FORMAT FOR SENDING COMMENTS ON THE DOCUMENT

[Please use A4 size sheet of paper only and type within fields indicated. Comments on each clause/sub-clause/ table/figure, etc, be stated on a fresh row. Information/comments should include reasons for comments, technical references and suggestions for modified wordings of the clause. **Comments through e-mail in MS WORD format to eetd@bis.gov.in shall be appreciated.**]

Doc. No.: ETD 49 ( ) **BIS Letter Ref:** ETD 49/T **Dated:**

Title: Draft National Lighting Code of India: Part 12 Indoor Connected and IoT Based Lighting

[First Revision of SP 72 (Part 12]

Name of the Commentator/ Organization: ______________________________________

Part 12 INDOOR CONNECTED AND IOT BASED LIGHTING		
Clause No. with Para No. or Table No. or Figure No. commented (as applicable)	**Comments / Modified Wordings**	**Justification of Proposed Change**

Draft for comments only **Doc: ETD 49 (26462) P**

August 2024

BUREAU OF INDIAN STANDARDS

DRAFT FOR COMMENTS ONLY

Draft NATIONAL LIGHTING CODE OF INDIA

PART 12 Indoor Connected and IoT Based Lighting

[First Revision of SP 72 (Part 12)]

Illumination Engineering and Luminaries Sectional Committee, ETD 49

Last Date for Comments:29 September 2024

FOREWORD

Smart lighting refers to lighting equipment that incorporates intelligence and connectivity. These systems feature smart luminaires equipped with microcontrollers and sensors, which are interconnected via wired or wireless communication. This setup allows for both control and monitoring of the lighting, enabling devices to send and receive data. The user interface for smart lighting goes beyond traditional switches, incorporating mobile apps, virtual assistants, voice activation, and portable interfaces such as remote consoles

Smart lighting networks utilize various protocols for communication. Traditional wired protocols include 0-10V DC, DALI, and DMX. Ethernet cables are now employed for both power and data transmission through Power over Ethernet (PoE), eliminating the need for separate power cables.

Wireless protocols in smart lighting systems include Zigbee, WiFi, and Bluetooth Mesh, with hybrid systems that combine multiple wireless protocols also emerging. Industry experts anticipate a shift toward wireless smart lighting due to its enhanced ability to integrate with other devices on similar platforms and its simpler installation and maintenance. Future developments are expected to extend beyond lighting quantity and quality, with devices wirelessly connected to numerous other devices and sensors, creating a fully integrated smart system.

Wireless technology is continually evolving, with future versions expected to address current challenges such as obstructions and operating range limitations, and enhance interoperability.

Digital and wireless smart lighting systems are pivotal to the Internet of Things (IoT) in lighting. The vast amount of data collected from connected lighting systems will provide valuable insights into activity and space utilization patterns. This will enable scheduled maintenance and replacements, ensuring greater efficiency. Additionally, these systems can adapt to human moods and behaviors, aligning with functional activities and responding to seasonal or daily weather variations.

1 SCOPE

This part outlines the current smart lighting platforms which are the cornerstone of smart connected system, both wired and wireless for indoor space.

However, more emphasis will be given on Wireless Control System as this subject is an emerging topic and new technologies and system being introduced at great speed.

As a disclaimer, with rapid advancement in wireless digital communication, many features which seem impossible and difficult now, may be easily implementable in near and foreseeable future and some platforms may be rendered obsolete.

2 NORMATIVE REFERENCES

IS Number	*Title*
IEEE 802.15.4: 2020	IEEE Standard for Low-Rate Wireless Networks
IEEE 802.3: 2018	Ethernet Working Group
IECC 2018	International Energy Conservation Code (IECC)

Y. Akashi and J. Neches, "Detectability and acceptability of. illuminance reduction for load shedding," Journal of Illuminating Engineering Society, Vol. 33, No. 1, pp. 3– 13, 2004

Lopez-de-Teruel, Pedro E.; Garcia, Felix J.; Canovas, Oscar; Gonzalez, Ruben; Carrasco, Jose A Human behaviour monitoring using a passive indoor positioning system: a case study in a SME (December 2017)

Curran, Kevin; Furey, Eoghan; Lunney, Tom; Santos, Jose; Woods, Derek; McCaughey, Aiden (2011). "An Evaluation of Indoor Location Determination Technologies"

3 TERMINOLOGY

3.1 Lighting Control System

A network based lighting control solution that incorporates communication between various system inputs and outputs related to lighting control with the use of one or more central computing devices

3.2 Smart Lights

Equipment that has an element of intelligence or connectivity to it.

3.3 IoT

Internet of Things refers to the ever-growing network of physical objects that feature an IP address for internet connectivity, and the communication that occurs between these objects and other Internet-enabled devices and systems.

3.4 Dimmer

A device to control intensity of light emitted by a light fitting, by controlling its input voltage or current.

3.5 Analogue Dimming

A dc voltage is sent to the driver, which dims the LEDs in response to the voltage.

3.6 Digital Dimming

Driver receives a digital signal which tells it how to respond. The advantage of digital dimming is that fixtures are addressable.

3.7 Occupancy Sensor

Motion detecting device used to detect the presence of a person to automatically control lights or temperature or ventilation systems

3.8 Communication Protocol

A standard set of rules that allow two or more entities of a communications system to transmit information via any kind of variation of a physical quantity

3.9 Wireless Communication

Transfer of information or power between two or more points that are not connected by an electrical conductor. The most common wireless technologies use radio waves. Zigbee.

3.10 0–10 V Dimming

One of the earliest and simplest electronic lighting control signaling systems; simply put, the control signal is a DC voltage that varies between zero and ten volts.

3.11 Digital Addressable Lighting Interface (DALI)

Trademark for network-based systems that control lighting in building automation. The underlying technology was established by a consortium of lighting equipment manufacturers as a successor for 0–10 lighting control systems.

3.12 Digital Serial Interface (DSI)

A protocol for the controlling of lighting in buildings (initially electrical ballasts). It is based on Manchester-coded 8-bit protocol, data rate of 1200 baud, 1 start bit, 8 data bits (dimming value), 4 stop bits, and is the basis of the more sophisticated protocol Digital Addressable Lighting Interface (DALI).

3.13 DMX512 (Digital Multiplex)

Standard for digital communication networks that are commonly used to control stage lighting and effects.

3.14 Protocol

A standard set of rules that allow electronic devices to communicate with each other. These rules include what type of data may be transmitted, what commands are used to send and receive data, and how data transfers are confirmed. It can be thought as a spoken language.

3.15 WiFI

A facility allowing computers, smartphones, or other devices to connect to the internet or communicate with one another wirelessly within a particular area.

3.16 Bluetooth Low Energy (BLE)

Bluetooth Low Energy is a wireless technology standard for exchanging data between fixed and mobile devices using short-wavelength UHF radio waves

3.17 Bluetooth Mesh

Bluetooth Mesh is a computer mesh networking standard based on Bluetooth Low Energy that allows for many-to-many communication over Bluetooth radio. The Bluetooth Mesh specifications were defined in the Mesh Profile and Mesh Model specifications by the Bluetooth Special Interest Group (Bluetooth SIG).

3.18 Zigbee

Zigbee is an IEEE 802.15.4 based specification for a set of high-level communication protocols used to create personal area networks with small, low-power digital radios, such as for home automation, medical device data collection, and other low-power low-bandwidth needs, designed for small scale project.

3.19 App

A mobile application, also referred to as a mobile app or simply an app, is a computer program or software application designed to run on a mobile device such as a phone, tablet, or watch. Apps are generally downloaded from application distribution platforms which are operated by the owner of the mobile operating system, such as the App Store (iOS) or Google Play Store.

3.20 UI

The user interface (UI), in the industrial design field of human–computer interaction, is the space where interactions between humans and machines occur. The goal of this interaction is to allow effective operation and control of the machine from the human end, whilst the machine simultaneously feeds back information that aids the operators' decision-making process A mobile user interface (mobile UI**)** is the graphical and usually touch-sensitive display on a mobile device, such as a smartphone or tablet, that allows the user to interact with the device's apps, features, content and functions.

3.21 Cloud Database

It is a database service built and accessed through a cloud platform. It serves many of the same functions as a traditional database with the added flexibility of cloud computing

3.22Cloud Platform

The hardware and operating environment of a server in an Internet-based datacenter. The software infrastructure for a cloud computing service, which includes applications that let users create and manage their own accounts. Top Cloud Platforms and Solutions are Amazon Web Services: Amazon Web Services (AWS), Google Cloud Platform, Microsoft Azure etc

3.23 OTA

Over-the-Air programming (OTA) refers to various wireless methods of distributing new software, configuration settings, and even updating encryption keys to devices like cellphones, set-top boxes or secure voice communication equipment (encrypted 2-way radios). One important feature of OTA is that one central location can send an update to all the users, who are unable to refuse, defeat, or alter that update, and that the update applies immediately to everyone on the channel. A user could "refuse" OTA but the "channel manager" could also "kick them off" the channel automatically.

3.24 TCP/IP

It stands for Transmission Control Protocol/Internet Protocol, which is a set of networking protocols that allows two or more computers to communicate.

3.25 API

An application program interface is a set of routines, protocols, and tools for building software applications. Basically, an API specifies how software components should interact. Additionally, APIs are used when programming graphical user interface (GUI) components.

3 LIGHTING CONTROLS AND DIMMING PROTOCOLS

LEDs are low-voltage devices that allow current to pass in one direction only. AC mains supply has to be transformed to low voltage and then rectified into a DC supply. The voltage current characteristic of solid-state light sources is exponential in the area of operation. It means that small fluctuations in supply voltage cause large variations in current which can damage the light source. LEDs can be dimmed over a broad range by reducing the drive current (analogue dimming) or by pulse width modulation (PWM dimming). Dimming individual LEDs of multicolour LED systems permits for smart colour changing. This may also be applied for dynamic changing of the colour temperature from cool white to warm white as proposed in the context of non-visual biological effects of lighting (human-centric lighting).

In LEDs, dimming results in lower chip and junction temperature thereby having a positive impact on lifetime.

4.1 Analogue Dimming

As this method if dimming reduces the drive current, There may be noticeable changes in color temperature during deep dimming condition. Analog dimming has slower response times but results in lower electromagnetic interference. Additionally, luminous efficacy remains favorable during dimming. In well-designed products, LED efficacy can increase by up to approximately 60% at 10% power.

4.2 PWM Dimming

This is popular form of dimming in LEDs. This form of dimming turn the LED on and off rapidly, thus reducing the "on time" to achieve the desired dimming level. The frequency of dimming can influence whether the lamp exhibits noticeable flicker. Using phase-shifted pulse-width patterns can help reduce flicker. In this dimming method, efficacy remains relatively stable up to about 30% power, after which it may decrease slightly

In PWM dimming, the lumen output is linearly related to the duty cycle, or the percentage of time the power is on. During the "on" pulse, the current remains at the LED's rated value, ensuring that dimming does not adversely affect the LED's performance, lifespan, or color quality. The response to a dimming command is nearly instantaneous. The minimum pulse width the system can switch depends on the technique used, which can achieve dimming levels below 1% with the appropriate method. A simple electronic timer typically controls the on-and-off switching function.

Auto ON/OFF and dimming should be gradual to minimize flicker. Studies (Akashi Y, Neches J, 2004) indicate that most users do not notice a 20% reduction in illuminance, regardless of the initial brightness or dimming rate. The acceptability of reduced lighting levels depends on the task being performed: users working with VDU/computer screens can tolerate greater reductions than those engaged in paper-based tasks. Additionally, the acceptable level of artificial lighting is influenced by the amount of daylight present.

4.3 Networked Lighting and Data Communication Protocol

Automatic lighting control systems typically consist of an input device, like a photosensor, and a power controller, such as a switch. These components can either be integrated into a single device or installed separately. For effective operation, the input device must send a control signal to the controller, which then manages the load. Traditionally, control signals are transmitted via dedicated low-voltage wiring, known as "hardwired" systems. However, a newer and increasingly popular method uses radio waves to transmit control signals wirelessly, eliminating the need for dedicated control wiring.

Below Fig. 1 shows lighting controls and dimming protocols.

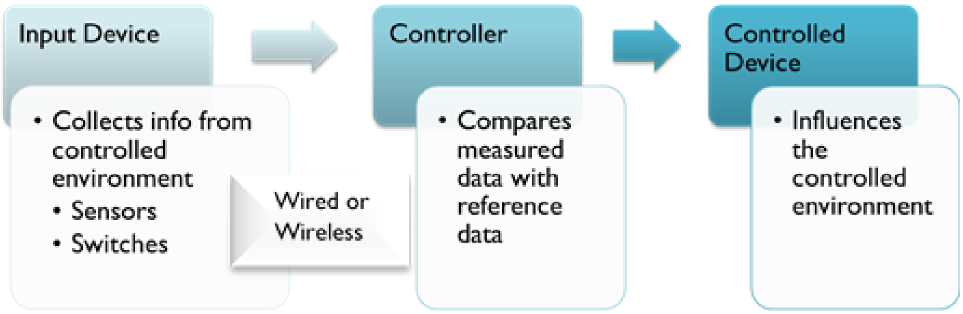

Fig. 1 Lighting Controls and Dimming Protocols

These networks can employ various protocols for communication among connected devices. A protocol establishes the rules and methods for data transfer, authentication, error detection/correction, and security. All devices within the network must use the same protocol to ensure they can effectively understand and communicate with each other.

Data transmission can be either analog or digital. There is no global or local industry standard dictating which protocol must be used for a particular application. As a result, a variety of protocols, both open and proprietary (manufacturer-specific), are available in the market. The use of proprietary protocols is not restricted by formal norms but is instead driven by market demands and customer needs.

Table 1 gives a comparison, and details are discussed in subsequent section

Table 1 Different Communication Protocols and Key Features

(*Clause* **4.3**)

Sl. No	**Wired Analog Control**	**Wired Digital Control**	**Wireless System**
(1)	(2)	(3)	(4)
i)	0 -10 V Control- Oldest of control systems Requires dedicated wire per channel , resulting in high	DALI Addressable interface, most popular successor of analogue system. Bidirectional communication possible	Zigbee Widely used standard or smart homes. Each device has its own built- in wireless capability

	cabling and installation cost		but they do require a smart hub.
ii)		DMX Serial Unidirectional protocol. Used for entertainment stage lighting	BLE Mesh Supports device-to device communication so that any device in the mesh network can communicate with any other device in the network. Messages are relayed across the network form devices in a series of ‘’hops’’ Consumes lower energy than wifi Does not require any hub or router to operate No remote access possible
iii)		Power over Ethernet Data and power are received over the same ethernet cable, making installation easier .	WiFi Device to Device communication as a substitution for cabled networks. Operates on 2. 4GHz for 5 GHz frequency band, an supports devices with a sustainable power supply Consumes Power even when not operating . Higher data rate compared to Bluetooth and Zigbee Remote Access Possible

4.3.1 *Wired Analog 0-10 Protocol*

Analog protocols are unidirectional, allowing commands to be sent to the lights without receiving feedback from sensors or luminaires. One of the earliest and simplest methods for electronic light control is the 0-10V protocol. This method uses a DC voltage that varies between 0 and 10 volts as the control signal. It is commonly used for dimming traditional lamps, such as incandescent and fluorescent, as well as LED light sources. The 0-10V DC protocol is standardized by ANSI (2017).

In a controlled lighting system using the 0-10V protocol, the output should scale such that 10V corresponds to 100% light output, and 0V turns the light off. For 1-10V systems, the light is at 10% output at 1V. The DC signal voltage used in these systems is low, ranging from 10 μA to 2 mA.

The protocol requires extensive cabling, involving four wires: two for supplying 10V from the ballast or driver to the controller, and two for the control voltage to the dimmer. Signal wiring must be kept separate from main voltage wiring to prevent damage from misconnection, and DC signal cables should be routed separately to avoid confusion, short circuits, and interference.

The system is polarity-dependent, and incorrect wiring can damage the equipment. Additionally, the number of ballasts that can be connected is limited by the source current capacity of the controller (e.g., 500mA). Due to its complexity and unidirectional nature, this protocol may become obsolete in the future.

Below Fig. 2 shows wired analog 0-10 protocol.

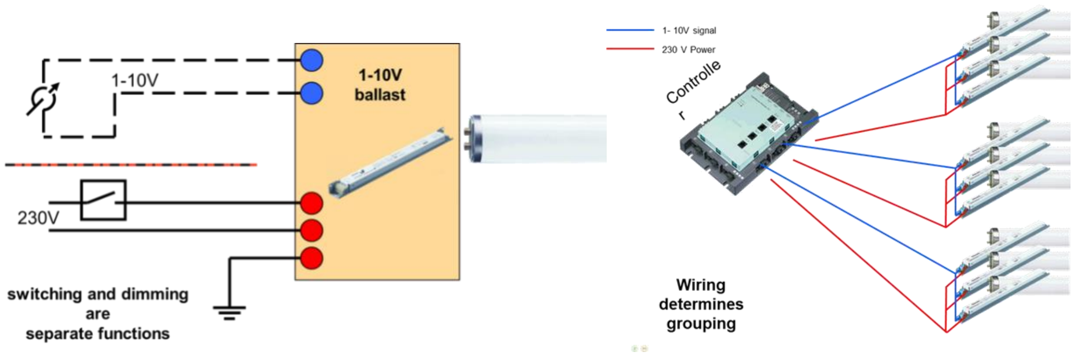

Fig. 2 Wired Analog 0-10 Protocol

4.3.2 *Wired Digital Protocol*

A digital protocol uses discrete signals, such as 0s and 1s for encoding messages, or integer values ranging from 0 to 255 for tasks like setting dimming levels. Messages are encoded in a series of eight bits, with one start bit and two stop bits indicating the beginning and end of the message. By combining an 8-bit address with an 8-bit command, specific instructions (e.g., dimming levels or switching) can be directed to individual light devices or groups.

Digital protocols can be either unidirectional or bidirectional. In bidirectional systems, feedback from sensors and luminaires is possible. Ethernet networks are commonly used for wiring and data transfer. Ethernet is a standard technology for connecting wired local area networks (LANs), allowing devices to communicate using a common protocol. Ethernet cables, which can be coaxial, twisted pair, or fiber optic, physically carry the data. However, Ethernet itself does not define how application data is encoded; this is specified by the communication protocol that operates on top of the Ethernet technology.

4.3.3 *DALI*

The name stands for Digital Addressable Lighting Interface (DALI), a protocol established by leading lighting manufacturers. It controls electronic lamp drivers using a digital signal transmitted over a two-wire cabling system.

DALI system uses DALI controllers, dimmers, switches and sensors. DALI can connect 64 devices .These are available from a broad range of different manufacturers for all kind of lamps, including incandescent and fluorescent lamps and LED light sources. DALI relays can also switch non-lighting electric devices.

This is a bi-directional protocol, which means along with switching and dimming it can receive feedback from lights , sensors etc ,for determining actual energy usage, and for checking the actual light setting and condition of lamp, driver or ballast (fault detection). Below Fig. 3 shows wiring details of DALI.

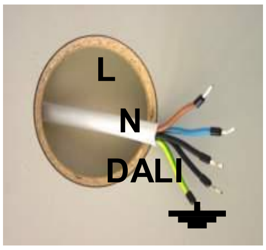

Fig. 3 Wiring of Dali

DALI uses one pair of wire for communication for both powering the network and for data communication. These wires can run in the same cable duct as the main power cables goes directly to the DALI ballasts and the controller is isolated from lighting network. High currents do not flow through the controller. Cabling is polarity independent and is more flexible and simple than analog systems . The cabling can run next to mains cables (part of multi-core cable) and no separate mains switching is required as this is part of the protocol . There is no problem with line voltage drop over longer distances . The maximum cable length depends on the maximum permitted voltage drop along the DALI cable; this is defined as 2 V max. Typically, this requirement is safely met for a cable length of 300 m and a cable cross-section of 1.5 mm².

Ballasts and controllers in a DALI system each have a unique address, with up to 64 addresses available. Each ballast can be individually addressed, and up to 16 groups can be created from these 63 ballasts (one address is reserved for the controller). Fig. 4 shows schematic diagram of DALI controller.

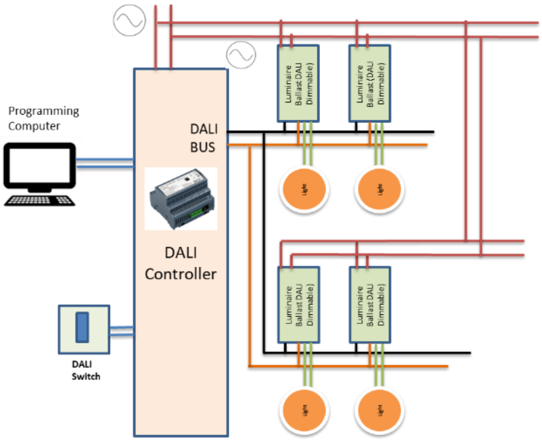

Fig.4 Schematic Diagram of DALI Controller

Devices drawing current from the DALI power should consume less than 2 mA. The power supply for the DALI network can be a separate device or be integrated with the DALI controller.

The data transmission speed of 1200 bits per second is sufficient for office, industrial, and retail lighting applications but is too slow for use in show and theater environments.

Initial programming of DALI systems can be complex and requires specialized software on a computer or an advanced handheld programming tool.

DALI networks can be interconnected to form a larger building automation network, integrating with systems for heating, cooling, ventilation, and security. Additionally, a DALI Wireless Gateway enables internet connectivity, allowing for control via smart mobile devices.

4.3.4 *DMX 512*

DMX stands for Digital Multiplex protocol, with "512" referring to the maximum number of devices that can be connected. Multiplexing combines multiple channels of information over a single transmission path. DMX is a unidirectional protocol used for dimming and switching devices, compatible with a variety of lamps from different manufacturers. It uses twisted-pair, shielded cables to connect DMX devices in a daisy chain topology, with a practical cable length limit of approximately 500 meters. A single cable can connect around 32 devices.

DMX controllers can include a wireless transmitter, allowing communication with a wireless receiver over distances greater than 500 meters. The data transmission speed is 250 kbit/s, enabling rapid scene changes essential for entertainment and theatrical applications.

The DMX 512-RDM (Remote Device Management) protocol is an extension of DMX512 that adds bidirectional communication. While DMX devices cannot initiate communication, the DMX controller can request feedback from each device regarding its identity and status. This feedback helps improve device control and monitor the technical status of the network to prevent issues during operation

4.3.5 *Power over Ethernet*

Twisted-pair cables, commonly used in wired data communication networks, typically include four pairs of twisted wires, as found in Cat 5 and Cat 6 IEEE-standardized cables. Two pairs are used for data communication, while the remaining two pairs can be utilized to power low-power devices (up to 12.9W), such as IP telephones, IP security cameras, and sensors.

The IEEE 802.3 at standard, ~~introduced in 2009~~, increased the maximum power delivery to 25.5W, enabling connection of low-power LED fixtures. The latest standard, IEEE 802.3bt (2018), further raises the maximum power to 90W per connected device. Since power is delivered as DC and data signals operate at high frequencies, there is no interference between the two.

The increased wattage to 90W allows for powering LED luminaires over Ethernet in many smart lighting setups. However, the cable length is limited by power losses, with a maximum length of 100 meters according to IEEE standards.

Power over Ethernet (PoE) systems significantly reduce cable and installation costs, enhance system robustness, and simplify maintenance and modifications.

4.4 Wireless Digital Protocols

Technology trends suggest that wireless and hybrid smart products will dominate future platforms. This section outlines the current protocols employed by manufacturers for product development.

Radio Frequency (RF) communication, also commonly referred as wireless communication, uses radio waves of high frequency as carrier. Frequencies are assigned to specific types of communication. For data communication four different frequency bands are often used, the 868 MHz - 915 MHz, 2.4 GHz - 5 GHz frequency bands. The higher the frequency, the higher the data transfer speeds but the ranges that can be covered are shorter. In wireless communication, digital wireless 0–1 packages are encoded by changes in the radio wave carrier. The changes, referred to as modulations, can be shifts in amplitude, frequency or phase of the carrier signal. The availability of radiofrequency bands is limited. New, higher frequency bands will be added to facilitate more and higher speed data transfer.

It must be kept in mind that in any RF communication, obstacles in the path of the waves reduce the performance and the range.

4.4.1 *Zigbee Protocol*

The ZigBee protocol, developed by ZigBee Alliance, is based on a standard of the Institute of Electrical and Electronics Engineers (IEEE 2015) .Zigbee is a low-power, low data rate, and close proximity (i.e., personal area) wireless ad hoc network. It is used in home, building and industrial automation, especially where many devices have to be connected.

ZigBee is also used for different types of application, such as security monitoring, smoke detection, patient monitoring, smart metering. ZigBee devices for dimming and switching of all kind of lamps are available from different manufacturers. ZigBee is a two-directional protocol. Because of the low power used for communication, the range over which data can be transmitted, depending on environmental conditions, is often not more than 10–20 m. Devices can be connected in mesh, star and tree topologies. Large networks can be created thanks to these topologies. A device out of direct wireless reach of another device may, nevertheless, communicate, because data “hops” from device to device interconnecting them all. If one device fails, there may be an alternative route to keep other neighbouring devices. Most Zigbee lights require a hub which is connected to a router for network connectivity. The topology also makes changes and extensions easy.

The ZigBee Alliance, consisting of a large group of companies, certifies ZigBee products so that devices from different manufacturers can be used together in the same ZigBee network.

Z-Wave is another low-power, low-speed and low range data communication protocol. It is developed initially for home automation. The maximum number of 232 devices in one network makes it less suitable for use in large commercial buildings.

4.4.2 *Bluetooth (Low Energy) Mesh Protocol*

This protocol is developed and maintained by Bluetooth SIG which has a large supporting membership of manufacturers. The Bluetooth SIG is a global community of over 34,000 companies serving to unify, harmonize and drive innovation in the vast range of connected device.

It is generally known as the method for short-range wireless communication between smartphones, tablets, computers and nearby electronic devices as, for example, audio equipment and wearable devices for measuring fitness and health. Bluetooth initially only supported point-to-point connection, permitting one device to be connected to another device.

Since 2017, Bluetooth supports mesh networking. The new mesh capability enables many device communications and is optimized for creating large-scale device networks. It is ideally suited for building automation, sensor network, asset tracking, and any solution that requires tens, hundreds or thousands of devices to reliably and securely communicate with one another.

Bluetooth mesh networks use peer-to-peer communications and multipath message relay to ensure uninterrupted message delivery. With Bluetooth mesh, all nodes communicate directly with one another. There are no centralized hub or routing nodes, and therefore no single points of failure. Bluetooth mesh uses a managed flood message relay architecture that, in addition to simple deployment and management, is inherently multipath and self-healing for reliable message delivery. Bluetooth mesh adopts a security architecture that is designed to address the security concerns of companies deploying large-scale wireless device networks. Devices added to a network can be provisioned using 256-bit elliptic curves and out-of-band authentication. All mesh communication is secured using AES-CCM with 128-bit keys. Encryption and authentication are implemented at two layers, the network layer and the application layer. Each mesh packet is obfuscated to remove any identifying information from the message. By using gateways, the Bluetooth network can communicate with many other types of network.

4.4.3 *WiFi Protocol*

Wi-Fi, commonly intended as the abbreviation of Wireless Fidelity, is a technology brand, owned by the Wi-Fi Alliance, aimed at improving the interoperability of wireless local area network products based on the IEEE 802.11 standards. Wi-Fi is the generally used protocol for connecting devices wirelessly with the worldwide net (Internet). It is also the most used method to enable high-speed wireless communication between smartphones, tablets, laptops and computers.

The access point (equipped with an aerial or aerials) receives the information from the wireless devices, while the router organises and controls the two-directional traffic between the access point and all connected devices of the network. If the network has to be connected with the Internet, also a modem is needed that provides that connection. Wi-Fi uses the frequency bands of 900 MHz (slowest transfer speeds), 2.4, 5 and, very recently, 60 GHz (highest speeds). Transfer speeds are between 100 Mbit/s and,theoretically, 1.5 Gbit/s. Because of the high transfer speed, large amounts of data can be transported. Of course, for connected, smart lighting networks, these high speeds are not needed. The range that can be covered is indoors approximately 30 m and outdoors up to 100 m (lower ranges with higher frequencies and thus with higher speeds). Wi-Fi requires more power than Bluetooth and ZigBee. Wi-Fi has a higher standard of security.

These Wireless system is a building block of Internet of Things and offers immense possibilities like integration with other non lighting devices , remote access etc

5 WIRELESS BASED SMART LIGHTING PRODUCTS AND INTERFACES

Wireless lighting products are available with either integrated or non-integrated sensors and RF devices, allowing them to both control and monitor lighting. This integration enables the luminaire to function as both a light source and an information hub.

Wireless smart lighting products typically comprise three key layers and an interface as shown in Fig. 5

Fig.5 Three Key Layers of Wireless Smart Lighting System

a) *Lighting layer* — lighting hardware, such as LED module which include some integrated sensors. The microcontroller it includes is a programmable chip capable of executing code.

b) *Wireless communication layer* — WiFi , Zigbee or a BLE Mesh Module can be embedded within the system.

c) *Application layer* — This is where product behaviours are implemented. In general, the application layer drives the product behaviour.

During setup, all devices are discovered and added to a programmable network, where they're grouped and given assignments. Setup methods vary by manufacturer and include pushbutton programming, bar code scanning, mobile app setup, graphical database generation and others.

For devices to communicate, they must be in range of each other to ensure reliable signal transmission. It is important to ensure reliable signal pathways , and all devices must be designed to interoperate using the same protocol (communication method).

5.1 User Interface

The attractiveness and acceptability of lighting systems largely depend on the user interface, including its functionality, design, and ease of use. Additionally, the responsiveness of the lighting product to commands is crucial. For consumer-oriented wireless lighting products, the primary interface is a mobile application (Mobile UI). This interface features a graphical, often touch-sensitive display on a smartphone or tablet, enabling users to interact with the device's apps, features, content, and functions.

These apps can be easily downloaded from public app stores (iOS and Android). While app design varies by manufacturer, most require users to register with a user ID and secure their accounts with a password. Network details are encrypted and stored in a secure cloud database, allowing users to save and restore their network configurations. Multiple users can be granted secure access as needed.

The app is designed to be intuitive, enabling users to easily configure their lighting network. Although features can differ by manufacturer, common functionalities include setting up site locations, rooms, and groups, as well as creating scenes. Depending on the application, users may also have the ability to create dynamic lighting scenes, schedule events, and integrate music.

6 GUIDELINES FOR SELECTING A COMMUNICATION PROTOCOL

Before designing and deciding on a connected smart lighting system, it is important to first layout the lighting strategy.

The objective of the smart lighting system should be first identified to ascertain the features of the system. Objectives could be one or a combination of many attributes

a) *Personalised Control*— User have control over the lighting (intensity. colour or both) over their workspace. This improves wellbeing, productivity, ambience

b) *Automatic Control and Pre Set Schedules*— Lighting system is connected to sensors (occupancy /daylight) and lighting is automatically adjusted as per pre-set settings. This is a key element of energy saving. The lighting system can also be programmed using a scheduler or time clock to turn lights ON or OFF, or to set a specific lighting scene. A lighting scene is defined as a composition of lighting with various products set at different intensities and colors

c) *Centralised Monitoring of Lighting System*— By monitoring all lighting equipment, the owner can anticipate end of life for LED luminaires and automatic notifications can be generated for maintenance response, which can make maintenance more efficient and enhance lighting quality by helping the owner ensure all lighting is operational. By monitoring occupancy sensor status, the owner can better understand and manage space utilization, improve operational efficiencies such as cleaning, and gain insights valuable for future building designs.

d) Circadian Rhythm Based Lighting — In modern workspaces, lighting is automatically adjusted in intensity and color using an algorithm that mimics natural daylight changes while minimizing glare and overlighting. By monitoring light levels, valuable insights into user preferences can be gained, informing future lighting designs. This approach enhances well-being and productivity. (Refer to Part 11 'Human-Centric Lighting of this code).

e) Integration with Building/Home Management Systems— The lighting system may also need to integrate with the home or building management system, with the level of integration varying based on requirements. Through thermal mapping, owners can balance HVAC loads by placing lighting and temperature controls where they are needed, thereby enhancing comfort. Additionally, security surveillance systems can be connected to the lighting system.

f) *Remote Access of Lighting System* — When users wish to control the lighting remotely or off-site, the system must be capable of wireless connectivity with their control devices.

Both the owner and designer need to thoroughly analyze the behavior and usage patterns of the premises to define the requirements for a smart lighting system. This analysis will influence the complexity of installation and maintenance, as well as the total cost of ownership.

The choice of protocol for a lighting system is driven by both technical and commercial considerations. While wired systems are often seen as more robust, they require extensive cabling, making them more suitable for new constructions or complete renovations. Additionally, analogue protocols necessitate pre-defined lighting configurations (such as groups and scenes), offering less flexibility. Physical space must also be allocated for mounting controllers, dimmers, and lighting control panels.

In contrast, wireless systems offer significant advantages. They are easy to install and operate without specialized skills, making them ideal for existing installations since they don't require additional wiring or large control panels. Wireless systems also allow for remote access if connected to the internet, and enable easy grouping and regrouping of light fittings through an app or software, facilitating the creation of customized scenes

Table 2 gives a comparative between different systems/protocols

Table 2 Pros and Cons of Different Systems/ Protocols

(*Clause* **6**)

Sl. No	**Protocol**	**Pros**	**Cons**
(1)	(2)	(3)	(4)
i)	BLE Mesh	• Simplest Installation and operation without additional devices • No internet/WiFi connection is required for operations • Low parasitic power as compared to WiFI, "green" operations • Large no of points can be controlled simultaneously without using special Hub.	• Centralised switch ON/OFF /Remote Access for entire installation not possible. • Seamless connection with Voice services require a gateway for each zone and room • Need additional interface for connecting to Home Automation systems

		• Lighting system totally unaffected by performance of Home Internet system • Easily scalable to connect other controlling devices like fan etc if they are on same platform • Can make /change groups, scenes easily without additional wiring Mostly available with Mobile based App, no additional costs	Limitation of operation distance/obstruction
ii)	WiFi	• Seamless connection with external voice services • Remote Access possible • Centralised switching possible • Realtime activity possible • Can connect to IFTT and other WIFi based Home automation systems with 3rd party App • Can make /change groups, scenes easily without additional wiring Mostly available with Mobile based App , no additional costs	• Performance of lights is dependent on quality of WiFi router, Suitable for small installation with 5-10 points . Cannot control large number of light points with standard Home WiFi Router , as the system will become slow. • Higher parasitic power even when not in operation • Performance depends on internet connectivity and may not operate when service is down • Privacy issues need to be validated with manufacturer Limitation of operation distance/obstruction where WiFi signal is weak
iii)	Zigbee	• Seamless connection with external voice services • Remote Access possible • Centralised switching possible • Realtime activity possible • Can connect to WiFi Based Home automation systems • Can connect to IFTT and other WIFi based Home automation systems with 3rd party App Can make /change groups, scenes easily without additional wiring	• Special Hub required to be connected to WiFi router. • Limited to 40-50 light points /hub • Performance depends on internet connectivity and may not operate when service is down Limitation of operation distance/obstruction where WiFi signal is weak

iv)	Wired System	• Robust system, not dependent on distance of operation/obstruction • Can wire and connect other devices like music and curtain systems	• Lighting control panels required in multiple areas • Very complex engineering , installation and maintenance leading to high initial and maintenance costs • Dedicated Interface which is propietary • Limited lighting features (mostly dimming) • Groups and scenes need to be pre decided. Changing scenes require re programming

Below are tips for selecting protocols based on common application practices, user behavior prevalent in India, and the available technologies at the time of this publication. However, these are not mandatory guidelines, and preferences may vary for various reasons as previously mentioned.

6.1 Residences

6.1.1 *Wireless Lighting Solutions*— For users seeking a high-quality, complete wireless lighting solution, BLE Mesh is an ideal choice. This system easily configures and controls residences with multiple rooms, managing up to 100 light points per zone and 1500 points in a single location without the need for a Wi-Fi hub or control wiring. If internet connectivity is required for a specific room or zone, it can be effortlessly achieved with a Wi-Fi gateway. BLE Mesh offers a cost-effective and energy-efficient solution.

6.1.2 *Lighting as a Gadget*— Users who view lighting primarily as a gadget for creating mood effects and integrating with virtual assistants, and who wish to access and control lighting remotely or through IFTTT applets, may prefer a Wi-Fi-based system. Current home Wi-Fi networks often limit the number of devices connected to a router. For a large-scale Wi-Fi lighting installation, a high-capacity router and repeaters may be necessary, which could require specialized installation and maintenance support.

6.1.3 *Smart Home IoT Solutions*— For users seeking a comprehensive smart home IoT system, hybrid solutions offer flexibility. Lighting within individual rooms can be connected via BLE Mesh, which, through a gateway, links to the internet and cloud database. A Wi-Fi system with adequate router capacity can also be employed. To integrate the lighting system with a smart home app, the manufacturer may need to provide an API for seamless connectivity.

6.2 Commercial

6.2.1 *Small and Medium-Sized Offices, Retail, and Hospitality Establishments*— For environments with a significant number of light points, such as small and medium-sized offices, retail spaces, and hospitality venues, BLE Mesh is the most convenient and energy-efficient option. It operates with low parasitic power and does not require integration with the office Wi-Fi system, thus enhancing security and privacy. BLE Mesh systems can be connected to sensors for automatic lighting control, including switching lights on and off. They also offer personalized control for scene settings and adjustable lighting preferences. Additionally, BLE Mesh is ideal for retrofitting existing installations, allowing for easy upgrades to sensor-based solutions with daylight and occupancy sensors, without the need for additional wiring.

6.2.2 *Large Multi-Floor Establishments* — For large, multi-floor buildings, a hybrid system is often preferred. Each floor can use a BLE Mesh system for local communication among lighting devices, operating as an autonomous, pre-programmed room-based system. These floor-level networks can then be integrated into a building-wide system through gateways, enabling centralized control and monitoring. This hybrid approach allows for programmable, controlled lighting across the entire building and facilitates the transmission of operational data back to a central server.

6.2.3 *Commercial Establishments*— For commercial establishments requiring integration with complex building automation systems and extensive inter-device communication, wired systems remain the preferred option, with Power over Ethernet (PoE) systems often being favored. These setups enable seamless control of various building services, including heating, ventilation, air conditioning (HVAC), access control, fire detection, curtains and blinds, and entertainment systems.

Numerous building automation protocols, such as BACnet, EnOcean, KNX, and LonWorks, facilitate these integrations.

7 BEYOND LIGHTING

7.1 Internet of Things (IoT) in Lighting

The application of Internet in every daily commodity is colloquially termed as Internet of Things. Lighting is one of the components which can be introduced in IoT family also. More precisely, lighting can also be ‘controlled’ using IPV6 protocol just like other existing communication protocols. Hence, using internet protocol the intensity and color of the light may be changed based upon the requirement.

The internet of things, or IoT, is a system of interrelated devices that are that are provided with unique identifiers (UIDs) and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction.

TCP/IP: TCP/IP (Transmission Control Protocol/Internet Protocol) is the set of protocols used by the Internet for exchanging information. Wi-Fi, Internet and Cloud Database are key elements in the Internet of Things (IoT)

The sensors in a smart lighting network can be expanded to include additional sensors that collect data on occupancy, temperature, humidity, and air quality. This data can be used to control and optimize other systems within the building, positioning the smart lighting network as the central hub of the building's Internet of Things (IoT) ecosystem.

IoT system typically consists of three basic layers:

a) Device layer
b) Network layer
c) Platform layer.

a) *Device layer* — It contains the things that participate in the Internet of Things .These are connected devices installed in the environment in which are meant to collect and transmit data—whether it's home or workplace.
b) *Network layer*— It includes everything needed to connect devices to each other and to the platform layer. The network layer includes the networking hardware itself (switches, gateways) and the communications methods used for sending and receiving data—cellular, wired Ethernet, Wi-Fi, Bluetooth, and RF, for example, and often a combination of these.
c) Platform layer—It includes everything needed for ingesting, processing, and visualizing collected data, and for extending and integrating the system

An IoT lighting system can considerably increase the energy efficiency of the electric installations in a building and reduce the costs of operating that building while ensuring optimized performance, comfort and health of the building users. In a residential space smart lighting can be connected to home surveillance , where any intrusion can create alight setting as well as alerting the owner .

The network of light points can serve as the infrastructure for IoT systems. By having the sensors, or most of the sensors, integrated with the luminaires themselves, the lighting system becomes an IoT lighting system. Data can be stored and processed in the cloud. Local storing and processing of some of the data can be advantageous to get actions, as a result of sensed changes, fast enough for security reasons and to avoid failures of the system in case of bad network connections. The control system may have the wireless communication, bandwidth, intelligence, and software to deliver data to other building systems and third-party software. This could be data from occupancy and daylight sensors or other integrated sensors. By adding sensors using ubiquitous luminaires as the physical platform, the owner can geometrically increase available data and associated capabilities, such as inventory tracking and location-based services. For example, in a hospital, RFID tags could be placed on wheelchairs and crash carts, with the RFID signal passed through luminaires enabling hospital staff to locate equipment using apps.

The Internet of Things (IoT) is still evolving, grappling with challenges like interoperability, cybersecurity, and managing the massive amounts of data it generates. However, networked lighting controls are already well-established and can provide immediate benefits. They offer the potential for future IoT integration and enhance our ability to understand and optimize lighting quality**.**

7.2 Visible Light Communication and LiFI

7.2.1 Optical Wireless Communications (OWC) use unguided visible, infrared (IR), or ultraviolet (UV) light to transmit signals. A cutting-edge application of OWC is visible light communication (VLC), which operates in the visible spectrum (390–750 nm). VLC can simultaneously provide both data transfer and illumination.

VLC offers extremely high data transfer rates: for instance, red light at 750 nm has a frequency of 400 THz, while blue light at 400 nm has a frequency of 750 THz. In comparison, 3G radio frequencies are around 2 GHz, 4G ranges from 2–8 GHz, and 5G spans 3–30 GHz.

The dual functionality of LEDs enables innovative applications. Specialized electronic devices, often equipped with photodiodes, can receive signals from light sources. In some cases, a cell phone camera or digital camera, which contains an array of photodiodes (pixels), can be used instead. These image sensors, with their multi-channel capabilities, offer spatial awareness of multiple light sources, enhancing VLC applications.

Many Visible Light Communication (VLC) applications focus on information transfer, such as downloading or broadcasting content. VLC offers several advantages over radio frequency (RF) communication, including reduced congestion, lower installation costs, lower energy consumption, enhanced security, and no electromagnetic interference. These benefits make VLC particularly valuable in environments like healthcare, laboratories, control rooms, and industrial settings where RF interference can be problematic.

In addition, VLC, combined with location beacons, creates new opportunities for marketing in retail lighting. VLC operates by rapidly switching the current to LEDs on and off at speeds imperceptible to the human eye, eliminating any flicker and ensuring smooth operation.

7.2.2 LiFi is a wireless optical networking technology that utilizes light-emitting diodes (LEDs) for data transmission. It leverages LED light bulbs, similar to those found in many energy-efficient homes and offices, to deliver data. LiFi offers several advantages over traditional Wi-Fi, including significantly higher speeds and a frequency spectrum up to 10,000 times greater than that of radio frequencies.

7.3 Indoor Navigation

An Indoor Positioning System (IPS) is a network of devices designed to locate people or objects in environments where GPS and other satellite technologies are imprecise or ineffective, such as within multistory buildings, airports, parking garages, and underground areas.

IPS utilizes a variety of techniques and devices, ranging from repurposed technology like smartphones, Wi-Fi and Bluetooth antennas, digital cameras, and clocks, to purpose-built installations featuring strategically placed relays and beacons. These systems find broad applications in commercial, military, retail, and inventory tracking sectors. While several commercial IPS solutions are available, there are no universal standards; each system is customized based on spatial dimensions, building materials, accuracy requirements, and budget constraints.

IPS networks employ diverse technologies, including distance measurement to fixed anchor nodes (such as Wi-Fi or Li-Fi access points and Bluetooth beacons), magnetic positioning, and dead reckoning. These systems can either actively track mobile devices and tags or provide ambient location and environmental context. IPS can achieve location accuracy within a few centimeters, significantly surpassing the meter-level precision of GPS.