IoT-enabled Smart Lighting Systems for Smart Cities

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***Abstract*—Over the past few decades, the rate of urbanization has increased enormously. More enhanced services and applications are needed in urban areas to provide a better lifestyle. Smart city, which is a concept of interconnecting modern digital technologies in the context of a city, is a potential solution to enhance the quality and performance of urban services. With the introduction of Internet-of-Things (IoT) in the smart city, new opportunities have emerged to develop new services and integrate different application domains with each other using Information and Communication Technologies. However, to ensure seamless services in an IoT-enabled smart city environment, all the applications have to be maintained with limited energy resources. One of the core sectors that can be improved significantly by implementing IoT is the lighting system of a city since it consumes more energy than other parts of a city. In a smart city, the lighting system is integrated with advanced sensors and communication channels to obtain a *Smart Lighting System* (SLS). The goal of an SLS is to obtain an autonomous and more efficient lighting management system. In this paper, we provide an overview of the SLS and review different IoT-enabled communication protocols, which can be used to realize the SLS in the context of a smart city. Moreover, we analyzed different usage scenarios for IoT-enabled indoor and outdoor SLS and provide an analysis of the power consumption. Our results reveal that IoT-enabled smart lighting systems can reduce power consumption up to 33.33% in both indoor and outdoor settings. Finally, we discussed the future research directions in SLS in the smart city.**

***Index Terms*—Smart Lighting, Internet of Things, Smart City.**

I. Introduction

Human have become more dependent on networked Information and Communication Technologies (ICT) than ever [1]. By 2050, more than 70 percent of global population will live in urban areas [2]. The population growth in cities and our increased dependence on ICT necessitate intelligent and efficient management of critical infrastructure (e.g., energy, transportation, etc.) and address challenges of development and sustainability. To achieve these goals in a holistic manner, the *smart city* concept embraces these ICT challenges [3]. Indeed, a smart city is a vision of future urban area where smart ICT technologies will connect every major sector of the city through rich features such as the smart economy, smart mobility, smart environment, smart people, smart living, and smart governance [4]. On the other hand, another emerging technology paradigm Internet of Things (IoT) is envisioned as a crucial part of the smart city concept. IoT is a network of interconnected devices with advanced capabilities to interact with each other, human beings, their surrounding physical world to perform different tasks. IoT enables easy access and integration between a variety of devices such as home appliances, vehicles, smart phones, etc. in an intelligent urban living setting. By integrating IoT in the smart city, flexible resource management for different application domains can be achieved in urban areas [5].

In such an IoT-enabled smart city environment, one of the major concerns is the efficient management of energy because, with the growing population, demand for electricity has to be met by the limited resources. A basic need for electricity is for lighting in public and private residential areas. Today, approximately 10% of the total energy distribution is consumed by public lighting [6]. Moreover, the lighting in the offices, hospitals, and large residential buildings also contribute to the excessive use of electricity. Undoubtedly, the efficient management and control of lighting systems in a smart city realm integrated with many IoT technologies demands a *Smart Lighting System*.

A Smart Lighting System (SLS) is an automatic and intelligent lighting control system that is managed in a centralized or distributed way by different IoT communication protocols, devices, and their sensors. Efficient illumination system and energy consumption control in homes, offices, and streets are the key concepts in an SLS. An IoT-enabled SLS can be utilized as a solution to reduce the wastage of electricity in a smart city environment. The architecture of IoT-enabled SLS has three basic layers: perception or sensor layer, communication layer, and management layer [7]. Sensors integrated into the light nodes provide automatic control based on the light intensity (using the light sensor) or human presence (using the motion sensors). With IoT communication protocols, these light nodes can forward sensor data and communicate with each other. A management system is needed for analyzing provided data and taking autonomous decisions to ensure efficient power management. *In this paper, we focus on IoT-enabled Smart Lighting Communication Protocols for smart cities that can be used for efficient power management*. We introduce a generic communication model for an SLS and present a brief overview of different IoT protocols that are used in different SLSs. Then, we also discuss the impact of SLSs with a simple evaluation of different SLSs in different lighting settings (indoor and outdoor lighting).

The rest of this paper is organized as follows. In Section 2, the overview of an SLS in the context of the smart city is given. In Section 3, we discuss some of the existing IoT communication protocols that can be used to implement an SLS focusing on the integration of street and indoor lighting scenarios. We present energy consumption in different SLS

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scenarios and note some advantages of using an SLS in Section 4. Finally, we discuss the future scope and identify existing problems in implementing SLS and conclude our paper in Section 5 and 6, respectively.

II. Overview of Smart Lighting Systems

In this section, we introduce basic components of smart lighting systems (SLSs) and give detailed categorization based on different features of SLSs. The term *smart* in a lighting system in a smart city environment refers to its being autonomous and efficient which is achieved by the features of the IoT technology. Normally, efficiency for one lamp can be increased significantly with the advances in lamp technology (e.g., LED). Despite improvements, there is still great potential in the current lighting systems to save energy. For instance, by introducing different sensors (e.g., light sensor, motion sensor, etc.) and efficient communication schemes, a lighting system can be autonomous, efficient, and interoperable with other components of the smart city. Such a sensor-equipped lighting system that can communicate with other lamp units and a central management system efficiently is referred as *Smart Lighting System* (SLS). In addition to the reduction in power consumption, an SLS also provides a reduction in the maintenance cost since faults in the lamps can be easily detected and fixed.

Conventional lighting approaches which are proposed to monitor and control the energy consumption of lighting systems have been focused on either manual solutions (e.g., using LED bulbs, efficient wiring, etc.) or arranging on/off duration of the lamps for certain period of a day. While manual solutions suffer from higher implementation cost, timer-based solutions waste the power in less populated regions during uncrowded nights. However, to consider these drawbacks, an SLS uses multiple sensors (motion sensors, light sensors, fog sensors, etc.). These sensors are used to adjust the on/off time according to human presence and light intensity. Figure 1 gives a detailed view of an SLS in the context of a smart city. In an SLS, there are three basic components of the system architecture:

1) *Lamp Unit (LU):* In recent years, significant improvements have been achieved in lamp manufacturing technologies. The introduction of LED in lighting systems has reduced energy consumption remarkably. Moreover, the use of reflection and refraction features of light in manufacturing offers efficient intensity control of a lamp unit. In addition to these features, different control mechanisms (wired or wireless) provide seamless integration with LU and other components of an SLS. Typically, an LU of an SLS consists of a controller and several sensors connected to it, which gathers data and provides the ability to communicate with each other as well as with a control unit called Control Center (CC). The data can be gathered from motion sensors or light sensors. While motion sensors are used to detect the pedestrians and cars, ambient light sensors like LDR can be used to both check the operational condition (intensity, on/off) of the lamp and the intensity of the daylight. Some other types of sensors like the temperature sensor can also be deployed to detect the fault in the power lines. In summary, LUs of SLS should have following three features:
   - Lamps used in SLS must be energy efficient and should have easy maintenance steps.

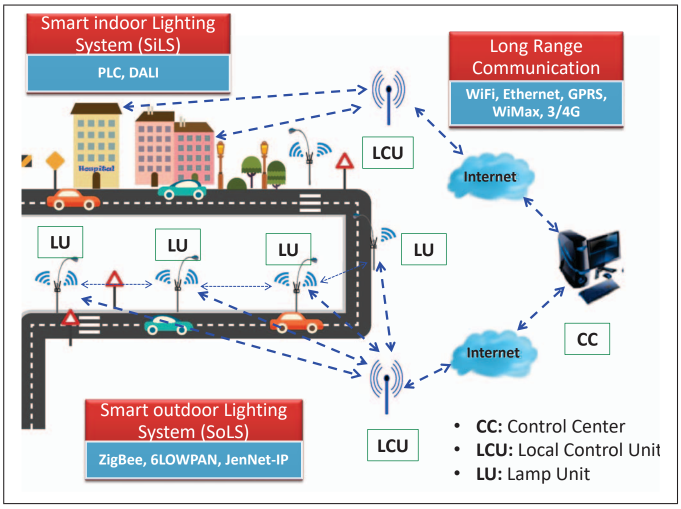
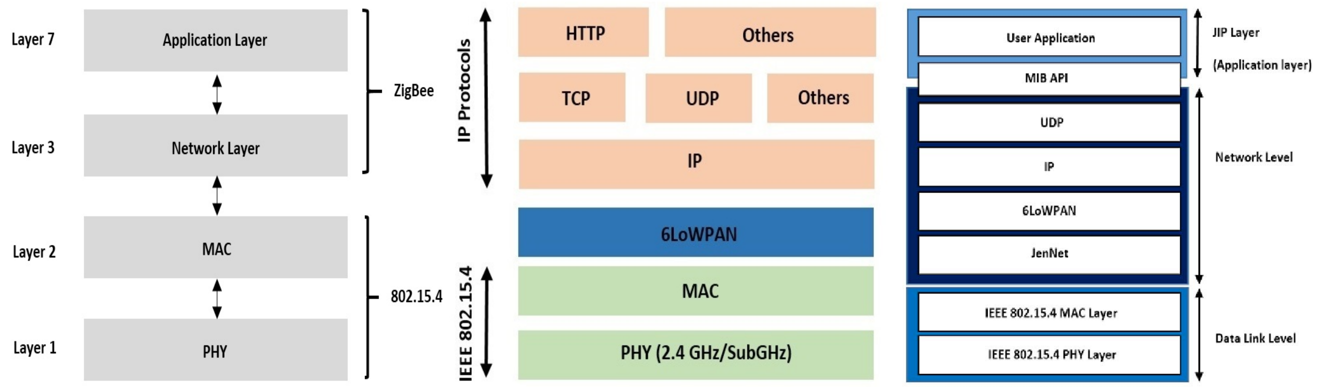


Fig. 1: Overview of Smart Lighting Systems in a Smart City environment

   - LUs must be comprised of necessary and sufficient sensors to provide automatic control to the overall system. Also, sensors must be deployed to provide the intelligent on-off scheme to reduce power consumption.
   - As an SLS must utilize both centralized and localized control schemes, an efficient and reliable control system is needed with LUs to handle various conditions.
2) *Local Control Unit (LCU):* Local control unit collects the data from an array of LUs through a short range communication protocol (e.g., IEEE 802.15.4 protocols such as ZigBee, 6LoWPAN or Bluetooth Low Energy etc.) transmit the data to the Control Center. In some distributed architectures, they can build a mesh network topology and have the ability to talk to each other as well.
3) *Control Center (CC):* The Control Center collects all types of data from LCUs and stores it on a server. With recent advancements in cloud computing it is also possible to store data in the cloud instead of a server. With this, a more cost-effective SLS model is possible as storing data from all the LCUs for large urban areas requires large storage unit on the server. Then, different data analysis tools are then used to visualize and analyze such data. Based on the results of these analysis process; different decisions can be made and actions can be taken to control overall SLS by the administration.

In a general sense, an SLS can be categorized under two types of architectures: *Centralized* and *Distributed*. In the centralized approach, after LCUs collect the sensor data from LUs, each LCU transmits data directly to the CC via long range protocols. Although this method has an advantage of controlling all the system from one location if one of the LCUs were down, the lighting system of all over the street or building would fail. However, in distributed approaches, even if one or some of the LCUs were down, LUs can communicate with the CC via the working LCUs. Distributed approaches also provide a modular structure. Modular structures are instrumental in finding failures and simplifying maintenance.

Moreover, based on the ambience, SLSs can be used in either *Indoor* or *Outdoor* lighting. Smart indoor lighting systems (SiLS) are used in the public service buildings like hospitals, schools or big factories, and companies. There are two aims of



(a) ZigBee stack [8] (b) 6LoWPAN stack [9] (c) JenNET-IP stack [10]

Fig. 2: IEEE 802.15.4 based wireless protocols for the short-range SLS in smart city

using an SiLS. The first one is to save the energy by adjusting on/off duration and the second one is is to maximize the usage of natural daylight by dimming the lamps near windows. On the other hand, smart outdoor lighting systems (SoLS) are used in the street lighting which consumes more energy. In an SoLS, both light and motion sensors can be deployed to save energy by controlling street lighting based on daylight and human presence.

III. IoT Communication Protocols used in Smart Lighting Systems

As discussed in the previous section, an SLS consists of three basic components. In fact, the primary concern of an SLS is how all these components can communicate with each other in an intelligent fashion. Usually, a suitable IoT communication protocol stack is needed to share information between the LU as well as the CC. In this section, we articulate various IoT-enabled SLS communication protocols.

There are two types of communication to be utilized in an SLS.

Long-range Communication: Long-range communication in the context of SLS usually refers to information sharing between LCUs and CC and also between LCUs. For a large urban area, SLS usually consists of several LCUs and one central CC. After collecting data from LUs, LCUs all over the area transmit the data to a CC. Again, LCUs also share information with each other. As LCUs are distributed proportionally all over the city, distances between LCUs and between LCUs and CC can be long (from few hundred meters to few hundred kilometers) [11]. Hence, a long-range communication protocol is needed to establish a communication channel to connect LCUs and CC. Protocols such as Wi-Fi, Ethernet, GPRS, WiMax, 3G/4G/5G are utilized to establish communication channels between LCUs and CC [12].

Short-range communication: Short-range communication usually refers to communication between devices that are in the line of sight. For an SLS, distances between LUs and corresponding LCU are in small range (less than 100 meters) [13]. Short-range protocols are utilized to provide a communication mainly between the LCUs and LUs in an SLS. Short-range protocols can be both wired (e.g., DALI [14]) and wireless (e.g., ZigBee [8], JenNET-IP [10], 6LoWPAN [9]).

As affiliation of IoT technology in SLS is becoming popular, we focus on IoT-enabled communication protocols for SLS in this paper. An IoT-enabled SLS consists of thousands of LUs all over the city and LCUs are formed from the clusters of LUs. To communicate with large number of LUs and LCUs, a communication protocol should meet the following requirements: (1) ability to deal with large number of LUs, (2) support for long battery life, (3) low-cost operations, (4) low data rate, and (5) low complexity. Both wired and wireless communication protocols can be deployed for the short-range IoT-enabled communications. While wireless option offers flexibility and clean environment without wires and complex cables, in the wired option, the cost can be decreased by using the already existing infrastructure. In the existing proposed schemes, wireless protocols are typically suggested for outdoor lighting systems (for SoLS) while wired protocols are used in indoor lighting (for SiLS). Different types of wireless and wired protocols and their implementations on SLSs are described below.

A. Wireless Protocols

IoT-enabled wireless protocols are based on IEEE 802.15.4 (Low Rate wireless personal area network) standard. It specifies PHY and MAC layer of the OSI model [15] and modifies it efficiently for low-power IoT devices. The proposed IEEE 802.15.4-based wireless protocols for the short range communication of an SLS are ZigBee, 6LoWPAN, and JenNET-IP. The protocol stacks of these IEEE 802.15.4-based protocols are shown in the Figure 2.

1) ZigBee: ZigBee is the most popular 802.15.4-based protocol considered for IoT devices and applications. Its standard is specified by a group of companies called ZigBee Alliance. ZigBee Alliance has maintained, supported, and developed ZigBee as a high-level communication protocol for mostly wireless sensor network applications. It uses 802.15.4 as MAC layer and defines Layer 3 and above by adding some additional services including encryption, authentication, association (only valid nodes can be added to topology), and routing protocol (AODV, a reactive ad hoc protocol). There are three kinds of nodes defined in ZigBee which are coordinator, routers, and end devices. In a general SLS given in Figure 1, these correspond to CC, LCU, and LU, respectively. Since they have one to one correspondence, an SLS can be implemented

TABLE I: Summary of specifications of the IoT-enabled communication protocols used in an Smart Lighting System (SLS)

	ZigBee	**6LoWPAN**	**WiFi**	**PLC**	**DALI**
Reference Standard	IEEE 802.15.4	IEEE 802.15.4	IEEE 802.11 b/g	IEEE 1901/1905, Home Plug AV	IEC 62386/60929
Main Application Area	Control	Control and Application	Broadband	Home networking	Home Lighting
Max. Supported Nodes	1024	10000	32	-	64
Bandwidth	20-250 kbps	250 kbps	11/54 Mbps	Up to 500 Mbps	1200 baud
Range	100 m	200 m	100 m	Up to 1500 m	300 m
Security schemes	AES-128	AES-128	WPA	WEP	None

easily using the ZigBee as the communication protocol. For instance, Leccese et al. [8] proposed an intelligent outdoor lighting system using ZigBee. In their proposed system, ZigBee protocol is implemented with the use of XBee modules.

2) 6LoWPAN: 6LoWPAN is the short form of IPV6 over Low-Power Wireless Personal Area Networks. The basic idea behind developing 6LoWPAN is to apply Internet Protocol suite in the context of smaller IoT devices [9]. Data communication and control system can be both centralized and distributed using 6LoWPAN, which provides more flexibility in SLSs. LUs can transmit sensor data and control messages in the same data packet to other LUs in 6LoWPAN. After each successful packet transfer, an acknowledgment handshake is initiated in this protocol stack. Information can be sent to LCU and CC by using both wired and wireless network for 6LoWPAN which considerably reduces the implementation cost [10]. Moreover, 6LoWPAN provides higher data rates than other wireless protocols (e.g., ZigBee, JenNET-IP) which ensures faster communication between components of an SLS. Apart from these technical advantages, 6LoWPAN provides a common application platform to integrate other IoT devices or sensor networks via Internet Protocol. Different applications e.g., temperature control, weather measurement, etc. can gain access via 6LoWPAN to SLS which allows developers to design new applications.

3) JenNET-IP: JenNet-IP was developed by NXP/Jennic which is a communication protocol stack also based on IEEE 802.15.4 for low power wireless networks. JenNET-IP is an enhanced version of the previously developed 6LoWPAN. JenNet-IP uses IPV6 addressable network which can be used to communicate between the CC and LUs in the SLS. The architecture of JenNet-IP is similar to 6LoWPAN except for the addition of two new layers (JIP and JenNet layer) in the protocol suite. The primary function of the JIP layer at the application level is to provide the users with access to device functionalities. This layer can be used for managing the total system. Additional data communication is possible using this protocol layer by developing different applications. The JenNet protocol in network layer provides the multi-hop capability to the system. The JenNet layer is used for applying security to outgoing messages, adding and removing devices from the network. The main advantage of using JenNet-IP in the SLS is that it supports more nodes than other IoT-enabled protocols. JenNet-IP can support more than five hundred LUs which can be used to build a large network [10]. Moreover, as an enhanced version of 6LoWPAN, JenNet-IP also provides a flexible platform for developing different applications.

Moreover, there are other potential protocols that can be deployed in an SLS. For example, Z-Wave [16] is also another IEEE 802.15.4 protocol and it is very similar to ZigBee in many ways. Both are designed for the short range communication of low-power and low-cost devices. However, compared to the ZigBee, Z-wave also supports mesh network topology, i.e., the devices can also communicate to each other. This increases the range of the devices and provides ability to deliver the packet even if LCU fails. However, Z-Wave only supports 232 devices and its was proprietary until 2016 and recently its specifications has been opened to the public. Long Range Wide Area Network (LoRaWAN) is also introduced in SLS domain in recent years. LoRaWAn is built on top of LoRa technology introduced by LoRa Alliance [17]. LoRaWAN-based SLS provides seamless connectivity between SLS and other smart city applications which provides a common platform and reduces maintenance and asset management cost.

Another protocol worth mentioning in this section is Bluetooth Low Energy[1] (BLE) [18]. BLE is primarily designed for one-to-one communication and mostly applied in daily applications such as health and fitness monitoring devices, and PC peripherals and accessories. It supports multiple network topologies and is a good candidate for low power, low cost sensor networks. Moreover, the recently released Bluetooth mesh [19] also supports many-to-many communication, which makes it ideal for creating large-scale indoor or outdoor SLSes.

B. Wired Protocols

SLS of a smart city comprises not only street and traffic lighting control, but also includes indoor lighting such as lightings in residential buildings, schools, office spaces, etc. For a smart indoor lighting system, there are some established wired protocols which allow an SLS to be integrated into a centralized control system. The wired protocols we articulate here for the short-range communication of an SLS are Power Line Communication (PLC) [20] and Digital Addressable Lighting Interface (DALI) [14].

1) PLC: Power line communication uses power line infrastructure both in indoor and outdoor settings for networking and communication purposes. The main purpose of using PLC in SLSs is to reduce the cost by utilizing already established wired networks. The architecture of PLC-based lighting system consists of two main hardware components: one microcontroller and one PLC modem. The microcontroller in PLC allows receiving, processing data, and forwarding the control messages towards a PLC modem. The PLC modem is used to modulate and demodulate data before communication between LUs and thus ensures to minimize the effect of noise and interference in the communication channel. Communication between LUs based on PLC uses a serial communication scheme which can provide data rate as high as 500 Mbps. An RF transmitter in PLC modem transmits data and microcontroller receives this data using an RF receiver. Mainly control message is

[1] Also known as Bluetooth Smart.

transmitted in PLC and control of the full lighting system is achieved using PLC in power cables.

2) DALI: DALI is a lighting standard adopted by International Electrotechnical Commission (IEC). DALI integrates lighting system by using bus or star network topology and custom communication protocol. DALI uses digital circuitry to establish an SLS. Each LU in an SLS based on DALI uses a Manchester-coded frame to communicate with each other. Different sensors such as motion sensors, light sensors, etc. send and receive information regarding control command and their response using this bit stream. DALI needs two wires to connect the devices and initiate data communication between the devices. DALI uses 6-bit addresses which allow only 64 nodes to connect to the system. DALI provides certain advantages for SLSs. DALI can integrate different manufacturers' products in one control system. In this way, the lighting system does not have to use different protocols for different products. It also uses less power which offers energy saving. DALI cannot support more than 64 LUs which makes it obsolete in a street lighting scenario. Yuan Ma et al. proposed a new data transfer method for DALI system to make it faster and more compatible for a wireless sensor network deployment [14]. This method uses a combination of NRZ and MPE (Manchester Phase Encoding) with a baud rate of 9600 baud which is higher than normal baud rate of 1200 baud. A new transfer layer is introduced in DALI providing a better platform to integrate different sensors in the lighting system.

IV. Impacts of Smart Lighting Systems on Power Consumption

Implementation of SLS in the smart city can reduce power consumption in indoor and outdoor scenarios significantly. Use of different sensors such as light sensor, motion sensor, etc. in SLS provides flexibility in controlling the light intensity of LUs which eventually leads to lower energy usage in lighting systems. In this section, we analyze the power consumption of different smart lighting systems (SiLS and SoLS) in different scenarios.

A. Scenario 1: Indoor lighting

The power consumption of a smart infrastructure can be reduced significantly by an SiLS. Different infrastructures (e.g., corporate offices, hospitals, educational institutions, etc.) use lights all day long. An SiLS with a light sensor can reduce power consumption in these infrastructures by utilizing daylight. As an example, assume a moderate office floor with six arrays of LUs each consisting 10 LUs and daylight access to the floor. By implementing light sensors in LUs, SiLS can effectively adjust the intensity of light on the office floor based on daylight access on the floor. Control of light intensity in SiLS relies on the peripheral environment and hence, we can further assume three types of scenarios: clear sky, mixed sky, and overcast sky. LUs near the windows will have less intensity due to better daylight access from the outside. Similarly, the light intensity of LUs away from the windows will be higher. As the light intensity of an LU depends on the current flow, by controlling the intensity of LUs, one can reduce power consumption. To measure the energy consumption of a typical office floor with SiLS, assume LUs can provide three possible light intensity: rated intensity, 60% of the rated intensity, and 40% of the rated intensity. Furthermore, we can assume, each scenario has 60 LUs with 240 Watt bulbs. Table II gives a detail calculation for a typical 8-hour power consumption for SiLS under each scenario. We determine 8-hour power consumption on basis of average work hour. For conventional lighting system, LUs will have the rated intensity and the total power consumed will be 115.2 kWh. In the partial cloudy environment, the light intensity will be adjusted according to daylight and on average 30 light nodes will have the rated intensity and 30 light nodes will have 60% of intensity [21]. In this scenario, the total power consumption will be 92.16 kWh, which is 20% less than the conventional lighting system. For a clean sky environment, LUs near the windows will need the lowest possible intensity because of the access to daylight. In this case, the light intensity of LUs will be distributed proportionally and three groups of light intensity will have 20 LUs each. The total power consumption in clean sky environment will be 76.8 kWh, which is 33.33% less than typical scenario. So, by implementing SiLS in smart infrastructures, power consumption can be reduced as high as 33.33% than the conventional lighting system.

B. Scenario 2: Outdoor lighting

Street lighting consumes higher power than other application domains in the smart city environment [22]. A typical street lighting scenario is controlled by fixed time switching scheme, which means twelve hours operational time (on time) on a daily basis as street light is needed only in the night time. Implementing both light and motion sensor in SoLS, one can control the operational time of street lights, thus, control the power consumption. Assume a 10km road with each LU 20m apart in both sides of the road. In total, 100 LUs is needed to properly brighten the road. In a typical day, lights are kept on for 12 hours mostly from 6 pm to 6 am. For the summer time, the light sensor in SoLS can reduce operation time (on duration) of LUs as daytime is longer than usual. If we calculate year around average on-time for street lights considering daytime duration, it is nearly 10 hours. Again, traffic profile is not the same throughout the night time. Using motion sensors, LUs can detect the traffic situation of the roads and according to traffic profile, the operation time can be controlled in SoLS. Usually, from 6 pm to 12 am midnight, traffic on the street is expected to be higher. Consider a usage scenario with an approximate traffic volume distribution based on pick and off-pick hours. Traffic volume after midnight can become as low as 10% of the total traffic [23]. For SoLS, LUs can be functional at rated intensity from 6 pm to 12 am (pick operational hours) and after 12 am till 6 am (off-pick operational hours), LUs can use the motion sensors to control on/off duration. As the traffic volume is proportional to the operation time of the street lights, total power consumption depicts a reduction from the conventional street lighting system. Here, we assume average operation time of LUs will be reduced by 60% for the 12 am to 6 pm time interval. Power consumption calculation for SoLS is shown in Table III. In the conventional lighting system, all LUs will be functional for 12 hours on average and total power consumption will be 288 kWh. On the other hand, if we use both light and motion sensors, average on time for the light nodes can be reduced to 8 hours and the total power consumption can be reduced to 192 kWh, which is 33.33% lower than the typical scenario. For the light sensor only and motion sensor only cases, the power consumption can be reduced by 14.28% and 20%, respectively.

TABLE II: Power consumption calculation for a typical office floor using Smart Indoor Lighting System (SiLS)

Scenarios	No of nodes in rated intensity	No of nodes in 60% intensity	No of nodes in 40% intensity	Power consumed in rated intensity (kWh)	Power consumed in 60% intensity (kWh)	Power consumed in 40% intensity (kWh)	Total power consumed (kWh)
Clear	20	20	20	38.4	23.04	15.36	76.8
Mixed	30	30	-	57.6	34.56	-	92.16
Overcast	40	20	-	76.8	23.04	-	99.84
Conventional Lighting	60	-	-	115.2	-	-	115.2

TABLE III: Power consumption calculation for a street lighting scenario using Smart Outdoor Lighting System (SoLS)

Scenarios	Total no of nodes (n)	Average Operating time (hr)	Time in fully on state during operation (hr)	Total power consumption (kWh)
Conventional Lighting	100	12	12	288
Light Sensor	100	10	10	240
Motion Sensor	100	12	9.6	230.4
Light and Motion Sensor	100	10	8	192

V. Open Issues and Future Research

The concept of the IoT-enabled smart lighting system is emerging rapidly and different countries are already adapting this concept [24]. In this section, we discuss some of the open issues regarding implementation and security of SLSs in the context of a smart city. These open issues can be explored further to improve the efficiency of SLSs.

A. *Standard platform*

IoT-enabled communication protocols that connect all the components is the heart of an SLS. Regarding efficient communication, IEEE 802.15.4-based IoT communication protocols (ZigBee, 6LoWPAN, and JenNET-IP) are the most promising candidates to be used in the area of SLSs. IEEE 802.15.4 based IoT protocols are actually designed to deal with a large number of IoT devices and certainly are the best match for this aim. Most of the proposed SiLS and SoLS are based on ZigBee, 6LoWPAN, and JenNET-IP. Furthermore, other protocols such as ISA 100.11a, Wireless HART, MiWi are also proposed in different smart lighting schemes [25]. Recently, Low-power Wide Area Network (LoRaWAN) is proposed in different application domains of smart city which enables low data rate communication over long distances by different IoT devices [26]. However, different SLSs using different protocols need to communicate in an efficient manner to build one centralized lighting system. Hence, developing a standard communication protocol stack for IoT devices that can integrate different SLS schemes is one of the promising future research directions. Again, most of the proposed projects regarding SLSs feature a centralized control system for maintenance and monitoring the system. A good unified control interface that can control both SiLS and SoLS regardless of the communication protocol is needed to operate the SLS efficiently and it can be another promising avenue for research.

B. *Merging different applications*

The concept of the smart city is to connect different application domains to augment the performance of urban facilities. SLSs can be integrated with different amenities to provide enhanced services to urban areas. Smart traffic management system is a promising paradigm which can be merged into SoLS to provide a cost-effective autonomous solution. Additionally, the use of different environment sensors (e.g., rain sensor, temperature sensor, humidity sensor, etc.) in SLS can enable smart weather systems, too. Further research in connecting SLS with different applications can provide more cost-effective and efficient urban services.

C. *System Security*

SLSs can be a potential target for attackers because a centralized control system of an SLS can give access to other interconnected services. Furthermore, attackers can gain access to the confidential information from CC which can lead to potential malicious attacks [27] or they can get the control of the whole lighting system of the city, if they can exploit the underlying security mechanisms. Moreover, attackers can launch sensor-based attacks to impair normal behavior of an SLS [28]. Hence, implementing different security mechanisms over smart lighting protocols can be a challenging research area for future researchers. The encryption system in the protocols is not yet mature or well-defined and key management and revocation issues need to be addressed properly. Not security, but also a privacy preserving mechanism can be implemented in SLSs to preserver the user privacy [29]. As the end devices are low-power and low-cost devices, there will be always trade-off between security and efficiency. Strong security schemes in communication protocols can compromise the performance of the system and it increases the cost of implementation. On the other hand, the poor implementation of the security mechanism can cause catastrophic results. These issues should be considered while implementing an SLS.

VI. Conclusion

In an IoT-enabled smart city environment, one of the major concerns is the efficient management of energy consumption. This issue is critical as more people start living in urban areas in the coming decades. Hence, in this paper, we focused on IoT-enabled Smart Indoor and Outdoor Lighting Systems (SiLS, SoLS) in a smart city, which can effectively reduce the power consumption and provide more intelligent operations. We highlighted different IoT-enabled communication protocols that can establish an efficient smart lighting system in terms of power consumption, connectivity, and reliable management system. Then, we analyzed different usage scenarios for SiLS and SoLS and provided power consumption analysis. Our analysis showed that implementation of IoT-enabled SLS can reduce power consumption up to 33.33% than conventional lighting system in the indoor and outdoor environment. Finally, we discussed the advantages of SiLS and SoLS and provided interesting open research problems for other researchers.

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