

TECHNICAL REPORT



Connectivity for lighting systems

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TECHNICAL REPORT



Connectivity for lighting systems

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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CONNECTIVITY FOR LIGHTING SYSTEMS

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Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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INTRODUCTION

Lighting systems are used in various applications such as indoor lighting (both residential and non-residential), outdoor lighting and emergency lighting. These lighting systems can include functionalities such as lighting monitoring and control, lighting energy management and data collection. There are many communication protocols in the global market. It is important for system designers and integrators to have an understanding of the variety of communication protocols used in lighting systems. By taking into account knowledge and information of other industries, designers can create appropriate systems that integrate lighting and non-lighting performances. Standards and reports referencing communication protocols such as the ISO/IEC 14543 series, the IEC 62386 series and ANSI/IES TM-23-17 exist, but a need for a comprehensive international technical report has been identified.

Technologies of lighting systems are rapidly developing as a result of evolving customer needs and new connectivity technologies. Examples of such systems are smart homes/buildings, smart cities, adaptive roadways and horticultural lighting. The internet of things (IoT) enables the interconnecting of lighting systems. This document provides information and guidance on how lighting systems operate and interconnect with other systems.

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CONNECTIVITY FOR LIGHTING SYSTEMS

1 Scope

This document provides information and guidance on the connectivity aspects of lighting systems to operate and to interconnect with other systems.

This document provides an overview of various connectivity solutions used within lighting systems, including topologies, communication protocols and related embedded functionalities.

This document does not express preference for any specific topology or protocol.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

NOTE Terms and definitions for lighting systems and related equipment are given in IEC TS 63105.

3.1

communication protocol

set of rules for data transmission in a system interlinking several system components

[SOURCE: IEC 60050-351:2013, 351-56-14, modified – The term "protocol" has been replaced by "communication protocol", in the definition "participants" has been replaced by "system components" and the notes to entry have been deleted.]

3.2

open protocol

communication protocol which is publicly available and developed in an open consensus process under the auspices of a recognized organization

[SOURCE: ANSI/IES TM-23-17, 2.14.1, modified – "open protocols are standards that are" has been replaced by "protocol which is" and "typically not-for-profit" has been deleted.]

3.3

proprietary protocol

communication protocol that is not an open protocol

3.4

connectivity

capability of a system or device to communicate to other systems or devices without modification

[SOURCE: ISO/IEC 13066-1:2011, 2.9, modified – "be attached" has been replaced by "communicate".]

4 Topologies, OSI model, physical layers and communication protocols¹

4.1 Topologies

4.1.1 Point-to-point topology

Point-to-point topology is a type of topology where two fixed nodes are connected directly to a single line. This topology is the basic form of a network. See Figure 1.

- Features:
 - This topology is the simplest topology which connects two nodes in the network.
- Examples of use in lighting systems and other systems which can control lighting:
 - Bluetooth®, ECHONET Lite™ (ISO/IEC 14543-4-3) and Ethernet (IEEE 802.3)

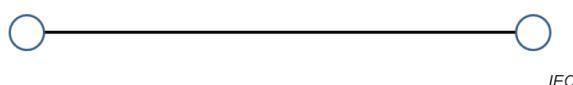


Figure 1 – Point-to-point topology illustration

4.1.2 Bus topology

Bus topology is a type of topology where each node is connected to a single line. This topology is one of the basic forms of a network. See Figure 2.

- Features:
 - A new connection on the bus topology is possible simply by attaching a new node.
 - Small to even relatively large systems can be configured in a relatively economical way.
 - Faults on each node have no effect on other parts of the network. However, failure of the main line will affect the whole network.
- Examples of use in lighting systems and other systems which can control lighting:
 - DALI® (IEC 62386 series), 0-10 VDC, PWM (IEC 60929), KNX® (ISO/IEC 14543-3-10 and ISO/IEC 14543-3-11), BACnet® (ISO 16484-5), LonWorks® (ISO/IEC 14908 series) and ECHONET Lite™ (ISO/IEC 14543-4-3).

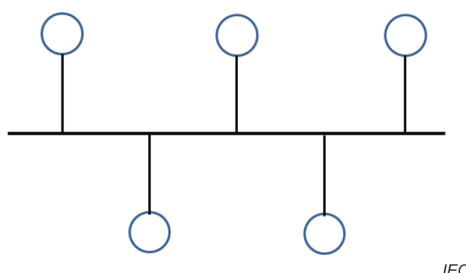


Figure 2 – Bus topology illustration

4.1.3 Daisy chain topology

Daisy chain topology is a type of topology where one node is connected to the next node in the chain. For example, node A is connected to node B and node B connected to node C, and so on. See Figure 3.

¹ The trademarks and trade names mentioned in this document are given for the convenience of users of this document. This information does not constitute an endorsement by IEC of the products named.

- Features:
 - This topology is one of the simplest topologies to add more nodes in the network.
- Examples of use in lighting systems and other systems which can control lighting:
 - DALI® (IEC 62386 series), DMX, BACnet (ISO 16484-5), LonWorks (ISO/IEC 14908 series) and ECHONET Lite (ISO/IEC 14543-4-3) .

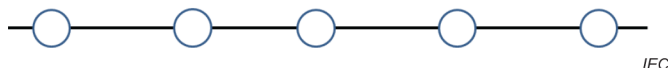


Figure 3 – Daisy chain topology illustration

4.1.4 Ring topology

Ring topology is a type of topology where each node is connected to two adjacent nodes, forming a closed loop or ring shape. See Figure 4.

- Features:
 - This topology, compared to the bus topology, has a longer configuration line. And in the case of a one-way connection, faults on each node will affect the whole network.
- Examples of use in lighting systems and other systems which can control lighting:
 - BACnet (ISO 16484-5), LonWorks (ISO/IEC 14908 series) and ECHONET Lite (ISO/IEC 14543-4-3).

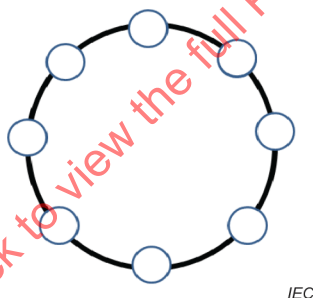


Figure 4 – Ring topology illustration

4.1.5 Star topology

Star topology is a type of topology where each node is connected to one central node and where the central node has the responsibility of managing the whole network. A star topology can be used for wired and wireless connections. See Figure 5.

- Features:
 - This topology is one of the most popular topologies for a local area network. In the event of a fault on a specific node, the remaining nodes in the network will function normally. However, a fault on the central node can affect the whole network.
- Examples of use in lighting systems and other systems which can control lighting:
 - DALI® (IEC 62386 series), KNX (ISO/IEC 14543-3-10 and ISO/IEC 14543-3-11), BACnet (ISO 16484-5), ECHONET Lite (ISO/IEC 14543-4-3), LonWorks (ISO/IEC 14908 series), Ethernet (IEEE 802.3) and Wi-Fi™.

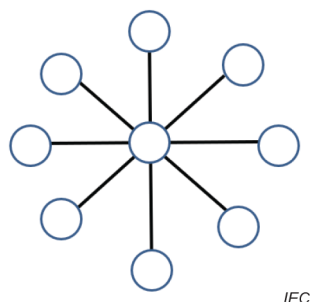


Figure 5 – Star topology illustration

4.1.6 Mesh topology

Mesh topology is a type of topology where every node in the network is connected to all other nodes. Mesh topology is mainly used in wireless technology having logical connections instead of direct physical connections. See Figure 6.

- Features:
 - This topology, compared to the star topology, can be less efficient and less economical. But since all nodes in the network are linked to others like a net, faults on any node will have no effect on other parts of the network.
- Examples of use in lighting systems and other systems which can control lighting:
 - ECHONET Lite (ISO/IEC 14543-4-3), Zigbee®, Bluetooth® mesh, Z-wave®, Thread®, EnOcean® (ISO/IEC 14543-3-10 and ISO/IEC 14543-3-11), IEEE 802.15.4 and VEmesh®.

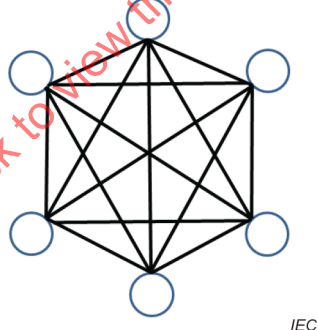


Figure 6 – Mesh topology illustration

4.1.7 Hybrid topology

Hybrid topology combines two or more of the topologies described in 4.1.1 to 4.1.6. See Figure 7.

- Features:
 - This topology is used to maximize the benefits of different network topologies in certain environments. Combined star and ring topologies and star and bus topologies are examples of hybrid topology.
- Examples of use in lighting systems and other systems which can control lighting:
 - DALI® (IEC 62386 series), 0-10 VDC (IEC 60929), KNX (ISO/IEC 14543-3-10 and ISO/IEC 14543-3-11), BACnet (ISO 16484-5), LonWorks (ISO/IEC 14908 series) and ECHONET Lite (ISO/IEC 14543-4-3).

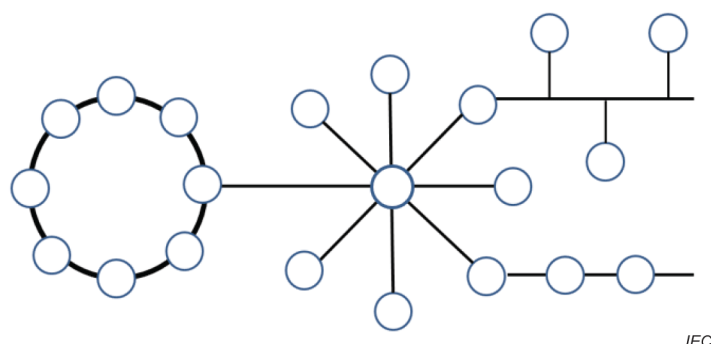


Figure 7 – Hybrid topology illustration

4.2 Open systems interconnection (OSI) model

4.2.1 Layer 1: physical layer

The physical layer provides the mechanical, electrical, functional and procedural means to activate, maintain and de-activate physical connections.

4.2.2 Layer 2: data link layer

The data link layer provides functional and procedural means for the connectionless mode among network entities and for the connection mode for the establishment, maintenance and release of data link connections.

4.2.3 Layer 3: network layer

The network layer provides the means to establish, maintain and terminate network connections between open systems containing communicating application entities and the functional and procedural means to exchange network service data units between transport entities over network connections.

4.2.4 Layer 4: transport layer

The transport layer provides the functional and procedural means of transferring transparent data between session entities and relieves them from any concern with the detailed way in which reliable and cost-effective transfer of data is achieved.

4.2.5 Layer 5: session layer

The session layer provides the means necessary for cooperating presentation entities to organize and synchronize their dialogue and to manage their data exchange. To do this, the session layer provides services to establish a session connection between two presentation entities.

4.2.6 Layer 6: presentation layer

The presentation layer provides for the representation of information that application entities either communicate or refer to in their communication. It also provides for common representation of the data transferred between application entities.

4.2.7 Layer 7: application layer

The application layer provides the sole means for the application process to access the open system interconnection environment. Hence the application layer has no boundary with a higher layer as shown in Table 1.

Table 1 – Seven-layer OSI model

Layer	Name
7	Application layer
6	Presentation layer
5	Session layer
4	Transport layer
3	Network layer
2	Data link layer
1	Physical layer

4.3 Lower layers

4.3.1 General

Lower layers are the subsection from the physical layer to the transport layer in the OSI model in Table 1.

4.3.2 IEEE 802.3 (10BASE-T, 100BASE-T and 1000BASE-T Ethernet)

Ethernet is a point-to-point topology based lower layer that especially applies to local area network (LAN) technology. It was adopted as the IEEE 802.3 standard and commercialized in the 1980s. Ethernet is the common physical layer for wired internet networks.

– Features:

- Depending on the maximum transmission speed, it is classified as legacy Ethernet, fast Ethernet and gigabit Ethernet, with each maximum transmission speed of 10 Mb/s, 100 Mb/s and 1 Gb/s, respectively.
- Ethernet uses the carrier sense multiple access with collision detection (CSMA/CD) method for data transmission. First, the availability of the network is checked to determine whether the network is in use or not. Data is transmitted only when the network is available. If the network is in use, the transmitter will wait a certain amount of time and then try again.

– Examples of use in lighting systems and other systems which can control lighting:

- Common use cases of Ethernet are for commercial wired lighting systems including indoor applications such as communication towards central controller(s) (backbone), connections to other building systems and stage lighting applications with streaming CAN (sACN), Art-Net.
- Communication wiring is also used for powering, by combining data and power in the same wires. The Ethernet standard has been extended with powering up to 90 W (IEEE Std 802.3bt) and includes powering using Ethernet: "Power over Ethernet" (PoE). This is also used in some lighting systems for easy connection and high data rate.

4.3.3 IEEE 802.11 (wireless local area network (WLAN), Wi-Fi)

IEEE 802.11 is a lower layer dedicated to the wireless local area network (WLAN). It primarily uses a frequency of 2,4 GHz or 5 GHz for communications. The Wi-Fi alliance certifies specific implementations of the IEEE 802.11 standard in order to facilitate interoperability between devices. Wi-Fi is an example of a star topology with the possibility to connect several stars in one network.

– Features:

- Wi-Fi allows users to use high-speed communication within a certain distance, where a wireless access point (AP) is installed. Because it uses wireless frequencies as a medium, it has the advantage of being able to build an infrastructure that is easy to deploy and highly scalable.
- Initially, Wi-Fi was limited to products developed based on the IEEE 802.11b standard in the 2,4 GHz band with a data rate up to 10 Mb/s. The IEEE 802.11ax standard expanded this frequency range to include the 5 GHz band. The sixth generation Wi-Fi, which was adopted in 2019, provides a data rate up to 1 Gb/s.

– Examples of use in lighting systems and other systems which can control lighting:

- Common use cases of Wi-Fi include commercial and residential wireless lighting systems. Indoor applications such as office and home lighting as well as outdoor applications within a medium distance range are also common.

4.3.4 IEEE 802.15.1 (low-rate wireless personal area network (LR-WPAN), Bluetooth)

Bluetooth is a multi-topology (point-to-multipoint and mesh) generally used as a wireless solution for short-range, low-cost and low-power applications using a 2,4 GHz frequency.

– Features:

- Bluetooth technology can be categorized into Bluetooth Basic Rate (BR)/Enhanced Data Rate (EDR) and Bluetooth Low Energy (LE).
- Bluetooth LE was introduced in version 4.0 of the Bluetooth core specification in 2010 to address the requirements of lower power consumption, complexity and cost compared to BR/EDR.
- Bluetooth Mesh is a full-stack wireless mesh technology which provides mesh networking (i.e. Mesh Profile) using Bluetooth LE and defines interoperable application layer functionalities (i.e. Mesh models), including support for lighting applications. It was released in 2017.
- With version 5.0 of the Bluetooth core specification, which was released in 2016, data rates and communication range can be traded off flexibly.

– Examples of use in lighting systems and other systems which can control lighting:

- Common use cases of Bluetooth are for commercial and residential wireless lighting systems including indoor applications such as office and home lighting applications within a short distance range. Bluetooth technology also enables additional applications such as indoor asset tracking and indoor positioning which can leverage the indoor lighting infrastructure.
- Bluetooth technology defines multiple methods to estimate the location among communicating devices. With version 5.1 of the Bluetooth core specification, it is possible to determine the direction from which a received signal was transmitted from another Bluetooth device.

4.3.5 IEEE 802.15.4 (low-rate wireless personal area network (LR-WPAN), ZigBee and Thread)

IEEE 802.15.4 is another type of LR-WPAN. It is the basis for the various LR-WPAN based technologies such as Zigbee, SNAP, Thread and Wi-Sun specifications.

IEEE 802.15.4 is commonly used for low-speed, low-cost, low-power wireless networks in home networks and wireless sensor networks based on two-way LR-WPAN. IEEE 802.15.4 operates in the 2,4 GHz frequency band, the industrial scientific medical (ISM) band, in most parts of the world, but also uses 868 MHz (Europe) and 915 MHz (North America) frequencies to avoid interference with wireless technologies that use the same frequency band, such as Wi-Fi and Bluetooth. The modulation method is a direct sequence spread spectrum (DS-SS) method and the normal data transfer rate is between 20 kb/s and 250 kb/s.

– Features:

- IEEE 802.15.4 was originally designed for periodic or intermittent data transmission or for simple signal transmission, such as sensors and input devices.
- IEEE 802.15.4 was designed to target relatively simpler and lighter technologies compared to other WPAN technologies such as Bluetooth and Wi-Fi.
- Applications include wireless lighting switches, in-house power meters, traffic management systems and other personal and industrial devices that require near-field low-speed communication.

– Examples of use in lighting systems and other systems which can control lighting:

- Common use cases of IEEE 802.15.4 are for small commercial and residential wireless lighting systems including indoor applications such as office and home lighting applications within a short distance range.

4.3.6 IEC 62943 (VLC and Li-Fi, IEEE 802.15.7)

Visible light communication (VLC) is a kind of communication technology using modulated light sources. The communication signals are not perceived by the human eyes. VLC can provide both lighting and communication simultaneously. Light Fidelity (Li-Fi) is a solution for high data rate communication using LEDs.

Visible light communication (VLC) technology provides new application possibilities to the lighting industry. For location applications there are several indoor positioning systems and protocols using low data rate (up to kb/s). For communication applications, high speed communication systems using photo diode (PD) receivers (Mb/s or Gb/s) and several protocols including Li-Fi exist.

– Features:

- IEC 62943 is a VLC standard for an indoor positioning system using the photodetector receiver or the image sensor of smart phones. This standard defines a transmitting signal waveform format (I-4PPM) from luminaires as identifiers (ID). The receiver (smart phone) can easily detect and connect to a network or cloud system, then deliver related information with the ID to customers or users.

– Examples of use in lighting systems and other systems which can control lighting:

- VLC technologies are used with systems connected to the cloud or other big systems for positioning or communication services. Protocols of VLC systems usually transfer IDs or signals to special data or commands for other systems.

4.4 Communication protocols

4.4.1 BACnet

BACnet is a protocol for building automation and control systems (BACS) specified in ISO 16484-5. By defining multiple transmission networks so that different products can work together, it provides more flexibility in system deployment, enabling seamless communication between different products.

BACnet specifies a standard model for interaction between building automatic control systems and various control devices. BACnet has the following characteristics:

- 1) data and functionality structured in object form;
- 2) services that address the transmission and reception of data;
- 3) network data link layer;
- 4) structure of building automatic control network.

- Features:
 - Various types of data link and layers can be defined in the BACNet protocol.
 - Up to 18 object definitions, expression and sharing of data through objects and 32 services in 5 categories (data sharing, alarms and events, scheduling, trending and device management) are described in BACNet.
 - Multi-topologies such as daisy chain, star and hybrid topology can be structured with wired physical layers such as twisted pair and optical fibres.
- Examples of use in lighting systems and other systems which can control lighting:
 - Common use cases of BACNet include commercial building automation systems, building management systems (BMS) and energy management systems (EMS) such as networked lighting systems and automated HVAC systems. In general cases, the connected lighting system transmits data using the BACNet protocol to connect to the higher EMS/BMS system.

4.4.2 IEC 62386 (digital addressable lighting interface, DALI®)

IEC 62386 is a dedicated protocol for digital lighting control that enables the easy installation of robust, scalable and flexible lighting networks and is specified in the IEC 62386 series.

The Digital Illumination Interface Alliance (DiiA) also known as the DALI Alliance manages the specification, certification and promotion of the digital addressable lighting interface. It cooperates with IEC to manage the IEC 62386 series. The IEC 62386 protocol is designed for lighting control in all applications. The IEC 62386 series was restructured and updated in late 2014 and many improvements were made. New features are continuously added by IEC TC 34 and are published as new parts of the IEC 62386 series. The certification of the digital addressable lighting interface implemented in products is managed by the DALI Alliance. The DALI Alliance distinguishes between two applications:

- network between luminaires based on the DALI-2 certification program;
- network within a luminaire, based on the D4i certification program.

The digital addressable lighting interface has specific standards for various types of control gear and features of control gear (e.g. dimming, emergency) in the IEC 62386-2xx series and for various input devices (e.g. sensors, signal switches) in the IEC 62386-3xx series. IEC 62386-101 contains general requirements for basic system components. IEC 62386-104 extends the requirements to wireless and alternative wired system components.

- Features:
 - The wires of the digital addressable lighting interface communication protocol (Part 101) transport the digital information but can also be used to power devices requiring very small amounts of power, such as a sensor.
 - A digital addressable lighting interface network is limited to 64 control gear and 64 input devices. This limitation does not hamper use in buildings with thousands of luminaires, since the total lighting control network can be split in multiple networks of up to 64 luminaires.
 - Each device which supports a digital addressable lighting interface can be assigned a separate address, allowing digital control of individual devices. Furthermore, these devices can also be programmed to operate in groups.
 - Energy reporting and diagnostics functions are available.
 - Digital addressable lighting interfaces can be configured generally with bus, star and hybrid topologies up to 300 m using normal mains wiring, so no special communication wiring is needed.
- Examples of use in lighting systems and other systems which can control lighting:
 - Common use cases of digital addressable lighting interfaces are for commercial and residential lighting systems including indoor applications such as office and home lighting with a wired digital network.

4.4.3 DMX 512 (digital multiple X) and RDM (remote device management)

DMX 512 is a dedicated protocol for digital communication networks especially for stage lighting. Remote device management (RDM) is an extension of DMX 512 with bidirectional function.

The DMX 512 protocol allocates 8-bit pulses for control of one lighting device. DMX 512 can control up to 512 lighting devices at a time.

The RDM protocol was developed to efficiently manage lighting devices with more diverse functions in DMX 512 based lighting networks as the performance of lighting devices improved.

Although RDM is a control protocol that operates on a traditional DMX 512, there are some significant differences from the DMX 512 protocol. While DMX 512 uses one-way communication, the RDM uses two-way communication to send control messages from the controller to the lighting device and then receive response messages. In order to avoid overlapping messages that could be caused by two-way communication, RDM has applied a polling system that allows only controllers to initiate message transmission.

– Features:

- For effective control of lighting devices, the RDM protocol supports configuration, monitors and manages functions, including the functions of lighting device discovery that were not supported by the existing DMX 512.

– Examples of use in lighting systems and other systems which can control lighting:

- Common use cases of DMX and RDM are for specific lighting systems including indoor stage lighting applications and outdoor architectural lighting.

4.4.4 Zigbee and Dotdot

4.4.4.1 Zigbee

Zigbee technology, developed by the Connectivity Standards Alliance (CSA, formerly known as the Zigbee Alliance) is commonly used for low-speed, low-cost, low-power wireless networks for consumer and building automation and wireless sensor networks based on two-way communication. Zigbee operates in the 2,4 GHz frequency band, the industrial scientific medical band (ISM), in most parts of the world, but can also be used over 868 MHz (Europe) and 915 MHz (North America) frequencies to avoid interference with wireless technologies that use the same frequency band, such as Wi-Fi and Bluetooth. The modulation method is a direct sequence spread spectrum (DS-SS) method and the data transfer rates are between 20 kb/s and 250 kb/s.

Zigbee technology defines the network layer on top of the IEEE 802.15.4 radio, which enables multi-hop unicast, group and broadcast communication in various topologies (point-to-point, star and mesh). It further defines network commissioning, network management (devices and service discovery) and rich application definitions through its Dotdot specification.

Zigbee was first released in 2004, with application focus on lighting, home and building automation. In 2011, the Zigbee Green Power protocol was added, allowing for integration of ultra-low power, including energy-harvesting (battery-less), sensors, switches and controls. In 2016, Zigbee 3.0 was released, providing unified device definitions and configuration methods.

– Features:

- Zigbee was originally designed for periodic or intermittent data transmission or for simple signal transmission, such as sensors and input devices.
- Zigbee was designed to target relatively simpler and lighter technologies compared to other wireless connectivity technologies such as Bluetooth and Wi-Fi.

- Applications include wireless lighting control systems (including sensors, switches and light state monitoring), heating, ventilation and air conditioning (HVAC), safety and security systems (including door/window sensors), window covering solutions, in-house power meters enabling energy management use cases, traffic management systems and other personal and industrial applications that require short-range low-speed communication.
- Examples of use in lighting systems and other systems which can control lighting:
 - Common use cases of Zigbee are for small and medium size (up to several hundred devices) commercial and residential wireless lighting systems including indoor applications such as office and home lighting applications within a short distance range.

4.4.4.2 Dotdot

Dotdot is an application protocol for smart objects. It was originally developed by the Connectivity Standards Alliance (CSA, formerly known as the Zigbee Alliance) as the Zigbee Cluster Library, for use in Zigbee networks. Each cluster focuses on one application scope, for example on/off control, level control, colour control, occupancy sensing, energy metering, intruder alarm systems, diagnostics and defines a dedicated set of commands and attributes as well as the related device behaviour. This allows, for example, occupancy or illuminance sensors of one vendor to control the light level of lighting devices of another vendor.

The Dotdot protocol can be used over network technologies other than Zigbee. Currently, the Dotdot application layer is being specified as part of the Matter standard (formerly known as Project Connected Home over Internet Protocol, also known as Project CHIP) within the Connectivity Standards Alliance (formerly Zigbee Alliance), which is expected to enable its usage over Thread, Wi-Fi and Ethernet.

- Features:
 - common protocol as the universal language of the IoT devices to communicate with other devices over various networks;
 - easy implementation using the Zigbee Cluster Library (ZCL, common data model) on Zigbee, and soon also over Wi-Fi, Thread and Ethernet based platforms as part of Matter.
- Examples of use in lighting systems and other systems which can control lighting:
 - Common use cases of Dotdot provide a common data model for various devices in lighting systems, including integration with home and building automation, security and safety systems and energy management systems.

4.4.5 ECHONET Lite

ECHONET Lite is a protocol for a reliable, low-cost home network that requires no new wiring and can be installed in existing homes. Lighting device objects of ECHONET Lite are specified in IEC 62394 and communication middleware is defined in ISO/IEC 14543-4-3.

ECHONET Lite has the following characteristics:

- 1) communications protocol for a reliable, low-cost home network that requires no new wiring and can be installed in existing homes;
- 2) multivendor-compatible home network equipment;
- 3) system models for use by individual vendors to facilitate the development of application systems;
- 4) communications middleware and development support tools to mitigate the burden on equipment developers;
- 5) application service-compatible middleware to facilitate the development of applications required for energy conservation.

- Features:
 - object-oriented modelling of system configuration;
 - open network architecture to develop and commercialize communication drivers, middleware and peripherals complying with the ECHONET Lite protocol;
 - achieving a multi-vendor environment through common specifications and enabling the interconnection and control of equipment from different vendors;
 - compatible with a wide range of equipment, such as residential equipment and devices for small- and medium-sized buildings and stores;
 - possibility of using different types of existing standard transmission media.
- Examples of use in lighting systems and other systems which can control lighting:
 - Common use cases of ECHONET Lite are for five lighting classes for controlling luminaires and lighting systems: mono functional lighting class, general lighting class, lighting system class, extended lighting system class and solid state lighting class.

4.4.6 EnOcean

EnOcean is a protocol for building networks based on self-powered (battery-free) wireless switches, sensors and controls. It is focused on promoting interoperability, maintenance-free and validated environmental systems based on the EnOcean standard (ISO/IEC 14543-3-10 and ISO/IEC 14543-3-11).

The EnOcean protocol offers the benefits of a broad and established ecosystem of interoperable self-powered wireless sensors available in smart homes and intelligent buildings. It ensures that sensors, switches and controls from one manufacturer can communicate with the receiver gateways from another manufacturer. It also includes a network of sensors that draw energy from the periphery using energy collection techniques such as motion, light or temperature differences. This principle enables the use of electronic control systems that operate independently of external power supplies.

- Features:
 - worldwide wireless protocol using the 1 GHz frequency band which is license free; 868 MHz for Europe and China, 902 MHz for North America and 928 MHz for Japan;
 - up to 30 m coverage in indoor applications without batteries or other power sources due to kinetic and thermal energy-harvesting techniques such as solar cells, making it economical to use and environmentally friendly;
 - standardized sensor profiles to ensure product interoperability;
 - low energy requirements and optimization for self-powered sensors and switches with data rate up to 125 kb/s.
- Examples of use in lighting systems and other systems which can control lighting:
 - Common use cases of EnOcean are for indoor lighting systems including building automation, smart homes and IoT networks.

4.4.7 KNX

KNX is a protocol for networked building automation systems. It provides local system communication and serves as a backbone between system level devices. It is specified in ISO/IEC 14543-3-10 and ISO/IEC 14543-3-11.

KNX is focused on building management and automation such as HVAC, lighting, security systems and monitoring systems via both wireless and wired physical layers, for example power line communication (PLC) up to a data rate of 1,2 kb/s with a carrier frequency of 110 kHz, radio frequency communication at 868,3 MHz or IP based Ethernet platforms.

– Features:

- KNX is a dedicated protocol for residential and commercial building automation for HVAC, lighting, security, remote access, blind and shutter control, visualization and energy management.
- Multi-topologies such as tree, bus, star and hybrid topologies can be structured with wired physical layers such as power line (KNX PL), twisted pair (KNX TP) and IP based Ethernet platform (KNXnet/IP).
- KNX can also work with other protocols via gateways.

– Examples of use in lighting systems and other systems which can control lighting:

- Common use cases of KNX are for residential and commercial lighting systems. It can be used for building automation that combines functions such as HVAC, security, remote access, blind and shutter control systems.

4.4.8 LonWorks

LonWorks (local operating network) is a protocol for building automation including lighting and HVAC systems. It is specified in ISO/IEC 14908-2 and supported by LonMark International, an independent consortium of manufacturers.

Devices with the LonWorks protocol are used for lighting and HVAC systems, but can also be used for many other applications such as transportation, utilities, process control and home automation.

– Features:

- LonWorks is a dedicated protocol for residential and commercial building automation with a simple installation.
- Multi-topologies such as daisy chain, star and hybrid topologies can be structured with wired physical layers such as power line and twisted pair platform.

– Examples of use in lighting systems and other systems which can control lighting:

- Common use cases of LonWorks are for residential and commercial lighting systems as well as for building and home automation having other HVAC and control systems.

4.4.9 0-10 VDC

0-10 VDC (current source) is an analog control method having a current source and a control voltage in the nominal range from 0 V to 10 V used for dimming light sources. It is specified in IEC 63128.

4.4.10 PWM (pulse width modulation)

PWM is a popular method for controlling the light output of lighting equipment. Control by pulse width modulation (PWM) is described in IEC 60929:2011, Clause E.3. The PWM method uses current pulses of varying duration, frequency and amplitude to control the output of the light source.

In recent times, PWM control based on IEC 60929 has been applied to LED lighting systems. The light output waveform of an LED light source is generated using the same shape of PWM as the input signal waveform for control gear.

Horticultural lighting is an emerging application for the lighting industry. In the horticultural field, PWM control is used because it is easy to connect a lighting controller to the main controller for coordinated control of multiple systems (e.g. lighting, air conditioner, shade). In this application, both LED light sources and discharge lamps are used to benefit plants.

- Features:
 - Dimming characteristics are easily controlled by pulse width modulation.
 - Dimming with minimal spectral change is a benefit of PWM control since only the pulse width and not the amplitude is altered to reduce the light source output.
- Examples of use in lighting systems and other systems which can control lighting:
 - Common use cases of PWM are for residential, commercial and horticultural lighting systems.

5 Examples of lighting systems and other systems which can control lighting

5.1 Typical OSI model layers for lighting systems

Communication protocols for lighting systems support various layers in the OSI model (see 4.2). Table 2 shows the typical OSI model layers of such lighting systems along with specific supporting communication protocols.

Table 2 – Typical OSI model layers for lighting systems and other systems which can control lighting

OSI model layer	Subclause	Supported communication protocol									
Layer 7: Application layer	4.2.7	ECHONET Lite	BACnet	Bluetooth	Zigbee	Doddot	DALI®	KNX	Ethernet	PLC	
Layer 6: Presentation layer	4.2.6										
Layer 5: Session layer	4.2.5										
Layer 4: Transport layer	4.2.4					Vemesh					
Layer 3: Network layer	4.2.3										
Layer 2: Data Link layer	4.2.2										
Layer 1: Physical layer	4.2.1					Wi-Fi					

5.2 Typical communication protocols for lighting systems

The selection of communication protocols for specific systems and functions depends on its characteristics. Useful communication protocols for lighting systems and other systems which can control lighting are presented in 4.4. Table 3 summarizes the typical communication protocols for specific use cases in lighting systems.