y	y	y
DMX/RDM	y	y	y	y	y	y	y
IGRS					y	y	y
UPnP					y	y	y
TALQ					y	y	y
GPRS/3G/4G/5G LPWAN	y						
GB/T34923.6					y	y	y
GB/T 35255					y	y	y

6.3 Main protocols used

Protocols listed in Section 3.1 are related to LED lighting system but not all of them have been used widely. In this section, a simple analysis of main protocols will be made. As the unbalanced development of different protocols, majority parts may change in the future. Therefore, the analysis here is only for reference.

About protocol used between the light controller and LED driver (control gear), 0-10V and PWM or DALI are used as the interface Ia protocol, however user-defined private protocols are used as the interface Id protocol; for home lighting, professional lighting, road lighting and landscape lighting system, the analysis of existing main protocols using in interface Ib and Ic protocols are shown in Table 15.

Table 15 Existing main protocols in interfaces of **LED** lighting control system

Application	**Ia**	**Ib**	**Ic**	**Id**
Residential lighting	0-10V PWM	Wi-Fi ZLL	Define the application layer protocol based on TCP/IP	User-defined
Professional lighting	0-10V PWM DALI	DALI KNX BACnet Zigbee POE Dynet	KNX BACnet	User-defined
Roadway lighting	0-10V PWM	PLC	Define the application layer protocol based on TCP/IP	User-defined

	DALI	RF-ZigBee like GPRS/3G/4G LPWAN(NB-IoT, Lora)		
Landscape lighting	0-10V PWM	DMX512	TCP/IP or UDP-based DMX512	User-defined

In the home lighting system, the control protocols Ib widely used between the light controller and segment controller (gateway) are ZigBee light Link, Bluetooth and Wi-Fi, while the communication network between the central management system (CMS) and segment controller (gateway) is based on the existing TCP / IP protocol and does not involve application layer, so it may be a working point to standardize the application layer. For instance, XML (Extensible Markup Language) and JSON usually using as a data communication protocol language is adopted as the standard format of application protocols, and through the HTTP/CoAP transmission protocol for data transmission, the interoperability of different devices and systems through servers can be achieved.

For professional lighting control system, the connection and compatibility with building automation systems shall be taken into full consideration. DALI, ZigBee-ZHA / ZBA, BACnet, KNX, POE, etc. can be used as the control protocols Ib between the light controller and segment controller (gateway). As the protocol between the segment controller (gateway) and CMS is based on TCP / IP protocol, it is considered to adopt KNX, BACnet or the application layer protocol as defined by vendor themselves.

For outdoor road lighting system, the interface protocol Ib between the segment controller (gateway) and light controller are ZigBee improved or PLC protocols, for protocol Ic between the segment controller (gateway) and CMS is based on the application layer protocol over TCP / IP protocol, such as user-defined protocols. Or XML (Extensible Markup Language) or JSON, a data communication protocol language is adopted as the standard format of communication protocols, and the HTTP or CoAP is used as transmission protocol for data transmission, the interoperability of different devices and systems through servers can be achieved. And meanwhile, GPRS/3G/4G and LPWAN(NB-IoT/Lora) are used by controller connect to CMS directly.

For landscape lighting system, Ib interface is DMX512 while for Ic interface, it is recommended to adopt DMX512 over TCP / IP or UDP. For low-cost solutions, the field bus protocol can be used.

7 Challenges for Standardization of the LED Lighting Control System

7.1 No available unified interface protocol standard

7.1.1 Diversity of (Ib) interface protocols between integrated controller (gateway) and light controller

At present, there is no general communication protocol in the industry. Although there are many communication protocols, each of which is supported by corresponding industrial chain and its application layer protocol is different. Luminaires and control equipment among different manufacturers are not replaceable. Different or same communication protocols are adopted by LED lighting system, such as DALI, ZigBee, PLC and building automation control protocols. No matter the protocols are the same or different, the problems such as interchangeable and communication-capable of the system existed. Application layer communication protocols for lighting systems of different scenes adopt different communication modes, address maintenance modes, data-packet formats, command formats and interactive modes.

Protocol standard of this interface shall be prepared to promote modularization, standardization, replaceability, wide range of application of lighting control system. Standardization work can refer to the hierarchical model of general communication protocols. Firstly, the specification of one or several physical communication mediums shall be determined, i.e., physical layer communication mode shall be selected. Then data link layer, network layer and transport layer shall be identified in sequence. Finally, the specification of application layer shall be developed. Only in this way, the interconnection between communication modes and communication protocols can be realized. Protocols such as DALI, ZigBee, PLC and POE can be used, and building control protocols such as KNX and BACnet can be adopted.

7.1.2 No available unified standard for application layer of (Ic) interface between Central Management System and integrated controller (gateway)

(**Ic**) interface between central management system and segment controller (gateway), or (Ic1) interface between light controller and central management system, (Ic2) interface between commissioner and central control manager are all built on the Internet of Things and TCP/IP layers. But there is no unified lighting control application layer protocol. IGRS and UPnP are mainly used in home appliances and information fields, and KNX and BACnet are mainly adopted for building control protocols. These application layer protocols can be used for reference. Sine there is no unified standard presently, the application protocols of the system of different manufacturers are different, resulting in unavailable for interconnection.

For (**Ic**) interface of lighting control system, application layer protocols based on TCP/IP layer shall be defined so as to realize the interconnection.

7.1.3 No available open API interface of service layer of central management system

For the lighting control system, it is necessary to develop the application service layer API if it is required to maintain a good APP ecological environment of application layer. Mutual access between systems can be conducted though the development of the unified API interface standard. Internet companies Alibaba, JD and Apple are trying to develop a unified API interface mode.

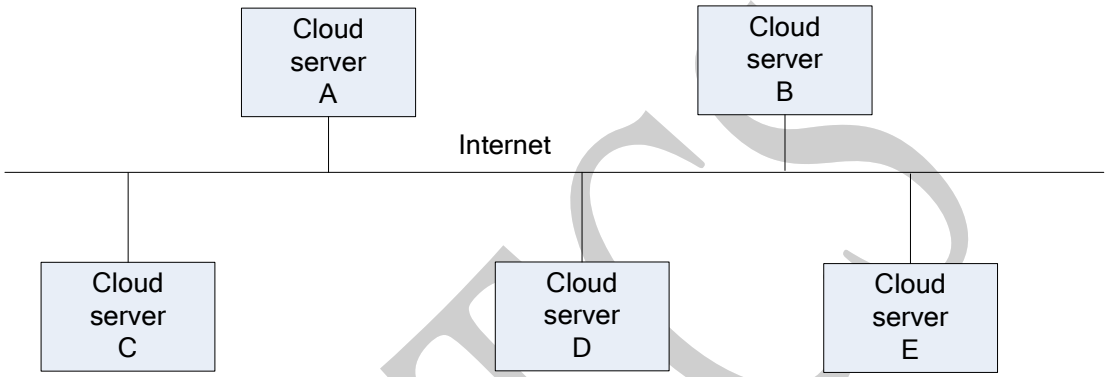


Figure 25 Interconnection frame diagram between cloud servers

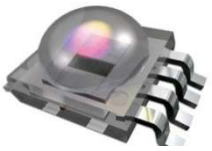
At the same time, as shown in Figure 25, central management system can be built on cloud servers. The interconnection between cloud servers is one of ways to realize fast interconnection between existing independent lighting systems. More importantly, it is required to develop standard API interface and the Internet can be connected based on TCP/IP or through LAN or Wi-Fi or mobile network (GSM/CDMA/3G/4G) to realize mutual access to application layer data.

7.1.4 No available unified (Id) interface standard for sensor

The sensor is used for the lighting control system to perceive the surrounding environment, which controls the lighting depended on the environment. The commonly used sensors are shown in table 16.

Table 16 Technical analysis of sensors

S/N	Type of sensor	Picture	Analysis
1	Infrared sensor		Small detection range and low detection accuracy. It can only detect whether there is a person in a certain range, and cannot detect the movements of people, such as waving hands.

2	Ultrasonic sensor		If there are several emitters and receivers, the launch interval of each emitter needs to be coordinated properly to make sure that the signal form wrong emitters would not be received during the listening time. The accuracy of the clock of the emitter is low for cost reasons. It is necessary to ensure that the time of clocks are synchronized between sensors with clock drift. It will be greatly impacted by the environment of application scene. The reflection of each panel is easy to generate clutter, with poor performance of robust.
3	Light sensor		It can only detect the lighting within a limited range. The accuracy is largely determined by the location of the sensor in the room, the size of the indoor flat material and the daylight intensity. It is generally installed on the ceiling and calibrates the mapping relation between illumination and measurement value at night. The calibration is only conducted one time after the installation of the system, but the mapping relation will change with the change of the reflecting surface from time to time, such as the movement of a user or an object in the environment.

Sensors can be divided into two categories: intelligent and non-intelligent. The intelligent sensor refers to the sensor which has communication interface and data handling capacity; the non-intelligent sensor is the sensor whose acquisition probe has no communication interface and data handling capacity, generally used as the component of the intelligent sensor. Digital and analog data interfaces are mainly adopted for non-intelligent sensors, with different modes used for different sensors.

As a discussion of standards, the standard of non-intelligent sensors is not considered, and the communication interface standard of intelligent sensors would be mainly discussed. There is no one unified and mature standard for (Id) interface. The standard for the sensor are being developed in ZigBee, SAC/TC28/WGSN and SAC/TC124. The same standard can be implemented by (Id) interface of intelligent sensors, the integrated controller (gateway) and Ib interface of light controller.

7.2 Integration and separation of light controller and LED driver (control gear)

For LED luminaire with dimming control function and drive power integrated light controller (as shown in Figure 26), the interface between the light controller and drive power supply is not needed to be defined, while the communication protocol of Ib between the light controller and the integrated controller (gateway) must be specified.

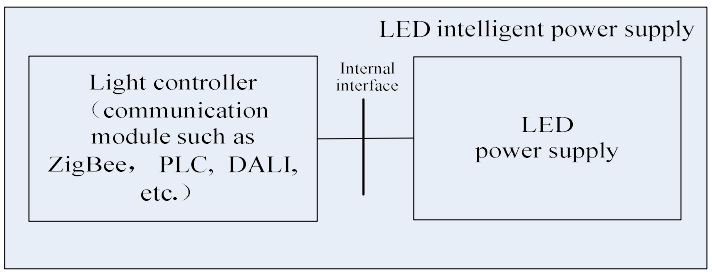


Figure 26 Interface protocols between integrated light controller and **LED** power supply

In the case of the drive power supply is separated by the light controller (as shown in Figure 27), the Ia interface standard of them is needed to be defined, including switch and dimming such as 0/1 - 10V, PWM, DALI, etc. The system and control standards can not specify the access of various luminaires, so specifications for the access modes of different luminaires shall be developed to increase the application range of control standard.

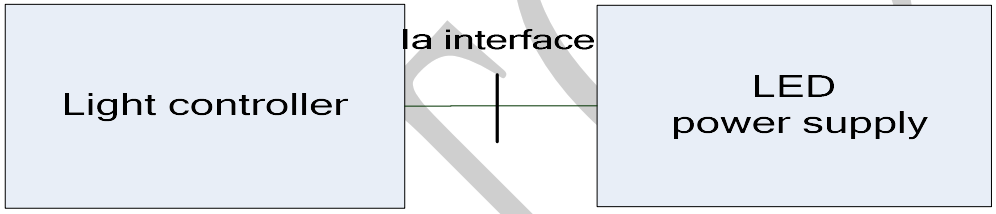


Figure 27 Interface protocols between light controller and LED power supply

Integration or separation of light controller and power supply shall be determined based on the application scene. For instance, for the bulb lamp of home lighting, the integration of light controller and power supply is adopted, while for streetlamps of road lighting, the separation of light controller and power supply is adopted.

7.3 No available interoperation specification with traditional lighting switches and luminaires

The fast development of LED lighting control system inevitably affects the market of traditional lighting switch. The matter of how the exchange and interoperation between LED lighting control system and traditional lighting system can be better realized shall be considered, such as how the traditional controllable silicon dimmer switch supports the dimming control of LED luminaires and realizes functions of color temperature adjusting and color adjustment. How the LED lighting control system realizes the intellectualization on the basis of wiring of traditional lighting control is also a matter must be considered for the development of the intelligent lighting industry.

7.4 No available LED lighting system network security and testing standard

Once connected to the Internet, the LED lighting control system will inevitably involve the problem of network security. How to prevent the data of the system from being stolen by hackers, the system from malicious attack and the privacy of users from revealing must be fully considered and avoided in the network design. When the system scale reaches a certain degree, real-time, effectiveness and stability of user operation shall be ensured. The requirement of security of Internet of Things is much higher than that of the Internet.

7.5 No available requirements and test standard for intelligent lighting function

For different applications, the function realized by LED lighting system is different. Only LED lighting system meets the need of the user can open the scale market of intelligent lighting. Functional lighting for different scenes - road/tunnel lighting, office lighting, home lighting, commercial lighting and building decoration lighting has different functional requirements for intelligent lighting. Consideration should be given to ensuring interconnection between different lighting systems. For the detection, the coordination and unification between each standard shall be realized, including commissioning, verification and reliability of standards.

7.6 Compatibility with other systems

7.6.1 Compatibility between home lighting control system and smart home system

Home lighting control system is a part of smart home. There are corresponding control protocols in the smart home field, such as IGRS and UPnP. Whether the home lighting control system requires the definition of independent control system and connection with home gateway or use smart home control protocols is a matter to be further debated.

7.6.2 Compatibility between professional lighting control system and building automation protocol

Professional lighting control system is a part of building control system. There are corresponding control protocols in the building control field, such as KNX and BACnet. Whether the professional lighting control system requires the definition of independent control system and connection with gateway and building control system or use building control protocols is a matter to be further debated.

7.6.3 Compatibility between outdoor road lighting control system and smart city in the future

LED lighting control system integrates microelectronic technology, sensor technology and LED luminescence technology to realize intelligence and humanization of lighting. In the future, LED will be applied to many fields - energy, information, transportation, life health, livestock and fishery. And the intelligent lighting terminal will be deeply integrated with computers, Internet of Things, cloud computing, mobile Internet and big data to become a necessary component of intelligent city and intelligent society. Compatibility, exchange of data and interaction between LED lighting control system (the subsystem of the intelligent city) and other systems of the intelligent city such as Intelligent Transportation System shall consider the expansibility and ease-of-development of outdoor lighting control system.

8 Standard system planning for LED lighting control system

The overall planning for the standardization system of LED lighting control system is shown in figure 25. The involved standards mainly include:

A. The system scope, framework and basic standard of LED lighting:

- **Terms and definitions** (Central Management System, commissioner, segment controller (gateway), light controller, sensor, driver and LED source of LED lighting).
- **Architecture**: home lighting system, professional lighting system, road lighting system and landscape lighting system.
- **Requirements**: requirements of lighting control system

B. Component standard (power supply, sensor, light controller, segment controller (gateway), commissioner and Central Management System).

C. Interface protocol standards involved in the LED lighting control system

- Interface protocol of application layer of Central Management System.
- Communication protocol and test standard between Central Management System and segment controller (gateway).
- Communication protocol and test standard between segment controller (gateway) and light controller.
- Interface standard and test standard between light controller and driver(control gear).
- Interface standard and test standard between light controller and sensor.
- Interoperation specification with traditional lighting switches and luminaires

D. Standard for design requirements of LED lighting control system.

E. Standard for security requirements of LED lighting control system.

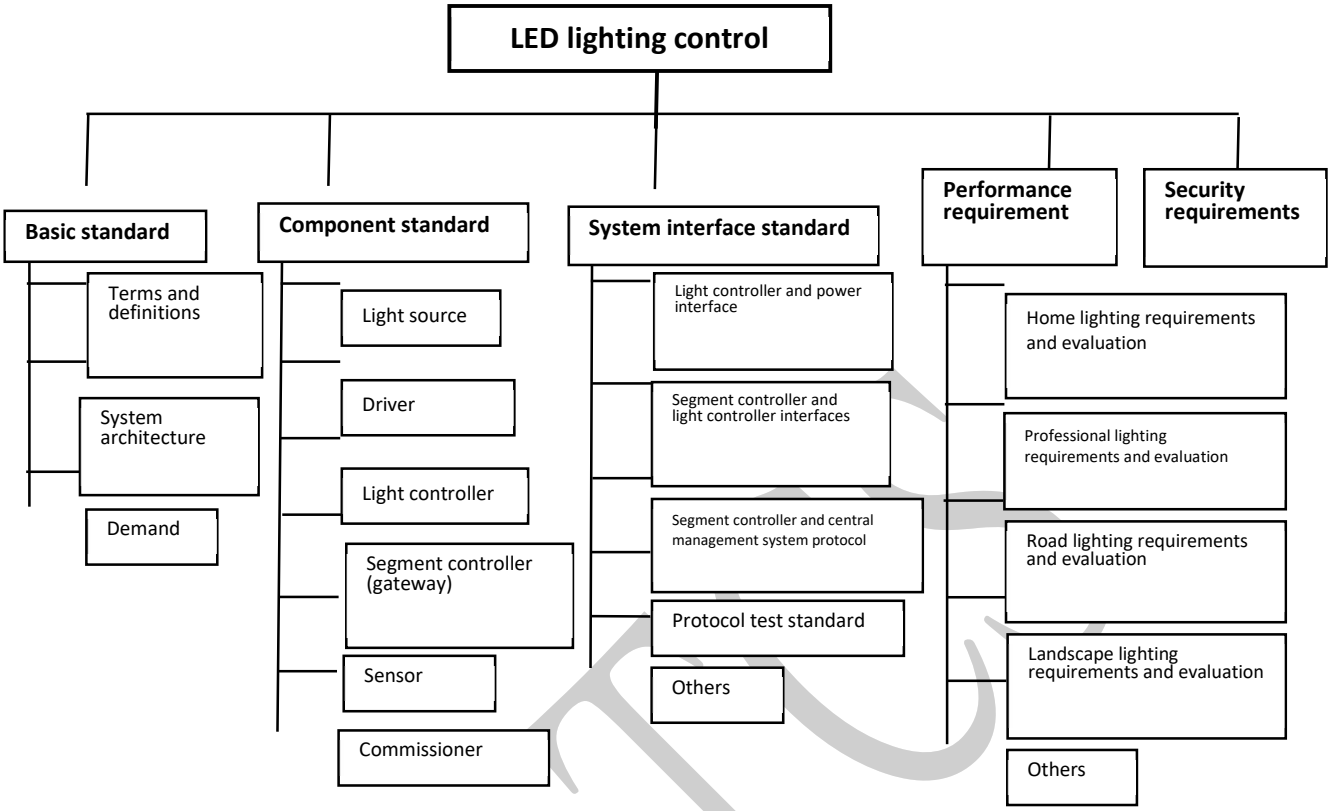


Figure 28 Standard system planning for **LED** lighting control system

Flexibility and controllability of LED lighting realizes the functional diversification of the lighting system. At the same time, the application of LED luminescence technology shows more characteristics than lighting, such as optical communication, health care, plant growth and animal husbandry, making the good prospect of the intelligent lighting industry. Lighting by need is the goal of LED intelligent lighting system. The demand for light requires more research on the design of supporting products for data. Meanwhile, the main technical route of the system is undetermined, and the technical scheme presents the characteristics of personalization and customization. Thus, the standardization and industrial development need to be promoted in a coordinated manner.

The standardization work shall be conducted, including the analysis of existing mainstream technical solutions, sorting of the existing standards, determination of the standardization work contents and making recent and mid-and-long term planning for standardization work. The standard documents urgently needed by the industry shall be developed and rationality, universality and practicability of which shall be ensured, to support the building of industry chains and coordinated development of intelligent lighting field, clear the design and positioning of products, promote the integration of innovative technologies and promote market development & application promotion.

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IEEE802.11 Part 11: Wireless LAN Medium Access Control and Physical Layer (PHY) Specifications

IEEE802.15.1- Part 15.1: Wireless medium access control (MAC) and physical layer (PHY) specifications for wireless personal area networks (WPANs)

IGRS-ISO/IEC 14543-5-x Information technology Home electronic system (HES) architecture

UPnP-ISO/IEC 24752-1 Ed 2.0 Information technology. User interfaces. Universal remote console. Part 1: Framework

IEC 62386-101 ed 2.1 Digital addressable light interface- part 101: General requirement System components

ISO 16484-5 A Data Communication Protocol for Building Automation and Control Networks