IoT Enabled Smart Lighting System for Smart Cities

Dankan Gowda ,V1, Arudra Annepu2, Ramesha. M3, Prashantha Kumar K4 and Pallavi Singh5

1Department of Electronics and Communication Engineering, B.M.S Institute of Technology and Management, Bangalore, Karnataka, India.
2Department of Computer Science and Engineering, Rajiv Gandhi Institute of Technology, Bangalore, Karnataka, India.
3Department of Electronics and Communication Engineering, GITAM School of Technology GITAM(Deemed to be University), Bangalore, Karnataka, India.
4Department of Civil Engineering, NMAM Institute of Technology, Nitte, Udupi (District) Karnataka, India.
5Department of Electronics and Communication Engineering, Hindustan Institute of Technology and Science, Chennai, Tamilnadu, India.
Email: dankan.v@bmsit.in

Abstract. The pace of urbanisation has risen tremendously during the last few decades. To provide a higher quality of life, urban dwellers will require a greater variety of improved services and apps. The term “smart city” refers to integrating contemporary digital technology in the setting of a city to improve urban services. There are possibilities to create new services and connect disparate application areas with each other as a result of the use of information and communication technologies in the smart city. However, to make sure the services in an IoT-enabled smart city environment remain running without depleting valuable energy resources, all of the apps have to be maintained using energy resources that are kept at a minimum. IoT can enhance a city’s lighting system since it uses more energy than other municipal systems. An intelligent city integrates lighting system sensors and communication channels with enhanced intelligence features for a Smart Lighting System (SLS). To control lighting more efficiently, SLS systems are built to be autonomous and efficient. We cover the SLS and evaluate several IoT-enabled communication protocols in this article. Furthermore, we evaluated several use scenarios for IoT enabled indoor and outdoor SLS and generated a report detailing the energy consumption in different use cases. By using IoT-enabled smart lighting systems, our research has shown that energy savings are possible in both indoor and outdoor settings, which is equivalent to a forty percent reduction in energy usage. Finally, we went through the SLS in the smart city research plans.

Keywords. Internet of Things (IoT), Internet of Lighting, Wi-Fi, Smart Lighting System (SLS), Communication, Interface.

1. Introduction

The phrase smart city is a fairly new word that has had a high rate of dissemination in the last few years. The arrival of the new paradigm has fostered cooperation among academia, industry, governments, and organisations, with people joining in as well. In [1], the authors use a smart city as an example of a well-defined geographical area, in which a range of technologies such as ICT, logistics, energy production, and more work together to help people achieve things like overall well-being, inclusion, and participation, while also ensuring that the environment is clean and healthy. Nowadays, along with practical implementations, the smart city idea has been blamed for frequently being solely technology-driven, and pushed only by the interests of technology firms. Meanwhile, the
municipality and citizens have been given very little attention. As a result, this has necessitated a more sustainable methodology.

Sustainability has been well-established throughout time and enjoys widespread support. It is built on three essential elements: social well-being, environmental well-being, and financial well-being. Recently, a new definition [2,3] has been proposed to refer to a “sustainable city.” It defines these cities as those that are able to absorb the inflow of materials and energy, as well as properly dispose of waste, without overextending the city’s ecosystem. In other words, if a city wants to conserve its natural resources, then the amount of resources used inside the city should be equal to or less than the quantity of resources given by the environment (e.g., soil, water, or energy resources). Finally, since the city’s activities have the potential to greatly impact the environment’s ability to provide resources to citizens and other members of the ecosystem, pollution levels resulting from those activities should not overwhelm the environment’s capacity to supply resources to citizens and other members of the ecosystem. While the idea of sustainability is quite basic and obvious, it has been attacked since in certain instances it does not align with contemporary societal trends, such as a rise in the amount of digital activity.

The idea's development is therefore leading to a new wave of academic debates proposing a new paradigm: Smart Sustainable City. In further depth, this paradigm strives to create a "smart city" by concurrently considering urban sustainability and smartness. Consequently, understanding how to apply ideas such as these will influence the day-to-day activities of people. The information used to create this strategy is derived from the latest wave of technological progress, namely the increase in the number of IoT-enabled devices and entities.

The IoT is at the core of technological change and transformation in many situations and environments by creating and managing a network of linked devices that gather information about the physical world and modify their behaviour based on the ever-changing context in which they “live.” Since IoT innovation is being introduced, smart sustainable cities will be able to enhance various elements of their urban administration, for instance, public transit, public lighting, e-governance, public safety, security, environmental monitoring, and mobility. The use of IoT technology is predicted to enable all of the available resources, including electricity, soil, water, people, and more, to be monitored, controlled, and managed [4,5]. Connection is crucial for organisations' ambitious goals; the most effective approach is to provide dependable connectivity to encourage efficient sharing of information. As such, due to the variety of different city scenarios that include varying communication technologies and network architectures, most instances necessitate heterogeneity of technologies and architectures, since they depend on the characteristics of specific services that need to be implemented or operational constraints, such as the availability of a power source. Connectivity, the backbone of a smart city, enables the implementation of services of interest to people and institutions.

2. Literature Survey

In order to build a smart city ecosystem, technology has to be a critical component as well as look at factors such as social and human capital. Most cities now use bespoke systems and solutions to meet their unique requirements, however these approaches are not appropriate for other cities across the world, and occasionally just a subset of different elements are required [6,7]. These results synthesise many of the literature’s findings on smart cities and their major obstacles, problems, and open challenges. These four problems may be split into four distinct categories, and these categories can be described in more depth as citizens, mobility, government, and the environment. Smart cities should take into consideration the quality of life of the inhabitants while also factoring in the privacy issue, particularly when their personal information and household-level data are concerned. Because people may be concerned about the introduction of new technology, or see it as invasive, this is noteworthy. In addition, it is critical to focus on equality, which means that everyone in the community should benefit from improvements in smart city technology, and in particular, no metropolitan regions should be left behind [8,9]. The need for a change in government models stems from the wider idea of the smart city concept, which involves combining institutional policies with bottom-up initiatives in order
to be more flexible and to improve the strength of community relations, fostering collaboration, and promoting communication among various entities to prevent the formation of multiple similar initiatives, which would not work together the most efficiently [10]. Mobile city deployment includes the provision of a sustainable, inclusive, and efficient mobility system for both products and people. Still another domain of smart city design that has not been thoroughly researched, and thus may hold answers to previously unanswered questions, is the incorporation of the environment into city services. For instance, sustainable resource management (such as water and energy), pollution, and the impact of urban activities can all be explored. The Key areas to deal with in a smart city are shown in Figure 1.

Interoperability, as now deployments are more frequently based on private and isolated solutions, is currently thought of as a potential obstacle to smart city development [11,12]. To achieve affordable scale and maximise the outcomes, open standard-based devices must be utilised at all levels. In order to effectively coordinate data collecting and analytic operations across many systems, further coordination also is needed between the systems.

Figure 1. Key areas to deal with in a smart city [1].

3. IOT Communication Protocols Used In Smart Lighting Systems

Size and scalability are important in SLS. An SLS's main focus is on how these different components may logically interact. The LU and CC should be able to communicate data via an IoT communication protocol stack. Various IoT-enabled SLS communication protocols are found here. Using an SLS requires two different ways of communication. Long-distance communication A LCSU and a CC unit are both examples of long-range communication in SLS. SLS is typically composed of multiple LCUs and a central CC. Following the LU study, local LCUs link the data to a CC. LCUs are also connected to exchange data. A few hundred metres to several hundred miles are CC distances since each LCU is accessible across the city. A long-range communication protocol is required to connect LCUs and CC. A variety of protocols are used to link LCUs to the CC. Short-range communication, or communication between devices within visual range, is a wide phrase. A SLS is a short range (under 100m) between LUs and connected LCUs. SLS uses short-range protocols to communicate between LCUs and LUs. Some short-range protocols (e.g., DALI [13,14]) are wired or wireless (e.g., ZigBee [15], JenNET-IP [16], 6LoWPAN [17]). This article will concentrate on IoT-enabled SLS communication protocols, since IoT use in SLS is growing. Hundreds of LUs are placed around the city in an IoT-enabled SLS, forming LCUs. A communication protocol should be able to communicate with a large number of LUs and LCUs while maintaining battery life, low cost, low data rate, and low complexity. Short-range IoT communications may use both wired and wireless methods. Wired solutions are less expensive than wireless solutions since they utilise existing infrastructure and do not need cables or complicated connections. suggesting wireless outdoors lights while favouring wired...
inside lighting (for SiLS). Wireless networking standards IEEE 802.15.4 is the IoT wireless communication standard (Low Rate WPAN). PHY and MAC layers of the OSI Model have been successfully modified for low-power Internet of Things devices. Among the IEEE 802.15.4-based wireless protocols used for these activities are ZigBee, 6LoWPAN, and JenNET-IP. Each IEEE 802.15.4-based protocol has its own protocol stack. 1) 802.15.4-based protocols, especially ZigBee, are in high demand for IoT devices and apps. The ZigBee Alliance sets the standard. As a mature communication protocol for usage in low- and medium-range wireless sensor networks, the ZigBee Alliance has maintained its commitment to support, innovation, and development. 802.15.4 implements the MAC layer and provides additional services like encryption, authentication, association (only valid nodes may be connected to the topology), and routing protocol (AODV, a reactive ad hoc protocol). End device nodes are defined in ZigBee. The three flavours (colours) of SLU in a generic SLS are CC, LCU, and LU. To build a ZigBee SLS, the SLS must have one-to-one communication. "ZigBee is suggested by Lecese et al. Their approach uses XBee modules to implement the ZigBee protocol. 2) IPV6 over Low-Power Wireless Personal Area Networks (WPAN). 6LoWPAN is built on the Internet Protocol Suite for smaller IoT devices. 6LoWPAN provides versatility to SLSs through data transfer and control. 6LoWPAN data packets allow sensor data and control message transfer. This protocol stack acknowledges each successful packet delivery. Combining wired and wireless networks may significantly reduce 6LoWPAN installation costs [10]. In this way, 6LoWPAN outperforms other wireless protocols (for example, ZigBee, JenNET-IP). The benefits aside, 6LoWPAN is a basic Internet of Things application platform that connects existing sensor networks or other IoT devices through IP. 6LoWPAN allows developers to build new applications such as temperature control and weather monitoring. 3) Jennic created JenNET-IP, a wireless protocol stack based on IEEE 802.15.4. 6LoWPAN is an improved version of JenNET-IP. For CC-to-LUC communication, the SLS uses an IPV6 network. JIP and JenNet are new layers in 6LoWPAN and JenNet-IP. The JIP layer provides application-level device access. Control the system by stacking this layer on top of the preceding one. Developing apps that utilise this protocol layer allows for more data transmission. The JenNet protocol offers multi-hop capabilities [18,19]. JenNet is used to manage the network and safeguard outbound communications. Using JenNet-IP in the SLS allows for more nodes to be connected than other IoT-enabled protocols. JenNet-IP says the system can handle over 1,000 LUs, allowing for enormous network building. In addition, JenNet-IP, an upgraded version of 6LoWPAN, offers a sophisticated application development platform. An SLS may also create additional procedures. Z-Wave is a comparable IEEE 802.15.4 protocol to ZigBee. They are low-cost, low-power communication devices. In contrast, Z-wave allows for the creation of a mesh network rather than a single point-to-point link. The range of the devices is increased, allowing delivery even if the LCU fails. Z-Wave was private until 2016, however now that the specs have been made public, anybody may build their own Z-Wave device. In recent years, long-range wide-area networks like LoRaWAN have emerged. The LoRaWAN platform uses LoRa technology developed by the LoRa Alliance. Various protocols are discussed here, including Bluetooth Low Energy (BLE). BLE is best used for one-to-one communication, such as monitoring exercise equipment, computers, and peripherals. An inexpensive option for simple sensor networks, this network may accommodate a number of network topologies. This enables for many-to-many communication, which is unique to Bluetooth mesh. also known as wired protocols Indoor lighting (in homes, schools, and businesses) is part of a smart city's SLS. While wired protocols exist to link an SLS to a CCS, wireless methods should be used instead. DALI [21] and Power Line Communication (PLC) [20] are herewire methods for transmitting an SLS across short distances. PLI: Power line infrastructure is used for indoor and outdoor networking and communication. Using PLC in SLSs is intended to save costs by using pre-built networks. PLC-based lighting systems include two primary hardware components: a microcontroller and a PLC modem. A PLC microcontroller receives, processes, and transmits control signals to and from a PLC modem. The PLC modem modulates and demodulates data before to transmission to reduce the impacts of noise and interference. Serial connection allows for data transmission rates up to 500 Mbps between LUs. In a PLC modem with an RF transmitter, a
microcontroller receives data. PLC integrated in power wires transmits most messages and controls the whole lighting system. DALI is a lighting standard.

IEC standard, DALI uses a proprietary protocol to link lighting equipment through a bus or star network. Digital circuitry is used to set up an SLS for DALI. A Manchester-coded frame connects each LU in a DALI-enabled SLS. Sensors such as motion sensors and light sensors provide and monitor data for the command to regulate motion as well as the reaction to that command. The DALI-compatible devices must be connected to the two DALI terminals. DALI's 6-bit addresses limit it to 64 nodes. DALI benefits SLSs. DALI allows the control of devices from a variety of manufacturers. Because it does not need several processes for various goods, this light is more efficient. Less electricity is utilised, saving money. DALI's total LU capacity is 64, making it useless for street lighting. DALI data transmission speed and interoperability with wireless sensor networks have been improved by Yuan Ma et al. NRZ and MPE (Manchester Phase Encoding) are used at 9600 baud. DALI has created a new transfer layer with sensors to enhance the lighting system's utility.

4. Elements of Smart Lighting System

Sensors are the most prevalent, followed by algorithms, with everything else in between. Lighting control systems may evaluate the day, light spectrum, or occupancy to decide the final reaction. Algorithms may operate inside devices or systems to manage workloads or tasks given to them. They may also be operated on the cloud, eliminating the need to transmit command messages [22]. Algorithms may refer to many cutting-edge technological solutions that constantly shift colours, such as tunable lights, techniques that control colour response, real-time colour adjustments, and real-time techniques that help reduce energy use. Circadian cycles are often used to create aesthetically complex lighting patterns. The initial lighting design schematic presented in Fig.2 represents the main components of the design. Rather than following rigid input design requirements, autonomous algorithms are taught to react to user choice and gender. The biological clock that controls our circadian cycles, as well as numerous other systems, including as hormone release, body temperature, and circadian awareness, have all been shown to be influenced by lightweight in the last decade. Since circadian cycles rely on luminescence rather than colour correction, the spectrum of light frequencies from red to blue is more significant. Because the system may affect and control many physiological characteristics, expanding can also imply gaining power. The museum benefits from complete spectrum management in gardening, fine arts, and public gathering spaces, among other disciplines.

In a network, the physical and logical layers interact at the system device level and the device hierarchy. Using different physical topologies, such as a loop, stars, or a combination of both star and bus, increases reliability and opens up expansion options. Traditional communication networks may be placed over wireless ones utilizing cables or wireless connecting covers in physical installations. You may connect to the network through wired or wireless connections.

Lighting products have been linked with IoT networking technologies to better serve a broader variety of applications. 0-10V, DALI, Digital Multiplexer (DMX), Local Area Network (LAN), and Power Line Communication (PLC) are the primary wired interfaces used for networking. They also utilise wireless technologies like as infra-s GHz, Bluetooth, and infra-shred optical Lumina[23]. 6LoWPAN, for example, uses a physical layer focused on short range and rapid network connection.
5. Sensors for Smart Lighting Platforms

A wide range of working sensor technologies and communication techniques is what makes a smart lighting device excellent, if not what keeps it inexpensive. In contemporary IoT applications, digital sensors are used to alter lighting mechanisms to aid in adaptive operation[16,17]. If you know about low-intensity light sensors and photodiodes, can they alert you when it becomes dark? Red, green, and blue sensors are used for LED and CFL recolour (fluorescent) lighting to detect their primary colour, producing RGB material for indoor environments and optical connections, but for wireless applications, visible light communication (VLC) is the most important photodiode works technology.

Creating white light by mixing individual red, green and blue LEDs as shown in figure.3. If you know about photo resistors and photosensitive cells that react to lesser amounts of light to alter the luminous flux depending on user activity. Spectroscopy is a unique and creative characteristic that allows us to utilise these devices to collect light in the visible spectrum.
Since any type of light spectrum and any point-range is generated by a circadian lighting device, the control ability is critical to tuning the Color Rendering Index (CRI) and correlated color temperature (CCT) in real time is crucial. Sensor technologies embedded in smart lighting is presented in figure 4. As well as optimizing the lighting efficiency, it is known that sensors and controls which use LED technology may lose Luminance levels increase with age and/ decrease over time.

6. Communication Interfaces for Smart Lighting

A professional lighting system must have universal connection, either wired or wireless. DALI, PLC, and Ethernet are required for critical infrastructure and street lighting. Non-critical infrastructure lighting applications and systems may utilise Wi-Fi, ZigBee, or a commercial traffic control system. For various reasons, these indoor LED lighting systems prefer IEEE 802.15.4, VLC, Bluetooth low energy, or sub-GHz protocols. Both ZigBee Light Link and 6WAN utilise the IEEE802.15.4 Media and Super Access Point (AP) Layers. Most of them have their own code names (encoding standards) to indicate how secure they are [20,21].

Manufacturers may build systems to connect with goods using simplified standards, data centre management, or automation (IPv4 and IPv6). Although based on the IoT platform, the Open AIS project (from Europe) is creating a framework for diverse lighting systems. A standardized framework for lighting interface and extendable APIs enable the light system to be utilized in a broad variety of building systems and independent of specific cloud services.

The answer to this interoperability problem is to standardize lighting protocols, which are helpful in situations where open ecosystems with conflicting protocols are acceptable and closed ecosystems are unfeasible. In this instance, utilizing lightweight protocols like Universal Plug and Play (UDP) and TCP may extend compatibility.

7. Future Research on Smart Lighting System

As the IoT-enabled smart lighting system continues to grow, the rate of development is increasing. This part details open issues connected to the execution of smart city initiatives and the security of SLSs. A lot of issues still need to be fixed in order to further increase the efficiency of SLS. This has been around for ages. Connecting all of an SLS's components with an IoT-enabled protocol is very necessary. The Low-power Wide-Area Network (LoRaWAN) makes it possible for low-data-rate connection to be established over large geographical areas, with many different IoT devices. Several SLSs, each using a different protocol, need to communicate in order to create a centralized lighting system. Looking at an issue from many angles To link various application domains, the concept of a Smart City is essential. SLS systems allow new services to be delivered to urban regions, making SLS more versatile. In conjunction with SoLS, low-cost autonomous solutions may be made available to traffic managers via smart traffic management. Additionally, weather systems using environmental sensors, including rain sensors, temperature sensors, and humidity sensors, may be used in SLS settings. Municipal services that use SLS may be less expensive and more efficient if used with other applications. System security system As they are centrally controlled, an attacker may target SLSs because this gives them access to other connected services. This also granted the attacker complete control over the city's lighting system, which might lead to even more severe attacks or allow them to totally rule the city. Sensors may be used to alter behavioral patterns that have been anticipated. With the implementation of future smart lighting standards, future researchers will confront difficulties. Unfortunately, at this time, there is no trustable method for granting and cancelling keys. A privacy mechanism may be employed to safeguard the user's privacy, but a complete security system may not be utilised. While low-power and low-cost end devices are available, security and efficiency will be sacrificed for them. A large and rigorous security system may slow down the functioning of the system and result in an increased installation cost. Implementation of inadequate security measures may have catastrophic results.
8. Conclusion
Energy efficiency is a critical problem in an IoT-enabled smart city setting. This is a serious issue, given the anticipated population growth in urban regions over the next few decades. We have devoted this article to discussing IoT-enabled Smart Indoor and Outdoor Lighting Systems (SiLS, SoLS) in the context of a smart city, where energy consumption may be reduced and operations made more intelligent via the use of sensors and actuators. In terms of power consumption, connection, and reliable administration, a variety of Internet of Things-enabled communication protocols may be utilised to construct a successful smart lighting system. Finally, we computed and provided the power consumption for SiLS and SoLS in a variety of use cases and situations. Energy consumption in indoor and outdoor settings may be decreased by up to forty percent when IoT-enabled SLS is used instead of conventional lighting systems. Finally, we addressed the benefits of SiLS and SoLS, as well as research difficulties for those who are interested in furthering their study in these areas.

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