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The Energy-Efficient Control Solutions of Smart Street Lighting Systems: A Review, Issues, and Recommendations

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HIGHLIGHTS

- Communication, control, and wireless sensor-based smart street lighting system were investigated.
- Various control technologies that may support many applications deployed on networked streetlights were evaluated.
- Issues and recommendations distinguished in this paper will pave the route for future smart street lighting systems.

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ABSTRACT

The smart street-lighting system (SSLS) is a leading candidate in the smart city. By the time of the last 15 cycles, many meaningful improvements have been executed in the SSLS with the impact of the internet of things technologies and universal networking devices. Conventional smart street lighting systems are restricted to wireless sensor networks, mobile devices, and old lighting control systems. This article presents a comprehensive treatment of network designs, namely communication, control, and wireless sensor-based smart street lighting system by deploying based on their existing system architecture, and network topologies including leading with it a host of privileges. In addition, choosing the right lighting class, high-intensity discharge (HID) lights, and retrofitting lighting technologies have all been covered in detail. This paper's objective is to evaluate various control technologies that may support the many applications deployed on networked streetlights. Moreover, issues and recommendations, distinguished in this paper, will pave the route for future smart street lighting systems that promote a reliable and seamless driving experience and are energy-efficient for environmental sustainability. It is far anticipated that LoRa and Sigfox with additional gateways could be the best possible smart street lighting system options as these technologies are facilitated for long distances but with a limited data rate. It is way more suitable for lighting control compared to other protocols to control thousands of streetlights.

1. Introduction

A street lighting system is a collection of aligned, elevated light sources that are placed along the edge of a road or path to illuminate traffic and pedestrians, mostly for security and safety reasons [1]. An intelligent lighting system's principal objective is to improve occupants' visual comfort while using less energy. According to research, an intelligent lighting system may save energy consumption by up to 70% when controlled properly [2]. Sanchez-Sutil et al. [3], built a real-time monitoring and control system for an energy-saving control system using a smart meter and Lora. The gateway for the street lights system, the operating and monitoring device for street lights, and the illumination level device make up this study design. It's important to note that the annual energy savings were 12,615.635 kW h. ZigBee has developed as a low-power, simpler, and more dependable wireless

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sensor network (WSN) for energy-efficient indoor and outdoor lighting [4][5][6]. Concerning energy-efficient smart street lighting in particular, the union of the light emitting diode (LED) and ZigBee protocol provides adjustable dimming in line with ambient circumstances, occupancy control, and automated defect detection [7]. Ouerhani et al. [8], compared to traditional static, time-based street lighting control, the installation of dynamic street lights in the actual world revealed 56% savings. and Sun et al. [9] For so-lar-powered street lighting, a multi-sensor system with an average energy consumption decrease of 40% has been suggested.

Dimmable LEDs, photodetectors, occupancy sensors, and controller units are the basic elements of a smart lighting system and have been the primary research issues in recent years [10-14]. Authors in the paper [15] presented a decision-making module-equipped smart street lighting system. The decision-making module combines fuzzy logic and artificial neural networks (ANN) to lower the system's total energy usage by combining data from several sensors. Utilizing solar energy results in WSNs that employ a variety of technology techniques to operate street lighting systems [16-18]. Sanchez-Sutil et al. [19], by sensing light levels and adjusting the SSLS using a LoRa low power wide area network (LPWAN) for system communication, integrated sensors can control each street light in a system. The components of smart lighting are connected by a communication protocol, which might be wired or wireless [20]. For internet of things (IoT) based street lighting systems, several wireless communication protocols have been suggested, including ZigBee [21], worldwide interoperability for microwave access (WiMAX) [22], global system for mobile communication (GSM) [23,24] , LoRa [25], and narrowband internet of things (NB-IoT) [26]. A typical smart lighting system's brain is a control unit that modifies the luminaire's dimming level based on the output of the photodetectors, the presence or absence of occupants, and the types of visual activities being performed in each zone. The development of effective control mechanisms and algorithms for smart lighting systems is a challenging problem that has received a lot of attention recently [27-29]. Andrzej Ożadowicz et al. [30], reported a study on the examination and creation of lighting control algorithms. Static and dynamic techniques are the two primary ones examined. The first one is predicated on fixed parameters. The lighting control system is configured with parameters such as (i) the kind and power level of light sources; (ii) the on/off periods, according to the calendar; (iii) modifying the length of the day; and (iv) light sensor signal. The second method, which uses dynamic algorithms, provides additional lighting control, optimization, and adjustment options. However, it requires a lot more infrastructure components and could have varying degrees of functional development.

Numerous lighting control methods, such as occupancy-based control systems, day-light-linked control systems, personal control systems, and institutional control systems, may be differentiated in addition to human control. Additionally, the topology of this system is either open- or closed-loop [31]. Ref. [32], designed a controller to enable closed-loop interior lighting management using occupancy and ambient light detection. Ref. [33] suggested intelligent lighting closed-loop technique to control luminaire brightness using the phone's ambient light sensor. These control services are based on sensor data analysis, followed by processing that takes into account user demands and power usage [34]. A distributed system known as a smart street lighting system serves as a remedy and may be used to regulate a variety of devices, such as the illumination of each lamp in a street or a set of traffic lights in a roundabout. These distributed systems may be managed in a variety of ways, including centralized management, cluster-based management, and autonomous management of individual system components [35]. The next step is the extraction of system optimization indicators to assess how well the control strategy is being implemented across the board. The best course of action in a control system may be determined in a variety of ways. Simple control loops with one input and one output that are based on periodic sampling are often assessed by measuring the deviation between the action taken, the output value, and the action anticipated or the reference value [36].

In this research, software and the development of intelligent lighting control solutions are the main topics of articles that are gathered and analyzed. This evaluation's goals are to locate the best research protocols that have arisen at the different locations for intelligent lighting fixtures, investigate the context, and locate viable control systems in the literature. With the help of identifying control protocol, a conceptual framework for integrating an intelligent street lighting system may be developed. Smart street lighting is the topic of the problem statement in Section 2, while the general reviewing methodology of the review article is covered in Section 3. While section 5 reported high-intensity discharge lights, section 4 included criteria for a streetlight, office light, and industrial light where numerous lighting standards were specified. retrofit lighting technology and net-work topology were covered in sections 6 and 7, respectively. In section 8, this article discussed the intelligent lighting system that uses several technologies such as LoRa, ZigBee, power line communication (PLC), DALI, ANN, Solar, and wireless sensor network depending on several control strategies. These technologies are split into three parts: communication, control, and sensor contain a detailed description of each technique. Next, the results and discussion on comparative comparison between a plethora of intelligent street light protocols to choose the optimal protocol covered in section 9. Finally, issues and challenges and conclusions, and recommendations are covered in section 10.

2. Problem Statement

A need for focusing on street lighting variables such as the controlling strategy, street light components, topology, energy usage, protocol, and prospective improvement in the regulating of streetlights has been established based on the survey answer. This article focuses on two aspects of street lighting: enhancing the technique for managing streetlights and choosing the optimal protocol to minimize needless streetlight use.

SSLS has to be improved since it has long-term issues including incorrect streetlight use and functional failure because of poor control planning. While lights are on throughout the day, there are certain locations where streetlights are not operating properly. Strangers' accidents and other shady behaviors impact those using the roadways. According to estimates, street lighting may cut down on crime by 20% and car accidents by up to 35% [1,2]. The issue may be solved by distributing light from streetlights properly, implementing effective control measures, and preventing wasteful use. A smart street lighting system is necessary for the efficient placement of lamps on roadways with low power consumption. Streetlights will continue to operate without interruption, and wasteful power consumption will be reduced, thanks to master controlling planning and effective administration of the street lighting.

3. Reviewing Methodology

Using the three screening stages, papers about street lighting control systems were selected as the basis for this review study. The literature study served as the first screening and assessment, and relevant papers were chosen utilizing a variety of platforms, including web of science, google scholar, Scopus databases, IEEE Xplore, and science direct. After the first search, 415 (n = 415) articles were selected in total. With the second screening, significant keywords were used. Energy saving, intelligent lighting, IoT, LED, SSLS, and topologies were the six keywords used to conduct the literature search. To discover the relevant publications, we looked at the article title, contents, abstracts, and uniqueness in addition to the keywords. According to the findings, a total of 284 articles were found during the second screening. Based on the review procedure, impact factors, and citations, the third screening was carried out, and 207 papers were discovered and examined. they were written by renowned authors and appeared in reputable journals, books, reports, and conference proceedings. To provide a critical study, analysis, and debate relevant to smart street lighting fixtures, illumination assessment, control techniques, concerns, and challenges, these 207 articles were thoroughly evaluated. Figure 1 provides a schematic representation of the reviewing approach.

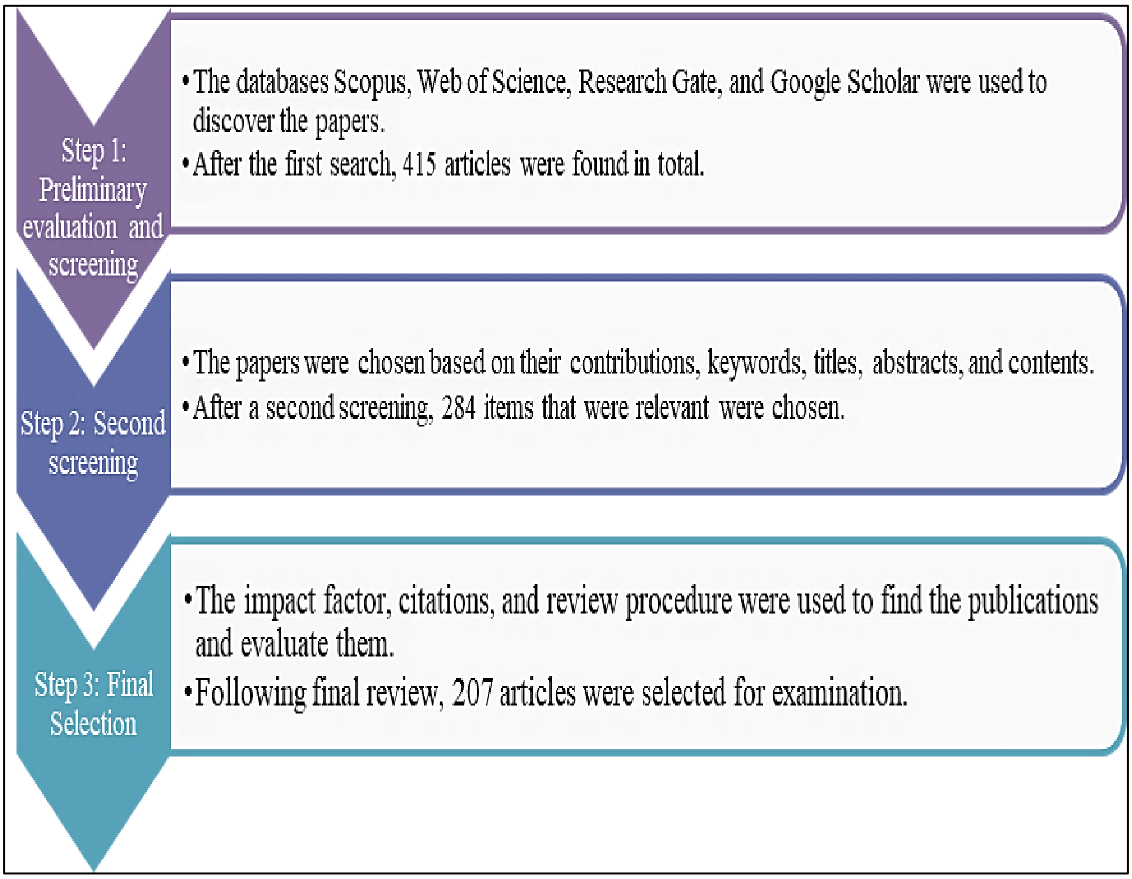

Figure 1: Schematic design of the reviewing methodology

4. Lighting Requirements

Photometric calculations, which are an essential component of the lighting design process, are used to define an installation's performance under various standardization-specified conditions and to determine if a solution complies with required standards.

The following parameters in Table 1 are used to evaluate street lighting: average road luminance (L_{av}), which ranges from 0.3 to 2.0 Cd/m^2, brightness uniformity (U_o), longitudinal uniformity, glare (between 10% and 20%), environmental ratio (SR), which should be at least 0.50, color rendering index (CRI), and visual inducement. Therefore, these are the considerations we must make while designing street lighting [37]. There are essentially three main sets of lighting classes mentioned in this European standard: lighting class P for pedestrian and low-speed zones, lighting-class C for conflict areas, and lighting class M for areas designed for motorized traffic. Such a specification is shown in Table 1 for the lighting classes (M, C, and P), which define performance standards.

Table 1: EN 13201-2's criteria for street lighting classes

Lighting class		L_{av} in cd/m^2	U_0	U_l	Ti	EIR
M	M1	2.00	0.40	0.70	10	0.35
	M2	1.50	0.40	0.70	10	0.35
	M3	1.00	0.40	0.60	15	0.30
	M4	0.75	0.40	0.60	15	0.30
	M5	0.50	0.35	0.40	15	0.30
	M6	0.30	0.35	0.40	20	0.30
C		**E_{av} in lx**	**U_0**		**Ti**	
	C0	50	0.40		15	
	C1	30	0.40		15	
	C2	20	0.40		15	
	C3	15	0.40		20	
	C4	10	0.40		20	
	C5	7.5	0.40		20	
		$E_{h,av}$ in lx	**$E_{h,min}$ in lx**	**Ti**	**If face recognition is required, additional criteria**	
					$E_{v,min}$ in lx	**$E_{sc,min}$ in lx**
P	P1	15.0	3.00	20	5.0	3.0
	P2	10.0	2.00	25	3.0	2.0
	P3	7.50	1.50	25	2.5	1.5
	P4	5.00	1.00	30	1.5	1.0
	P5	3.00	0.60	30	1.0	0.6
	P6	2.00	0.40	35	0.6	0.4
	P7	--	--	--	--	

L_{av}: average luminance, U_o: uniformity, U_l: longitudinal uniformity, TI: threshold increment, EIR: edge illuminance ratio, E_{av}: Average illuminance over the whole of used surface, $E_{h,av}$: Average horizontal illuminance, $E_{h,\ min}$: Minimum horizontal illuminance, $E_{v,\ min}$: Minimum vertical Illuminance, $_{Esc,\ min}$: Minimum semi-cylindrical illuminance.

From Table 1, class M values apply to roads (with largely dry road surfaces) that are long enough (approximately 20 to 22 times the mounting height) to employ the luminance concept, outside conflict zones and/or outside regions with traffic calming. Longitudinal uniformity (U_l) is a comfort criterion that prevents repetitive high and low brightness patterns from becoming overly noticeable. It only applies on lengthy roads. For lengthy tunnels, flicker is insignificant at 2.5 Hz and 15 Hz. The edge illuminance ratio (EIR) is only evaluated for roadways with an adjacent footway/cycle path (see lighting classes P). According to European Standard EN 13201-2, the edge illuminance ratio is the ratio of the average horizontal illuminance on a strip immediately outside the edge of a carriageway to the average horizontal illuminance on a strip within the edge of the same width as one driving lane. The minimum of both sides of a dual-carriageway must fulfill the criteria.

In class C, normative lighting requirements are maintained average illuminance (E_{av}) across the area examined and illuminance uniformity (U_o), and as informative criteria, the threshold increment (T_i) is obtained for relevant observer locations and viewing directions in the conflict region. The less strict glare requirements for low and very low speeds are established by the fact that in these situations, the observer's view is further down, 3° or even 10° below the horizontal, compared with a driver of a motorized vehicle at higher speeds (with a view 1° below the horizontal), causing a sensation of less glare than predicted by the usual method for calculating threshold increments.

In lighting class P, pedestrian and/or low-speed zones, maintained average ($E_{h,av}$) and minimum ($E_{h,min}$) horizontal illuminance are utilized. Facial recognition requires vertical or semi-cylindrical criteria. In well-defined traffic sections, such as residential roads, footways, or cycle paths, it appears desirable to employ the edge illuminance ratio used for motorized roadways. This would prevent a sudden cut-off of lights at the traffic area's margins and increase safety. Vertical or semi-cylindrical illuminances are required for face identification. Although not indicated, a 1.5-m reference height is recommended. For a recognition distance between 3 m and 4 m, employ light sources with acceptable color rendering capabilities ("white light"), otherwise, even the supply of the requisite levels will not produce sufficient results for the stricter lighting classes P [38].

5. High-Intensity Discharge (HID)

HID refers to lights that are brighter than regular headlights. The most widely used artificial light source for floodlighting, sports lighting, and road lighting are HID lights. This lamp family typically consists of high-power mercury vapor, sodium vapor, and metal halide lamps that are popular because they have better luminous effectiveness and a longer burn time than incandescent lights [39]. Regardless of supply voltage variations or fluctuations, conventional magnetic ballasts, and electronic ballasts are electronic conditioners that operate HID lights at the required power [40-44].Table 2 shows the effectiveness, longevity, and power of several electrical illumination sources [45-48].

Table 2: Distinctive features of different illumination sources

Lamp type	Luminous efficacy (lm/W)	Power (W)	Color temperature (K)	Averaged Lamp life (h)
GLS	5–15	X	X	1000
Incandescent	10	3–500	2400	1000
Tungsten Halogen	15–20	5–500	2700	3000
Compact fluorescent lamp	50–75	3–120	3500–5000	10,000
High-pressure mercury	34	X	X	24,000
Metal halide	40–150	30–2000	6500	22,000
High-pressure sodium	108	X	X	24,000
Low-pressure sodium	100–200	10–180	1700–2200	15,000

6. Retrofitting Lighting Technology (RLT)

In the present day, technology is being developed to reduce power consumption to solve various environmental issues. The typical brightness usage is based entirely on simple turn-on and off, or on occasion with the option to decrease the luminous flux [49]. As a result, the benefits of controlled lighting fixture systems are enormous, and they may lead to significant energy savings. LEDs are a crucial technical advancement. They are currently the most straightforward and potent option for replacing conventional lighting sources.

The photometric numbers of LED and HPS were studied and appraised in a study that determined LED to be the most energy-efficient luminaire source [50]. However, a distinction was created between LED and HPS types differently, considering human visual perception [51]. Photometric solids and optics can be used to have visual effectiveness, as well as the energy efficiency of road lighting [52]. A feasibility study of solar-LED highway luminaires found that LEDs might save 75% of the power used by mercury luminaires, reducing energy generation and electric line costs significantly [53]. The researchers looked at the amount of time it took to repay the cost of the general luminaire's workout, which covers up to 10 kilometers. According to the study, the payback period for LEDs powered by grid electricity is 2.2 years, and 3.3 years for LEDs powered by solar power [54]. Table 3 shows the task characteristics, which include upgrading lighting fixtures technology with a more streamlined review.

In addition, every other feasibility study of LED over HPS without or with a so-lar-powered streetlight is categorized using three distinct areas of interest [55]. Additionally, LED outperformed HPS in the test. In terms of payback time, LED luminaries presented a DPP (discounted payback period) of 3.5 years and an internal rate of return (IRR) of 30% for a 10 to 12-month-vintage scheme, indicating the LED's unique number one value as a barrier [56]. The on-grid PV LED system succeeded in meeting all the requirements, and its payback time was determined to be 20.54 years [57]. This study became expanded by combining HPS with other modern lighting fixtures technologies such as plasma and induction, in addition to LED [58].

Table 3: Characteristics of highlighted works along with RLT

Covered study	Existing Lighting Technology				Comparative Analysis					Ref.
	LED	HPS	ML	MH Lamps	Efficiency	Visibility	DC	PP	IRR (%)	
Photometric portions of LED and HPS	✓	✓	×	×	LED(150 W)> HPS (110W)	LED > HPS	LED	×	×	Li et al. [50]
Evaluation of LED over HPS	✓	✓	×	×	×	×	×	3.5	30	Yoomak et al. [62]
Value effectiveness of (LED, Plasma, and Induction) over antique HPS.	✓	✓	×	×	×	×	×	6/6+ (250 W HPS) 3/3+(400 W HPS	×	Jiang et al. [63]
Comparison between MH lamps, Mercury Vapor (MV) lamps, and LED lamps	✓	×	✓	✓	×	×	×	12	×	Prabu et al. [15]

Table 3: Continued

A Study to Improve the Quality of Street Lighting	✓	✓	×	✓	LED(90-130W)> MH(80-108W)/HPS(130W)	MH>LED/HPS	×	×	×	Alberto et al [64]
Techno-economic analysis of off-grid photovoltaic LED road lighting systems	✓	✓	×	×	×	×	×	20.4	×	A. CanDuman et al. [57]

ML: Mercury lamp, MH: Metal Halide, DC: Dimming control, PP: Playback period

7. Network Topologies

The way many links, tools, and connections on a network are directly or logically connected is called network topology. There are now different techniques for establishing a network, as there are several concepts for designing and managing a city-for example, ensuring that parkways and avenues can facilitate travel among the portions of town with the most considerable traffic. Individuals have advantages and disadvantages, and depending on the objectives of a firm, many systems may provide a higher level of connection and security [59]. With the adoption of a typical pattern, the LoRaWAN network topology develops from star-of-stars to mesh relay, router, and hybrid topologies [60]. The star-established, mesh-structured, and cluster-tree network development strategies are all used in ZigBee. These routers and end devices are then regulated by a network coordinator, who ensures that the end device communicates with the coordinator as efficiently as possible. It's growing in popularity for point-to-point and point-to-multipoint communication. In simulations, a novel address-allocation machine that supports ZigBee tree addressing is proposed, which allows for a few different results. For these reasons, the author decided to build a network layer that would allow the Dali protocol to adapt to a tree topology with a high number of stages [61]. Figure 2 shows many different network topologies, each suitable for another purpose, depending on the total network size and purpose. Table 4 shows a summary of topologies.

Table 4: Summary of topologies

Technology	Architecture	Scenario	Scenario Details	Ref.
ZigBee	Star, mesh, cluster	Smart street lighting	Low cost Long Battery life	[65]
Dali	Tree	Smart street lighting	Better energy consumption Level dimming	[61]
LoRaWan	Relay-Device	Smart Building Industrial	Improve connection Access to the power supply	[66] [67] [68] [69]
LoRaWan	Relay-Device	Smart city	Improve coverage area Concentrate data traffic	[60]
LoRaWan	Router device	Smart Building Industrial	Improve connection Access to the power supply	[70] [71] [72] [73] [74] [75] [76]

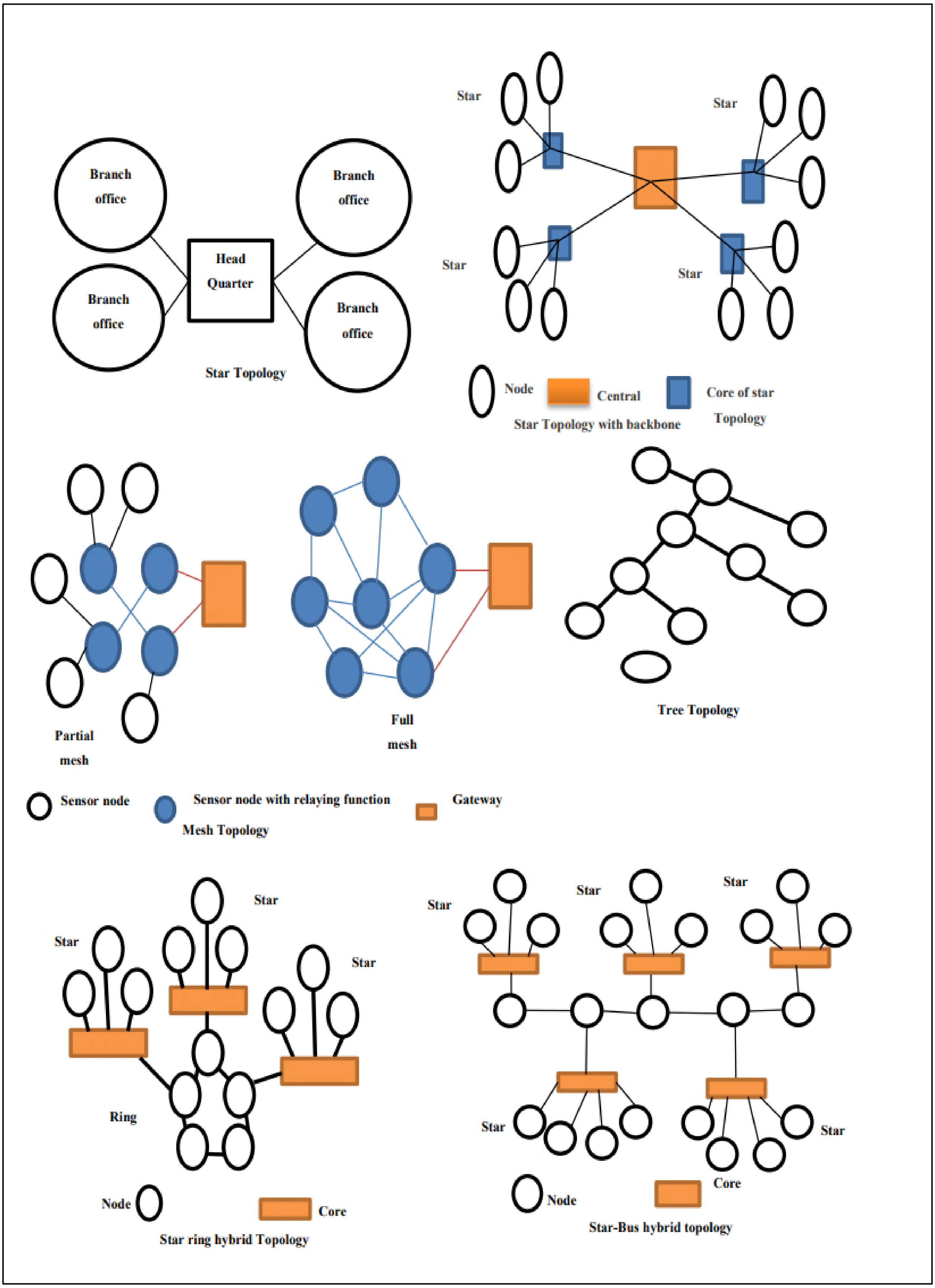

Figure 2: Network distribution for each Topologies

8. Various Connections-Based in SSLS

The concept of SSLS arose from the challenge of dealing with large amounts of light a long time ago. It was necessary to explain so that the lights could be counted in fewer numbers and controlled more effectively in turning on and off, power interruptions, preservation, and so on. Since then, street lighting has improved in terms of efficiency, energy consumption, and pollution. As a result, control systems have evolved to become 'smart,' enabling luminaire control and data collection. This was made feasible by using a variety of luminaire control approaches. This article will look at three different types of SSLS connections: communication-based, control-based, and sensor-based.

8.1 Communication-Based of SSLS

There are several communication-based SSLS available, such as LoRa, ZigBee, Dali, GSM, Bluetooth, Wi-Fi, etc. Having stated that, each technology has its network architecture or topology. Therefore, the control system, feasible apparatus, advantages, and drawbacks of this system are explored below, depending on their topologies.

8.1.1 LoRaWAN (long-range wide area network)

A star topology is used to manage LoRa LPWAN networks, which are made up of end devices, gateway devices, and network servers. End devices communicate with gateways through a single wireless hop, and gateways relay communications from servers in the central network across a non-LoRa LPWAN network [19]. A preliminary investigation using the approach suggested by Cano et al. [77] was carried out to establish the ideal LoRa LPWAN characteristics. The following variables were identified by the system as being ideal: Spread factor (SF) = 7, coding rate (CR) = 6, and bandwidth (BW) = 500 kHz. Kieu-Ha Phung et al. [78] provided a thorough evaluation of the functional aspects of LoRa LPWAN, comparing its efficiency and capacities. There are several configuration options for the LoRa radio, including carrier frequency (CF), spreading factor (SF), bandwidth (BW), and coding rate (CR) [1][79,80]. These factors work together to provide various energy levels and transmission ranges:

1) The transmission band's center frequency is designated as CF. The SX1276/SX1276 transceiver operates between 433 MHz to 915 MHz in North America, and 868 MHz in Europe.
2) The trade-off between data rate and range is offered by SF. The range may be expanded but the data rate may be decreased if a larger spreading factor is used, and vice versa. Multiple orthogonal spreading factors are used by LoRa (between 7 to 12).
3) BW: The transmitter transmits data at a chip rate corresponding to the system bandwidth measured in chips per second per hertz. There are only three frequencies available for LoRa: 125, 250, or 500 kHz.
4) CR: Lora employs forward error correction (FEC) methods to boost receiver sensitivity even further. FEC is determined by the code rate. The equation for the coding rate is $CR = 44/(40+n)$, where n ranges from 1 to 4. It means that five, six, seven, or eight transmission bits are used to encode every four usable bits.

Recently Several smart street lighting control strategies reported based on LoRa and LoRaWAN. Yuanchi Qu et al. [81] created a centralized control system for smart street lamps using STM32 and LoRa, which primarily integrates wireless communication technology with IoT technology design. F. Sánchez Sutil et al. [19] constructed a low-cost new system and successfully tested it by creating three devices based on the Arduino open-source electrical platform: the measure and control device for streetlights (MCDSL), lighting level measurement device (LLMD), and gateway LoRa network (GWLN). The design and implementation of the hardware and software are discussed in this work. Ngo Thanh Tung et al. [82] announced the introduction of four control modes, including automated, remote, connection-disconnection, and manual direct operation modes, for the LoRaWAN-based smart street lighting system. As part of the healthier choices management corp trend of new lighting development employing Lora technology, this study also conducts research, designs, and builds a standard model intelligent public lighting system using LED.

8.1.2 ZigBee

According to ZigBee Alliance, a low-power wireless communication network based on IEEE 802.15.4 is known as ZigBee. The properties of this communication network include self-healing, low power, high reliability, and cheap cost. Lighting control is one of the uses for the ZigBee protocol. A ZigBee-based mesh networked streetlight system, gateway node, and management software make up the proposed system in [83], which aims to monitor and operate the lighting system in real time. In [84], To manage streetlights effectively, a remote-control system based on the ZigBee wireless network is suggested. The suggested system makes use of many sensors to regulate and ensure the necessary system characteristics, and ZigBee transceivers are used to transport data from the streetlights to a control terminal. In [85][86], It is suggested to use ZigBee-TCP/IP communication networks to power smart streetlight installations. The suggested solutions use TCP/IP protocol for long-distance communication to enable remote monitoring through management software, while ZigBee technology is used to construct a wireless mesh network of streetlights for short-distance transmission. The study in [87] offers a single-level ZigBee wireless network-based streetlight monitoring and control system. Only the ZigBee-based streetlight system is introduced in this project to lower maintenance and energy costs. Global interoperability for a micro-wave access network and a ZigBee sensor network are proposed as the foundation for a fully managed streetlight system (WiMAX) [22]. The proposed method provides a WiMAX communication network to remotely operate and monitor the system via a website accessible over the Internet, while each streetlight post uses a ZigBee network to communicate data to a central control unit (streetlight post coordinator).

8.1.3 Power line communication (PLC)

An appealing basis for a wired communication network for smart lighting is provided by PLC. PLC is superior to wireless communication networks in several ways: (i) It adds a modulated communication signal to the already existing AC power connections, thus no extra wires are required for data transmission. (ii) PLC is very dependable and safe. (iii) It can send data in places where wireless technology cannot. The authors in [30] create a smart streetlight system using the ISO/IEC EN 14908 power line local operating network platform to reduce the energy consumption of HPS lights. At the field level, the PLC network is utilized to independently control each streetlight. By leveraging a PLC network, Atıcı et al. [88] created a user-focused system of intelligent streetlights. Ten streetlight controllers, a segment controller, and a control PC make up the testbed. The controllers on the field level interact with one another over a PLC network. The research suggests an LED streetlight system using a brand-new PLC technology for DC systems called P-BUS. For smart lighting, several researchers emphasize the usage of hybrid communication networks. In this regard, it is suggested that a PLC network be used at the field level to provide a secure and dependable short-range communication network among streetlights, while a type of long-range wireless communication network will be chosen to transmit data over long distances relying on ease of access. In [89], A hybrid communication network-based intelligent streetlight system (PLC- General Packet Radio Service (GPRS)) is described. The remote central unit, master board, and slave boards are the three primary parts of the proposed system. The remote central unit is linked to the master board through the GPRS communication network, and data is sent between the master board and the slave boards using a PLC network technology based on the ST7538 power line modem.

8.1.4 DALI (digital addressable lighting interface)

A lighting system's components may be controlled and can communicate with one another thanks to the two-way DALI protocol. It is possible to choose a proprietary or open lighting control protocol, such as TCP/IP, BACNet, DMX 512, LONWorks, X-10, 0-10 V, or DALI. DALI is a digital signal controller for controlling the interface ballasts of tubular fluorescent lamps that are described in annex E.4 of IEC 60929. It is modified by IEC 62386, which also incorporates other DALI applications outside of lighting and expands the type of lamp to high-intensity discharge (HID), halogens, incandescent, LEDs, etc [90]. Liang et al. [91] offer a micro-controller-based PIC 16F684 LED DALI dimming control system. Although this microcontroller is appropriate for this particular application, it doesn't meet the standards for upcoming experimental studies. The study in [61] shows a dimmable ballast with a DALI interface and a WSN-based remote management system for streetlights. An Arduino microcontroller is used to implement a single-level wireless communication network for the smart streetlights using Digi XBee-Pro® 868 Radio Frequency. The results of the implementation demonstrate that using a wireless sensor network (WSN) with a DALI ballast allows for half-duplex communication that can convey a lot of parameters for smart streetlights. For the usage of the DALI protocol in public lighting and its integration with WSNs, several viewpoints have been taken into account. Although the NumeLiTe Project [92] utilized the DALI protocol for applications including street lighting, the manufacturers failed to consider this, and as a result, the project was ultimately only used for interior lighting and not for public lighting systems. Another project created an electronic ballast based on the DALI protocol that uses a ZigBee module to transmit orders through radio waves [93].

8.1.5 Sigfox

A cheap, dependable, low-power option for tying sensors and gadgets together is Sigfox. Sigfox was established in 2009 and has had rapid growth ever since. It was the first LPWAN technology to be introduced in the IoT industry [94]. Emerging low-power and long-range communication technologies like LoRa, NB-IoT, and Sigfox achieve the IoT's objectives [95]. The top communication firms are pursuing this goal and searching for the most effective network solutions (AT&T, CISCO, and THALES). In addition, forward-thinking IT businesses like World Sensing, Aguila Technologies, and Connit have their solutions that may be used to build a Smart city framework. They use exclusive technology provided by businesses that provide IoT network solutions (SigFox) [96]. Only 12 bytes may be broadcast as the payload in a packet using Sigfox, which also has extremely low transmit power (only 22.5 dBm), poor data rate (only 100 bps), and a very long duty cycle lag between two consecutive packet transmissions (at least 10 minutes long) [97]. There is a restriction of 140 messages per day in the uplink direction and just four messages per day in the downlink direction [98]. Time and frequency diversity is a feature of Sigfox, which means that each message will be delivered three times using various frequency channels at various intervals [99], with a packet duration of up to 2ms [100]. To maintain spatial diversity, signals are sent between end devices and access points over several different propagation channels. Low noise levels are achieved by using ultra-narrow band (100 Hz) signals in Sigfox communications, allowing for long coverage distances (up to 10–40 kilometers in rural areas and 1–5 km in urban areas) at the cost of a maximum throughput of just 100 bits per second (bps) [94].

8.1.6 Other common technologies

Apart from LoRa, ZigBee, Dali, Sigfox, and PLC, SSLS applications may use Weightless Symphony Link, Narrowband-IoT (NB-IoT), LTE-M, and Cellular communication technologies, which are detailed below.

8.1.6.1 Weightless Symphony Link

Weightless symphony link is a well-known LPWAN technology developed by hyperlink Labs. It has four times the capabilities of LoRaWAN [101]. It also operates in the unlicensed band, which is 868 or 915 MHz. It has a record rate of up to 100 Kbps and a range of up to fifteen kilometers in rural areas and five kilometers in urban areas.

8.1.6.2 Narrowband-IoT (NB-IoT)

NB-IoT is a 3GPP standard tailored for MTC traffic to reduce IoT energy usage. Narrowband radio technology was built for LPWA to offer low data rates, low power consumption, scalability, and long-range cellular data coverage. It supports intelligent IoT. NB-IoT may be incorporated into 5G-NR networks to boost ultralow-end IoT applications, such as smart meters, streetlights, remote sensors, and smart health systems [7]. It has a data rate of up to 200 kbps and a coverage range of up to twenty kilometers. NB-IoT operates at frequencies less than 1 GHz, such as 700 MHz, 800 MHz, and 900 MHz.

8.1.6.3 LTE-M

is generally recognized as LTE Cat-M1, is the acronym for LTE class M1. LTE end devices often recommend excessive data rate rates at high power consumption. This isn't always appropriate for IoT applications because of its high energy consumption. To address these challenges, the 3GPP has established many LTE-based technologies, including LTE class 0 (LTE-Cat-0), LTE class 1 (LTE-Cat-1), and LTE class M. (LTE-Cat-M1). LTE-M is known as the second one-technology LTE era for IoT applications, which reduces the cost and energy consumption of the first-era technology, i.e., LTE Cat-0 and permit Cat-1. LTE-M enables IoT devices to connect to a 4G network without a gateway [102]. Unlike Sigfox and LoRa, it uses a certified spectrum. This allows LTE-M to avoid capacity concerns caused by other wireless devices operating in the unlicensed band. It also has a genuine LTE community, allowing suppliers to combine IoT devices without creating new antennae. LTE-M offers a data rate of up to 1 Mbps in the authorized sub-GHz band between 700 MHz and 900 MHz, with a coverage range of fifty kilometers in rural areas and five kilometers in city areas. However, LTE-M has the disadvantage of requiring its own SIM card [103].

8.1.6.4 Cellular

The 4G cell era, with its reduced latency and higher bandwidth, might be an excellent alternative for combining intelligent luminaires with various innovative town packages. Data rates of 50 Mbps to 100 Mbps (and even 1 gigabit per second (Gbps) promised for future generations) are feasible depending on the technology, distance from the base station, and network congestion. However, 1 Mbps to 5 Mbps speeds are standard under maximum circumstances presently [104].

8.1.7 Summary of various communications

This section gives a high-level overview of the current communications research. In Table 5, a few criteria will be covered, including the scenario utilized for testing, theoretical proposal (T), simulation (S), and a practical testbed (P).

Table 5: Summary of Various Communication

Communications	Study			Scenario	Ref.
	Theoretical	Simulation	Practical		
Lora	✓	x	✓	Smart Cities	[105]
Lora	✓	x	x	Smart Cities	[106]
LoraWan	✓	✓	x	Smart Cities	[107]
LoraWan	✓	x	x	Smart Cities	[108]
Lora	✓	✓	x	Underground	[70]
LoraWan	✓	✓	x	linear and bottleneck	[71]
Lora	x	x	x	Multiple-building area networks	[74]
ZigBee and GPRS	✓	x	x	Smart Cities	[109]
ZigBee	✓	x	x	Smart Cities	[110]
Dali	✓	✓	x	Smart Cities	[15]
NB-IoT	✓	x	✓	Smart Cities	[111]
NB-IoT	✓	✓	x	Smart Cities	[112]
Symphony	✓	x	x	Office	[113]
PLC	✓	✓	x	Smart Cities	[114]
PLC	✓	✓	x	Smart Cities	[115]

8.2 Control-Based SSLS

8.2.1 Artificial neural network (ANN) established roadway lighting system

An adaptive system known as a neural network learns by employing linked nodes or neurons in a layered structure. Fuzzy systems and artificial neural networks are two common AI techniques utilized in creating a smart street lighting system. Dr. S. Smys et al. [116] advocated the use of ANN in the street lighting system because of the frame's flexible reconfigurability, ability to get familiar with a range of inputs, and capacity to train established neural networks and change their parameters. As there are situations when different degrees of light are required, soft computing techniques like fuzzy logic will help operate the street lighting system. To regulate the street lighting's brightness levels, fuzzy logic controllers are employed. High, dim, and low brightness levels are distinguished. Based on the variance in brightness levels on the roadways, a fuzzy logic controller is utilized to set the luminance level of the street lights [117]. Soft computing techniques are utilized to identify approximate answers to difficult issues as well as accurate ones [118]. An artificial neural network is utilized in the street lighting system to examine the uniformity of illumination, and this data is used to enhance the lighting quality [119]. Through the design, an appropriate plan is created for the street lighting system. It is designed to guarantee that the roadways have a minimal amount of light. For road safety and the reduction of criminal activity, a suitable brightness level is necessary [120]. Manuel Burgos-Payán [118], reported Using a neural network, to create an intelligent streetlight control system. This study discusses how to increase energy efficiency by adapting light brightness to the current weather conditions. An algorithm has been developed to achieve overall illuminance uniformity and increase the effectiveness of street light installations [121].

8.2.2 Solar

As a kind of photovoltaic energy product, solar streetlight is evolving quickly. Due to solar energy's flaws, such as its low density, intermittent nature, and constant change in spatial distribution, there is an urgent need to increase demand for its collection and use[122-124]. A popular area of study for both local and international scientists is how to better gather and use solar energy. Tracking solar energy has been studied from several angles. Huang et al. [125], presented a comparison test that was conducted using two identical stand-alone solar-powered LED lighting systems employing a fixed PV and a 1A-3P (1 axis-3 position) tracking PV. A novel method developed by Seme and Stumberger for the time-dependent prediction of solar radiation availability is based on a dual-axis sun-tracking device [126]. Rhif et al. [127], investigated a sun tracker that works without sun sensors and rotates the solar panels using two motors in both the horizontal and vertical axes. Based on the created mathematical approach and monthly horizontal radiation, Ma et al. proposed a novel sun-tracking system idea that was theoretically studied [128]. Lin and Chen looked at double-feedforward compensation and repeated control for XY-axis precision tracking control [129]. Additionally, photoelectric tracking mode primarily has two things: no cumulative error, and a straightforward circuit design. The device's one flaw is that it cannot continually watch the sun will cause it to malfunction when it is exposed to rain or other unusual weather conditions [130-132] .

8.2.3 Wireless sensor network (WSN)

A series of sensors known as a WSN uses wireless connectivity to communicate while monitoring and recording conditions in various places. The establishment of a WSN-based communication network is one of the best options for data transfer in smart streetlights. In [133], presents single-level WSN-based smart streetlight systems. JN5148 and JN5139 wireless transceivers, based on the JenNet protocol, are used for hardware implementation in their smart streetlight systems to completely realize the WSN network. The systems may be scaled up to accommodate up to 2000 streetlights, which satisfies the standards for smart streetlights. WSN-based smart streetlight systems are being proposed similarly in [134,135], where the primary emphasis is on creating a new, effective routing network method to satisfy the criteria for applications including streetlights. Yusoff et al. [135], present early research on the creation of a workable WSN-based smart streetlight system. The study in [136], proposes a concept for a smart highway lighting management system based on road occupancy as well as a simulation of it. To detect the presence of cars on the road, the suggested system makes use of WSN. The system controls lamps appropriately by the information about road occupancy collected through WSN. Mendalka et al. [137] Describe intelligent streetlights based on WSNs in brief research. According to this research, combining WSN with streetlights paves the way for telemetry and intelligent transportation applications in addition to offering a platform for new, directly linked services.

9. Results and Discussion

9.1 LoRaWAN

To dynamically regulate the illumination brightness, the street lights Regulation (SLR) algorithm was created in [138]. The examination session lasts a total of 21 days each year. The conclusion of both the summer and winter terms coincides with these times. In terms of location, they chose the campus area and separated the zones into three sections, encompassing the structures, classrooms, and roadways, as well as the arrangement of the 107 lightings. The average high and low temperatures are 22.1 C and 11.8 C, respectively. The location of the system and the weather have a significant impact on how the system is regulated and how much energy is saved. The bulbs being utilized allow for a power reduction of up to 35%. When compared to the winter examination period's energy savings of 724.999 kW h, the summer examination period's energy savings of 737.614 kW h are the largest. It's important to note that the annual energy savings were 12,615.635 kW h.

9.2 ZigBee

349 LED luminaires are controlled in this system utilizing manual and mixed modes. Street lighting control offers signals to turn on the lighting at 6 p.m. and turn it off at 6 a.m. in manual mode. This functionality could be found in a total of 89 intelligent luminaires. The illumination is set to most in a mixed way, i.e., 6 p.m. to 11 p.m. These sensors make it easier for lighting fixtures to turn on and off when motion is detected. Sensors are undoubtedly active between 11 p.m. to 5 a.m. This option comes with a total of 260 intelligent lighting fixtures. In February and March, the total power usage for 8 intersections with 349 smart luminaires was calculated. The monthly energy usage is 10029 kWh and 100409 kWh, respectively. Energy consumptions for old luminaires are 22218 kWh and 24598.5 kWh, respectively. The energy savings of 14189.5 kWh may thus be readily obtained by subtracting old luminaires' energy consumption from LED luminaires' energy consumption. As a result, the energy savings

values were 12189 kWh and 14189.5 kWh, respectively, representing 54.9% and 57.7%. So, without compromising the nature of a resident's life, energy savings of roughly 55% over older/conventional lighting systems [139].

9.3 DALI

The energy savings for the recommended system are about 30%–40% of the overall execution period of each light. The financial savings may be even higher due to the fact the lighting levels at 60% of the set point are nonetheless higher than the inception built through management. The recommended method operates as exacted and practicing the laboratory data collected a simulation of the predicted performance for a complete cycle has been done for the onsite installation. In terms of energy consumption and power cost, the suggested system provides clear savings as opposed to others (average actual variety (ATR) up to 31% and DBL up to 5%). regarding the charge variant, it's far step by step declining. remaining 12 months the distinction turned into approximately 10%—concerning light on my own (UCODALI or DBL vs. ATR). If the replacement considers a pole and light, it falls to about 3%–4% (UCODALI vs. DBL). Estimating the full expense of ownership and return on investment (ROI) claims similar evaluation and similar market investigation [61].

9.4 Artificial Neural Network (ANN)

All the tests were conducted across 20 training intervals, with each duration having a repetition range of 200 to 40,000. Starting weight charges for each neuron were chosen at random and were close to zero. To prevent maintaining the erroneous function at a local minimum, at least a dozen simulations are required for an addressed number of neurons on this layer. The exercise dataset includes 9000 models gathered from a variety of climate stations in three great cities. The facts were divided into three datasets for trial, training, and verification. The training ended when a median square error was reached because a training technique of .1 to .9 was used. The predicted mistake was repeated 200 times in the training process. As a result, ANN can successfully facilitate energy management in street luminaires, lowering the amount of energy consumed and providing an energy discount on both recommended and old systems [15].

9.5 Solar

On a cloudy day, solar irradiance, short circuit current, and the resulting voltage. On a cloudy day, Figure 3 depicts sun radiation for fifty minutes. As can be seen in the graph, the power obtained by the solar panel has an excessive amount of intermittency due to shadows constantly disturbing the supply of sunshine rays. Figure 3 depicts the short circuit current and resultant voltage on cloudy days, respectively. The portion of solar irradiance is moderately steady near 1000kW/m^2, which is standard for exceptionally bright daylight, and respectively shows the short circuit and resultant voltage on a sunny day in Figure 3. There are irregular sharp pinpoints due to premature shadow shading, during which the energy is highly reduced. As can be seen from the findings, the share of solar energy is often substantially lower on gloomy days than on brilliant days. The tremendous variation that can be seen in voltage, current, and hence energy is partly due to the continual variation in the fraction of solar power transmitted during foggy days [140].

9.6 Occupancy-Based Management Scheme

According to the findings in Table 6, the share of power conserved is admirably hanging on the resident usage routine and the preset time pause supplied to combat the apprehension in the detector feedback data. Richman et al., for example, reported 3–50% power conservation for an everyday-use practice environment and 46–86% power conservation for an unusual-use practice backdrop with the same plan arrangement and period pause [141].

Table 6: Summary of Field Analysis

Examination	Power savings		Time duration (Min)
	Everyday uses (%)	Irregular utilization (%)	
Richman et al. [142]	3 - 50	46 - 80	5 - 20
Floyd et al. [143]	10 - 19	-	7 - 15
Maniccia et al. [144]	43	-	30
Maniccia et al. [145]	28 - 38	17 - 16	5 - 20
Jennings et al. [146]	20 - 26	-	15 - 20
Galasiu et al. [147]	35	-	8 - 15
Chung et al. [148]	26.1 – 33.3	-	5 - 20

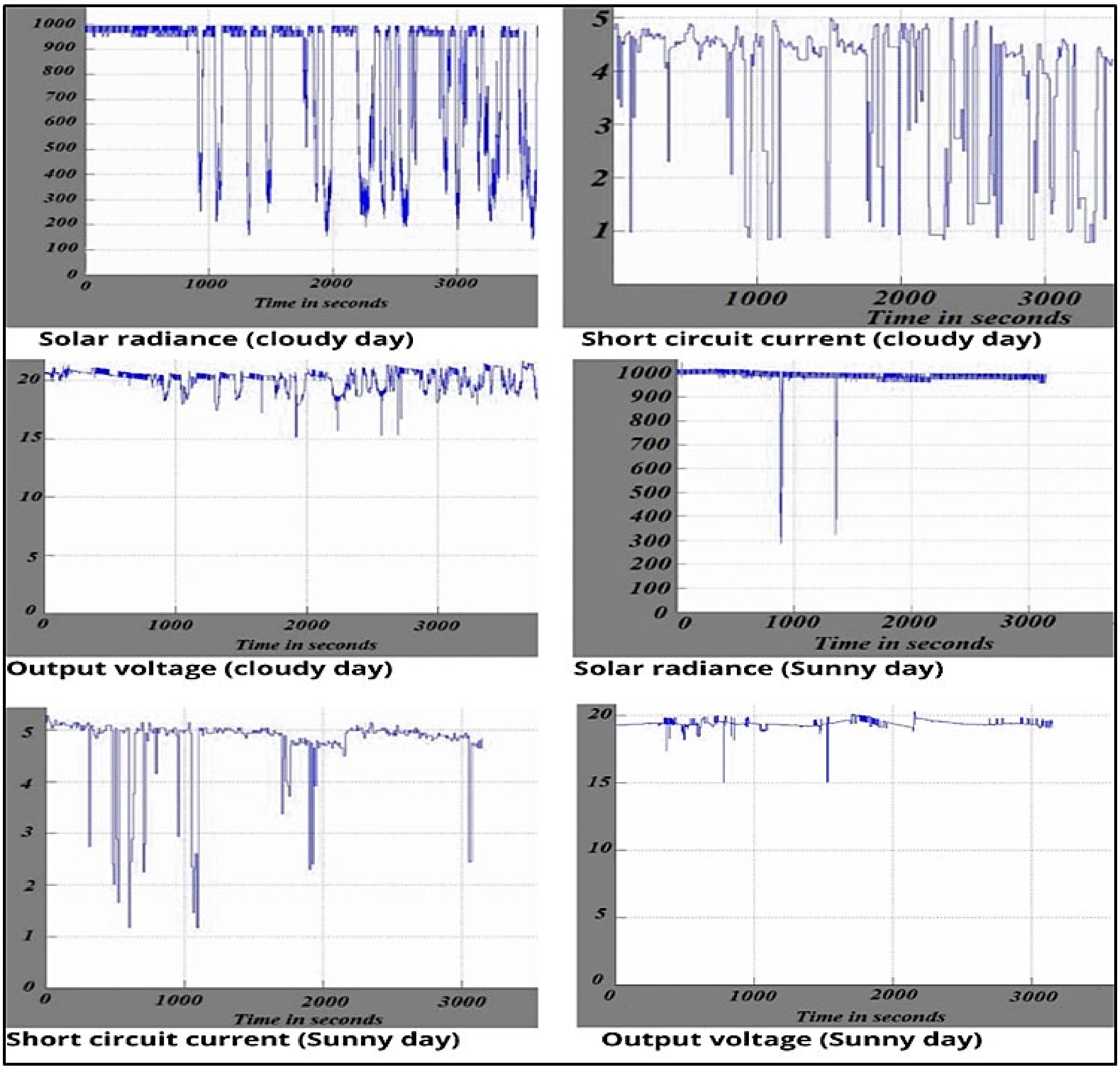

Figure 3: Solar Irradiance, Short Circuit Current, and Resultant voltage during fifty minutes on a cloudy and sunny day [140]

From Table 7, Bluetooth and Wi-Fi networks have the benefit of better information charges over LoRa and ZigBee systems. Sigfox holds out as one of the most economical choices open today, although its capacity is restricted to the maximum simplistic packages because of its very flat records transfer feature. For streetlight lights, which need to react quickly, DALI's significant latency for dimmer and control action is not ideal. It is less favorable because of its poor dimming resolution, fewer devices per controller, and need for hardware-software commissioning. The cell-primarily based solutions—NB-IoT and LTE-Cat1 hold the security advantages that multiple carrier intelligent street luminaire as a smart city Platform network appear. However, placing expenses into continuity implies the entire purchase rate will be extra expensive than with some different choices. RPMA and RF mesh solutions all leverage unlicensed spectrum, giving them conceivably unsafe barriers over the years. Taking into consideration that PLC is extra dependable than wireless community alternatives. Still, it's going to cost more in advance than the narrowband solutions consisting of Sigfox, Lora, NB-IoT, and so on. Also, it will likely be less possible because of that hardwiring: the communications can use most effectively power where electricity lines are established. The arrival of hybrid PLC/RF meshes solutions places this downside. In general, the broadband options (3G, 4G, and cell) will value more than the opposite protocol. Besides, they contribute way more incredible Wi-Fi characteristics which are required. The 3G/4G cellular alternatives can turn out to be quite high priced if statistics site visitor's wireless turns into high as properly Wi-Fi networks also can be expensive to increase. Nevertheless, the leading LoRa and ZigBee information ratio of 300 and 250 kbps is sufficient for sending and obtaining luminaire controls. The single solar deficiency that prevents the gadget from tracking the sun continually will result in a malfunction when the device is exposed to unusual weather conditions, such as rainy days. If you seek out a lower power, lengthy length, peer-to-peer answer, then LoRa is a fantastic preference. Albeit LoRa is designed to perform over a massive field, it isn't a cell era that may connect to cell networks. This completes it less complicated and more affordable to put in force.

There is no need to deploy a specialized gateway if a third-party network, such as Sigfox or LoRa, is utilized to provide communication linkages between streetlights and the Control Center. Given that a proprietary network must be set up, the ideal locations for the gateways must be found using a star topology. To provide greater coverage, star networks must give priority to the highest and most strategic places. Before beginning the in-field verification phase, one should make a rough decision about the placements of the gateways, giving priority to the top site. Then, one should install the gateways and see whether all of the light fixtures have excellent connection conditions. Sigfox streetlights are organized into clusters if gateways are required, like in the case of LoRa. Each cluster depends on its gateway to establish a communication connection with the Control Center. These clusters are made by assigning the MAC addresses of all lighting control systems that logically belong to the same group to the selected gateway. When thousands of streetlights are updated, more gates will need to be set up, however, it would be able to verify the gateway coverage for each one in advance. Therefore, the installation of one or more gateways necessitates a modification to the network partitioning, at least locally, and may need changing the reference gateway of lamps that have already been set. It is crucial to take into account whether the expense of expanding service to underserved regions is justified given the potential savings. We can end the discussion by saying this:

- IoT requires specific standards.
- Current cellular is not efficient as expected.
- Wi-Fi and Bluetooth have a limited range.
- LoRa and Sigfox are widely used for long distances but with a limited data rate which is way more suitable for lighting control compared to other protocols.

Table 7: Comparison between various protocols

Technology	Protocol	Coverage	Data Transmission	Energy Requirement	Sensitivity	Advantage	Disadvantage
Lora	Lora	6.2 miles or 10 km [160]	300-60kbps [160]	Very low [104]	-149 dBm [161]	A low-power wide-area network (LPWAN), low-power wide-area (LPWA) network, or low-power network (LPN) can be designed to facilitate long-range communication at a low bit rate.	The lower bandwidth, restrictions on the frequency range
Sigfox	Sigfox	10km (urban) and 50 km (rural) [103]	1 kbps [103]	Very low [104]	-126 dBm [161]	No need for network installation and maintenance	High latency, low bit rate
ZigBee	ZigBee and ZigBee pro	Up to 100m [162]	Up to 250kbps [162]	Very low [104]	-100 dBm [161]	Low implementation cost A considerable number of nodes, around 6500	Low transmission rate, low cover range
Bluetooth	Bluetooth [163]	Up to 10m [164]	< 1 Mbps [164]	Medium [104]	-97 dBm [161]	Allow two machines to exchange data	Expensive device Unstable security
Wi-Fi	Wi-Fi[165]	Up to 50m [161]	>1300Mbps [160]	excessive	-95 dBm [161]	No need for network installation and maintenance	Possible coverage gaps Low latency
Weightless Symphony Link	Symphony Link	5 km (urban) and 15 km (rural) [103]	100 kbps [103]	low [166]	-132 dBm [167]	cheaper due to repeaters' extensive coverage	requires Symphony Link software and LoRa chipsets, which increases reliance

Table 7: Continued

Narrowband-IoT (NB-IoT)	LTE Cat NB1 [103]	5 km (urban) 20 km (rural)	200 kbps	Very Low [104]	-133 dBm [168]	No need for network installation and maintenance	High latency, low bit rate No dynamic dimming
LTE-cat	LTE-Cat-1 [103]	5 km (urban) and 50 km (rural) [103]	10 Mbps (Downlink) [103]	Medium [104]	-141 dBm [169	certified spectrum	Sim card required
Cellular	2G 3G	up to 50 km [104]	14.4 kbps 2 Mbps [104]	High	-104 dBm [161]	No need for network installation and maintenance	connectivity is very critical to smart lighting

10. Conclusions and Recommendations

Streetlights are no longer standalone objects; instead, they have the potential to create a capillary, multipurpose, city-wide communication network that can transmit information, collect data, and provide services to and from millions of IoT devices. As a result, streetlights may be able to serve citywide IoT services, making them crucial facilitators of the smart city revolution. This study identifies the suitability of the communication, control, and WSN technologies that may be used for this application, including basic street lighting control, advanced street lighting control, performance monitoring, signage and alerts, emergency response, control challenges, and issues, and so on along with their advantages and disadvantages. Comparing LED with another conventional lighting, the on-grid PV LED system succeeded in meeting all the necessary requirements, and its payback time was determined to be 20.54 years. HID lights due to their high luminous flux (7000–40,000 lm), efficiency (40–150 lm/W), extended usable life (5000–22,000 hrs), and high color-rendering index (15–93 or more) as compared to all prior lamps, metal halide (MH) and high-pressure sodium (HPS) lamps are also popular. It demonstrated that LoRa and Sigfox networks are less likely to have coverage problems and low power use. LoRa and Sigfox showed the highest coverage range of around 10km and LoRa annual energy savings were 12,615.635 kW h. To avoid any problems with the installation and management of the communication network, which requires that a communication cost be borne for each streetlight, the public lighting holder must decide whether to deploy and manage its network with a low communication fee. LoRa and Sigfox devices' sensitivity is around -149 dBm and -126 dBm, much beyond cellular equipment in receiver sensitivity. By illuminating how diverse technologies integrate within SSLS, this study will likely be useful to academics and engineers working on smart city applications, particularly smart street lighting.

Expanding the intelligent luminaire controlling system is a complex activity because the general look can suffer from the operation's failure because of their hardware limitations or limited network structure that doesn't forget all feasible environmental situations. Therefore, examining the luminaire to lessen power consumption has many delicate concerns, but their vast potential. Key open analysis issues include:

A. Excessive light throughout the night disrupts melatonin synthesis, related to an increased risk of cancer, diabetes, and obesity. As a result, light pollution is becoming a significant problem for humanity [149]. Low-pressure sodium is recommended in areas where light pollution is a concern, such as nearby astrological sites or turtle nesting beaches [150][151]. Such luminaires have minimal spectral interference with astronomical observation since they glow just on two major spectral lines (with other considerably weaker lines) [152]. So now low-pressure sodium (LPS) luminaires are no longer manufactured, narrow-band amber LEDs, which have a color spectrum comparable to LPS, are being considered [153][154]. White LEDs are far more likely than high-pressure sodium (HPS) vapor luminaires to have detrimental effects on environmental ecosystems. White LED light pollution is expected to worsen ongoing household, such as moth swarm, a corporate infestation of sanitation facilities, and Phyto-sanitary pests, which are recognized to be attracted to white lighting. An additional aspect to consider in choosing public lighting is the possible nuisance impact of such undesirable household pest species. However, white LED illumination can enhance phytosanitary and biosecurity concerns, which might have further indirect ecological consequences [155].
B. Recent LoRa/LoRaWAN research has mostly focused on evaluating LoRa's performance in terms of coverage, capacity, scalability, and longevity. Additionally, adaptive strategies for allocating the best transmission parameters have been recently developed. But because most of these control systems are based on cutting-edge mathematical/statistical models, they have low scalability, few time-series/temporal data exploitation opportunities, restricted modeling assumptions, and limited learning. To create intelligent LoRa networks that adhere to intelligent radio resource management and a variety of communication needs from a huge IoT viewpoint, machine learning, and deep learning might be a possible topics of study [66].
C. Limitations of the DALI software implementation as a virtual peripheral include the MCU's resource consumption (often timers) and the lengthy processing time that results in "inappropriate synchronization" when transmitting control data to the network and interacting with other devices. Strict time constraints are necessary for the software implementation of "virtual peripherals," which entails setting aside a certain amount of processing time in addition to using MCU hardware resources. Virtual peripheral integration requires careful software development and makes heavy use of interrupt service procedures [156].

D. The outdoor luminaire models generally tend to vary from place to place. A risky protocol for command and automation of different road lighting fixtures would produce more opportunities for safe and cost-effective lighting [157]. Furthermore, new technologies are now accessible that provide numerous potentials for energy savings in road lighting in a short time frame. Better luminaire sources and remote access systems are among the technologies that allow the luminaires to be dimmed as needed. However, these options are likely to be limited to either new or replacement road lighting [158].

E. A simple solar-powered roadway luminaire system needs an excessive price for number one setup and carrying costs. Therefore, different other technology must be mixed with solar technology to magnify the productivity of the general procedure [159].

11. Recommendations

A methodological identity is the simplest factor in improving a road lighting fixtures system. Teachings from early adopters propose that towns starting on this marketing campaign are required to look at numerous other elements as nicely. Vital insights from preliminary adopters are defined following:

1) First, The industry and environmental cases for improving LED street lighting fixtures are universally received. Establishing a luminaire controls system capacity concurrently with LEDs can form a stage where future innovative packages may be multiplied. It could also reduce the payback time by using additional reductions in power and sustenance expenses.
2) Second, In addition to the monetary benefits of extra moderate power and renovation expenses, smart road lighting produces a wide variety of different advantages in phrases of the kind of luminaire and the extent of management. It's crucial to explain how these characteristics can be implemented to help with crime and asocial operation, foot-traveler and driver protection, or city improvement plans. Even though now not thinking to apply intelligent lighting fixtures management capabilities inside the coming term, think-tankers should look at viable destiny packages and use that planning to inform generation options.
3) Third, Multiple demands may be maintained on a road lighting fixtures network, which does not suggest that each one can be uniformly precious. To increase a street lighting fixtures system, one must have a defined plan for a way it's going to an agreement with the boom in the use of lots of technology. How do these upgrades shape enduring improvement policies?
4) Lastly, It's essential to evaluate the applications that can be likely for use on the road luminaires network inside the short (1-2 cycles) to the average time frame (3-5 cycles). That evaluation needs to be based on sensible expectancies and no longer an intermediate version. Longer-term objectives should additionally be granted; however, essential variations in choices and generation improvements imply that those should be seen as aspirational indicators in most cases of constant conditions.

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Author contribution

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Data availability statement

Not applicable.

Conflicts of interest

The authors declare no conflict of interest.

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