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Assessment of Communication Technologies Supporting Smart Streetlighting Applications

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***Abstract*— With increasing availability of Internet of Things (IoT) technologies and smart devices, many smart city applications have emerged. Smart streetlighting is one of most important building blocks in a smart city. As streetlights are widely distributed across a city and some are already networked, they have a great potential to serve as a readily available infrastructure supporting additional sensing and control devices, such as environmental sensors, traffic sensors and/or IP cameras, to provide city-wide services. To connect different sensors and actuators, communication technologies and networks are of prime importance. A variety of communication technologies are available, such as Cellular, WiMAX, LTE, SigFox, LoRa and Weightless. The objective of this paper is to review various communication technologies available for supporting different applications implemented on networked streetlights. Evaluation criteria are based on specific network requirements of different smart streetlighting applications with respect to their data rate, latency, reliability and security.**

Keywords*— *Smart streetlighting, smart city, communication technologies, and network requirements.

I. Introduction

In urban environments, streetlighting is the fundamental element that provides improvement in public comfort and security. In smart cities, a number of applications are possible with streetlighting systems, ranging from basic monitoring of light fixtures' status/power consumption and their ON/OFF/ dimming control in response to sunlight conditions or astronomical clock to advanced city-wide monitoring for air quality, traffic conditions, public safety, and much more. A typical deployment of smart streetlighting systems starts by replacing existing non-controllable, non-dimmable lights with dimmable light emitting diode (LED) light fixtures. These lights are then networked into a streetlighting system. With integration of sensors/controllers and underlying communication systems, the above lighting and non-lighting applications can be offered by networked streetlights.

In the literature, different smart streetlighting applications and their control methods are discussed. A lighting control system developed using low-cost microcontroller-based Arduino is discussed in [1]. Authors in [2] discuss lighting control using pulse-width modulation based on traffic conditions. In [3], authors design and implement a smart wireless streetlighting system equipped with LED lights and various sensors, such as, light sensor, motion sensor, current and voltage sensor. In [4], authors propose an approach to reduce the energy consumption of streetlights by taking into account the pedestrian and vehicle speed and rate of flow. In [5], authors propose an IoT based streetlighting system, which can reduce electricity usage and human intervention. In [6], authors compare different smart streetlighting projects in terms of energy savings potentials and return on investment (ROI). In [7], authors show that the energy consumption can be reduced by 20% and the average lamp life can be increased by 100% with a smart streetlighting control system.

Previous studies indicate that various communication technologies can be used to support deployment of smart streetlighting systems. Power line communications for streetlight control are discussed in [8, 9]. A simulation study in [10] reports that narrowband PLC can support streetlighting communications of up to 3.5 km without any repeater. ZigBee-based streetlighting systems are discussed in [11, 12]. In [13], authors present two smart city testbeds developed in Italy that use LoRa (Long-Range) and IEEE802.15.4 wireless communication technologies. According to their experimental results, LoRa technology can support communication range of up to 2 km in an urban environment, which is less than the expected range of 5 km.

Communication technologies being the most important elements that support various functions of networked streetlights are of focus in this paper. The objective of this paper is to compare various communication technologies --including Sigfox, LoRa, Weightless N/P, Symphony Link, RPMA, NB-IoT LTE-Cat-0/1/M, PLC, ZigBee, WLAN, Wireless Mesh, WiMAX and Cellular-- and evaluate their suitability in supporting different smart streetlighting applications. This evaluation is based on specific network requirements of different smart streetlighting applications, such as, basic and advanced lighting control, as well as non-lighting applications, such as city-wide air quality monitoring, traffic monitoring, emergency response, public safety monitoring and Wi-Fi hotspots.

II. Review of Smart Streetlighting Applications in Smart Cities

In smart cities, a number of applications are possible with a smart streetlighting system. These include:

A. Basic Streetlighting Control

This involves basic ON/OFF control of streetlighting systems based on pre-set schedules or photocells, and/or adjust the brightness of lights based on astronomical clock. Most streetlighting projects in the U.S. provide basic ON/OFF/DIM

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control. Examples of such projects are those in Boson, Detroit, Portland, Los Angeles and San Francisco [14].

B. Advanced Streetlighting Control

Advanced streetlighting controls include the integration of a broad range of control features and sensors for lighting controls in a networked lighting system. For example, ones can selectively dim individual streetlights or at a circuit level, such as the LED project in Cambridge, MA [15]. Streetlighting brightness can also be adjusted based on traffic/occupancy information and weather conditions. A pilot project in Carderock, MD [16] showcases a mean to integrate motion sensors for streetlighting control. The White Bear Lake LED project in Minnesota adjusts the color/brightness of the streetlighting system based on weather-related information from the IBM Wason [17]. Accordingly, brighter and warmer colors can be delivered during snowstorms/thunderstorms to enhance visibility and minimize glare.

C. Performance Monitoring

Networked streetlights are capable of providing electrical parameters (e.g., power consumption, voltage, current, power factor and frequency). Thus, electrical consumption of a streetlight system and malfunctioned streetlights can be monitored/detected in real-time [18].

D. Environmental/Traffic/Public Safety Monitoring

By deploying additional environmental sensors on light poles, several U.S. cities are using networked streetlights to monitor temperature, humidity and air quality of a city or a town, such as those in the city of San Diego [19]. Information about toxic chemicals, pollen counts and air pollution levels can be collected. With added noise sensors, the streetlights can also be used to detect the sound of broken glass, car crash or gunfire [20] and automatically alert police. With image sensors/cameras, the streetlights can be used to identify vacant parking spots and monitor traffic at intersections. These information is potentially valuable to inform drivers of vacant parking spaces, or adjust traffic signals. Additionally, streetlights can also be equipped with water detection sensors to measure the height of floodwater [21] and seismic sensors to measure seismic activities [22].

E. Signage, Alerts and Other Services

Inputs from sensors can be used to alert people in the vicinity of an event via digital signage and speakers. For example, the traffic level and travel time can be displayed automatically on digital signage, and storm warnings/high floodwater warnings can be announced using the speakers attached to streetlights [23]. Smart streetlights can also serve as emergency call station for use by the public to call for help. Some cities also plan to use light poles to provide Wi-Fi hotspots [24].

F. Emergency Response

There are several examples where a smart streetlighting system is used for emergency response, such as brightening lights in trouble areas to aid police navigation [25] and flashing lights to lead emergency responders to an accident scene [26].

III. BUILDING BLOCKS OF A SMART STREETLIGHTING SYSTEM

Fig. 1 depicts building blocks of a smart streetlighting system, including: (1) networked streetlights; (2) sensors; (3) smart server; (4) remote monitoring & control; and (5) audio/visual output and other optional services.

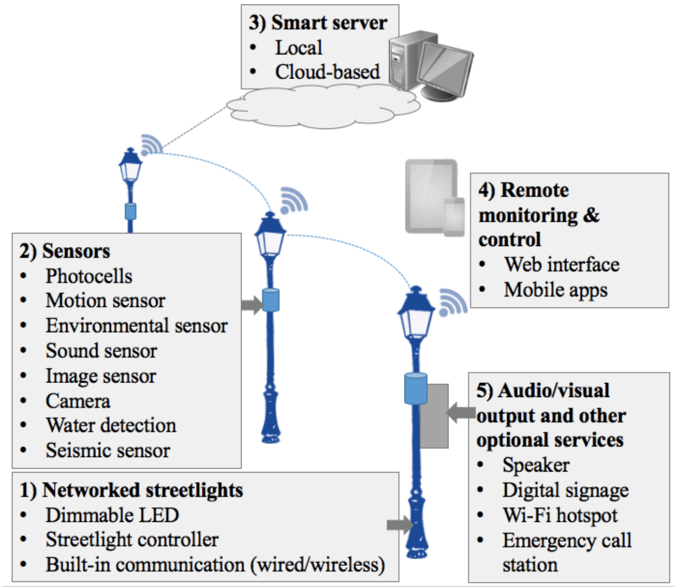

Fig. 1. Building blocks and components of a smart streetlighting system.

These building blocks are explained below:

A. Networked Streetlights

Key elements of a networked streetlighting system are: LED light fixtures, streetlight controllers and their underlying communication modules.

LED is an electronic light source based on the semiconductor diode. Compared with their high intensity discharge (HID) counterparts, e.g., high pressure sodium (HPS), metal halide (MH) and mercury vapor (MV) lamps, LEDs can deliver comparable luminous efficacy, have longer life, provide better light quality and have instantaneous responses to ON/OFF/dimming control commands [27]. In addition, LEDs contain no mercury in lamps. Because of its ability to provide instantaneous dimming control and these superior characteristics, LED has been deployed in a large number of smart lighting applications. Streetlight controllers are attached to each LED light fixtures, either inside the light fixtures or at the base of the light poles. They are responsible to perform the designated ON/OFF/ DIM control of individual or a group of light fixtures in response to commands from a central control center, which is the smart server (to be explained below). This element also allows polling information, such as failures, alarms, voltage, current, power, energy and number of burning hours, from the streetlights.

To be able to network individual streetlights, each streetlight must have a built- in communication module that allows each streetlight controller to communication with the smart server. Communication technologies selected depend on the applications to be deployed and the corresponding bandwidth needed to support selected applications. Section IV dedicates to discussion of communication technologies and network requirements of streetlighting applications.

B. Sensors

Many different types of sensors can be attached to a light pole to offer a number of interesting applications. Examples of these sensors and their corresponding applications are summarized in Table I.

TABLE I.
SENSORS FOR SMART STREETLIGHTING APPLICATIONS

Sensor	Application
Photocell	ON/OFF control based on sunlight
Motion sensor	Adjust brightness based on traffic
Environmental sensor	Monitor city-wide temperature, humidity, pollution
Sound sensor	Detect crime scenes, e.g., car crash, gunshot
Image sensor	Monitor traffic, parking violation
Camera	Provide video analysis of incident areas
Water detection	Detect flood levels
Seismic sensor	Detect seismic activities

These sensors collect large volume of real-time information, especially video cameras. Hence, edge analytics may need to be deployed for pre-processing recorded information, detecting abnormalities and transmitting only important information to the smart server. This will speed the response time and reduce the data burden from the underlying communication networks.

C. Smart Server

Traditionally, a smart server for controlling the networked streetlights is solely responsible for polling information about lamp status, energy use and running hours from the streetlight controllers; and issuing control commands to change light status (ON/OFF/DIM) based on inputs from photocells and astronomical clocks.

With the deployment of different types of sensors, the smart server must be capable of accepting and processing readings from a variety of sensors and performing the desired actions. For example, if motion/occupancy sensors are used in a parking lot area, the smart server should be able to increase the brightness of light fixtures upon detecting vehicle/pedestrian motions. The light intensity should also be gradually decreased after several (preset) minutes of inactivity. If other sensors are used for city-wide monitoring or public safety applications, the smart server should be able to forward the data to the corresponding server(s) for further data processing and analysis. Depending on specific deployments, the smart server can be a local solution, where a physical computer is located in a building for monitoring and control of networked streetlights, or a cloud-based solution, where the smart server is located on a commercial/private cloud server.

D. Remote Monitoring & Control

The ability to remotely monitor and control the networked streetlights, as well as visualize collected data from different sensors are of importance. At the minimum, authorized individuals should be able to monitor real-time streetlight status, obtain energy consumption information, and send ON/OFF/DIM control commands. With additional sensors supporting non-lighting applications, an enormous amount of data is now generated. Hence, data visualization and interpretation have become a challenge. There is now the need to leverage the power of data analytics, machine learning and graphics processing unit (GPU) computing to analyze and visualize such complex spatial, temporal and continuously streaming data.

E. Audio/Visual Output and Other Optional Services

Lastly, optional elements of a smart streetlighting system may include: speakers that allow any warning announcements; digital signage that allow display of visual output; Wi-Fi hotspots for internet services; and emergency call stations.

III. VARIOUS COMMUNICATION TECHNOLOGIES SUPPORTING SMART STREETLIGHTING APPLICATIONS

A comparison of various communication technologies for smart streetlighting applications in terms of data rate and coverage distance is presented in Table II. These technologies, including Sigfox, LoRa, Weightless N/P, Symphony Link, RPMA, NB-IoT LTE-Cat-0/1/M, PLC, ZigBee, WLAN, Wireless Mesh, WiMAX and Cellular, are discussed below.

SigFox is one of the low-power wide area networking (LPWAN) technologies using a proprietary protocol to achieve longer range data communication at low data rate, e.g., <1 kbps. It supports the star topology in terms of the communication network architecture, and uses unlicensed ISM bands, i.e., 868MHz in Europe and 902MHz in the US. It provides data rate of up to 1 kbps with the coverage distance of up to 50 km in rural and 10 km in urban areas.

LoRa is another low-power and long-range wireless (LPWAN) technologies. It was originally developed by Semtech, and now is managed by the LoRa Alliance [28]. LoRaWAN is a well-known protocol specification built on top of the LoRa technology. It is deployed in a star topology, where a gateway is needed to communicate between end-devices and a central unit. It also operates in ISM band radio frequency spectrums, i.e., 433, 868 and 915 MHz. It provides data rate of up to 50 kbps with the coverage distance of up to 20 km in rural and 5 km in urban areas [29].

Weightless is one of the narrowband LPWAN technologies, developed by the Weightless Special Interest Group (SIG) [30] for IoT devices. Weightless SIG offers three different protocols, namely Weightless-W, Weightless-N, and Weightless-P.

The Weightless-W technology is designed to operate in the TV white space (TVWS) spectrum. It is not suitable for IoT applications due to the rules and regulations for utilizing TVWS and difficulties in building a small antenna to work with the Weightless-W devices. Weightless-N is an ultra-narrowband system, which is similar to SigFox and LoRa. Weightless-P is the latest Weightless technology. The ranges of Weightless-W and Weightless-N are around 5 km in urban environments, while Weightless-P offers a range of around 2 km [31].

Weightless-N is typically deployed in the unlicensed ISM spectrum, i.e., 868 MHz band in Europe and 915 MHz in the US. It provides data rate of up to 100 kbps. Weightless-N is designed to reduce power consumption, i.e., a battery lifetime up to 10 years.

Weightless-P also provides data rate of up to 100 kbps over the whole range of license-exempt sub-GHz ISM, i.e., 169, 433, 470, 780, 868, 915 and 923 MHz. Cost and power consumption of the devices using Weightless-P are higher than those of the devices using Weightless-N. For example, a battery lifetime for Weightless-P devices can be up to 3-8 years [32].

Symphony Link is one of the proprietary LPWAN technologies developed by Link Labs[33]. It offers

TABLE II.
COMPARISON OF SELECTED COMMUNICATION TECHNOLOGIES

`	Standard/ Protocol	Max. Theoretical Data Rate	Coverage Range	Technology	Standard/ Protocol	Max. Theoretical Data Rate	Coverage Range
SigFox	SigFox	1 kbps	10 km (urban) 50 km (rural)	PLC	X10	120 bps	up to 0.3 km
					Insteon	13 kbps	up to 3 km
LoRa	LoRa	50 kbps	5 km (urban) 20 km (rural)		CE Bus	10 kbps	up to 3 km
					LonWorks	1.25 Mbps	up to 3 km
Weightless	Weightless-N	100 kbps	up to 5 km	ZigBee	ZigBee	250 kbps	up to 100 m
	Weightless-P	100 kbps	up to 3 km		ZigBee Pro	250 kbps	up to 1,600 m
Symphony Link	Symphony Link	100 kbps	5 km (urban) 15 km (rural)	WLAN	802.11x	2-600 Mbps	up to 100 m
RPMA	RPMA	634 kbps (uplink) 156 kbps (downlink)	3 km (urban) 50 km (rural)	Wireless mesh	Various (e.g., 802.11, 802.15, 802.16)	Depending on selected protocols	Depending on deployments
NB-IoT	LTE Cat NB1	200 kbps	5 km (urban) 20 km (rural)	WiMAX	802.16	75 Mbps	up to 50 km
LTE-Cat	LTE-Cat-0	1 Mbps	5 km (urban) 50 km (rural)	Cellular	2G	14.4 kbps	up to 50 km
	LTE-Cat-1	10 Mbps (Downlink)			2.5G	144 kbps	
					3G	2 Mbps	
		5 Mbps (Uplink)			3.5G	14 Mbps	
	LTE-Cat-M	1 Mbps			4G	100 Mbps	

four times more capacity than LoRaWAN [34]. It also operates in unlicensed ISM band radio frequency spectrums, i.e., 868 or 915 MHz. It provides data rate of up to 100 Kbps with the coverage distance of up to 15 km in rural and 5 km in urban areas [29].

Random Phase Multiple Access (RPMA) is a proprietary LPWAN technology for machine-to-machine (M2M) communication, developed by Ingenu in 2018 [35]. It operates in the 2.4 GHz spectrum, like WiFi, ZigBee and Bluetooth. RPMA has a significantly higher link budget, i.e., better coverage, than SigFox and LoRa [36]. The RPMA technology has high coverage and capacity. It allows to build very inexpensive networks capable of servicing hundreds of square kilometers and millions of devices with one tower. It generally offers the coverage distance of up to 50 km in rural and 3 km in urban areas. It data rate of up to 634 kbps and 156 for uplink and downlink, respectively [37].

Narrowband-IoT (NB-IoT), known as LTE Cat NB1, is one of the LPWAN technologies, which was set up by 3GPP [38]. It uses fundamental protocol stack of Long-Term Evolution (LTE) to reduce device costs and minimize battery consumption. Therefore, it does not support many features of LTE, such as, handover, measurements to monitor the channel quality, carrier aggregation, and dual connectivity. It uses the licensed LTE frequency bands [39], and typically works on a slightly higher bandwidth than LoRaWAN. NB-IoT eliminates the need for dedicated gateways, required by LoRa. NB-IoT infrastructure allows to connect a base station with sensors directly. It provides data rate of up to 200 kbps with the coverage distance of up to 20 km. NB-IoT operates at 700 MHz, 800 MHz, 900 MHz or other frequency bands less than 1 GHz.

LTE-M, commonly known as LTE Cat-M1, is the abbreviation for Long Term Evolution Category M1. LTE end-devices generally offer high data rate services at high power consumption. Due to its high power consumption, this is not suitable for IoT applications. To overcome these issues, 3GPP has published different LTE-based technologies, such as LTE Category 0 (LTE-Cat-0), Category 1 (LTE-Cat-1) and LTE Category M (LTE-Cat-M1). LTE-M is seen as the second generation LTE technology for IoT applications, which reduces the cost and power consumption of first generation technologies, i.e., LTE Cat-0 and LET Cat-1. LTE-M allows IoT devices to connect directly to a 4G network without a gateway [40]. It uses licensed spectrum, unlike Sigfox and LoRa. This allows LTE-M to avoid potential interference issues generated by the other wireless devices in the unlicensed spectrum. It is also compatible with an existing LTE network, and allows carriers to integrate IoT devices without building new antennas. LTE-M operates in the licensed sub-GHz band at between 700 MHz and 900 MHz. It provides data rate of up to 1 Mbps with the coverage distance of 50 km in rural and 5 km in urban areas. One disadvantage of LTE-M is that it requires its own SIM card.

Power line communication (PLC) is a wired communication technology using existing power lines for data transmission. It is a cost effective technology due to the use of existing infrastructure. A high frequency carrier is injected into power lines and modulated the carrier with the data to be transmitted. On the other hand, it has significant technical issues, such as its inability to transmit signals cross a transformer(s), power line channel distortion, interference, noise, harsh conditions of the power line environment, and security concerns [41]. Although wireless communication technologies have been used for streetlighting projects, PLC is still the leading technology used for streetlighting controls. In the market, there are well established PLC technologies, e.g., X10, Insteon, LonWorks and CE Bus. These PLC technologies typically provide a data rate of up to 120 bps-1.25 Mbps with the coverage range of up to 0.3-3 km. PLC is suitable especially for applications that do not have other existing communication infrastructures.

ZigBee is a wireless communication technology based on the IEEE 802.15.4 standard for personal area networks. It operates on unlicensed ISM radio frequency bands, i.e., 868 MHz in Europe, 915 MHz in the US, and 2.4 GHz worldwide. It supports the data rate from 20kbps to 250kbps, i.e., 250kbps at 2.4GHz, 40kbps at 915MHz, and 20kbps at 868MHz. ZigBee provides the coverage distance of up to 100 meters, while ZigBee Pro provides the coverage distance of up to 1,600 meters. It supports various network topologies, including star, tree and mesh topologies. It is a cost-effective, low-power, high-efficiency and secured wireless communication technology for short-range data transmission at low data speed. ZigBee faces severe interference problems in the presence of various networks due to sharing same channel spectrum with some protocols, such as, Wi-Fi and Bluetooth [**Error! Reference source not found.**41]. ZigBee is a good candidate for smart city applications, e.g., traffic control and smart streetlighting, etc.

Wireless Local Area Network (WLAN), known as Wi-Fi, is a high-speed wireless communication technology for local area networks. It is based on the IEEE 802.11 series of standards, i.e., 802.11, 802.11a, 802.11b, 802.11g and 802.11n. It operates in 2.4 GHz, 3.6 GHz and 5 GHz unlicensed ISM radio frequency bands. The IEEE 802.11x standards specify data rate from 2 Mbps to 600 Mbps, and the coverage range of up to 100 meters. The cost and power consumption of WLAN products are higher than other short-range wireless technologies such as ZigBee and Bluetooth [41]. In a mesh topology, Wi-Fi can be a good candidate for smart city applications, e.g., surveillance, traffic control and smart streetlighting, etc.

Wireless Mesh is a cost-effective, robust and flexible wireless network technology, consisting of many nodes, i.e., mesh clients and routers. In a wireless mesh network, each node can act as a signal repeater and automatically route messages from one node to another, i.e., dynamic routing. If one node can no longer operate, the rest of the nodes can still communicate with each other, directly or through one or more nodes. It helps increase the robustness. A wireless mesh network can provide a wide coverage range due to its ability to perform multi-hop routing. While a traditional wireless network may spread throughout a building or a neighborhood, a wireless mesh network can cover a much larger area, such as a city. Mesh networks can be implemented with various wireless technologies, i.e., 802.11, 802.15 and 802.16 [41]. Since wireless mesh networks have the advantage of being easy to implement, cost-effective, extend and automatically self-healing, they are becoming a key technology to serve many smart city applications, such as smart streetlighting, smart metering, traffic control, etc.

WiMAX is a 4G wireless technology for Metropolitan Area Networks (MAN). It is based on the IEEE 802.16 series of standards, i.e., IEEE 802.16-2004, 802.16e. It operates in the 2.3, 2.5, 3.3, and 3.5 GHz frequency bands, as well as the unlicensed 5.8 GHz band. It provides data rates of up to 75 Mbps with the coverage distance of up to 50 km, and has low latency (10-50 ms). WiMAX is a high speed, reliable and long distance wireless technology. It can serve hundreds of users with a single base station. The WiMAX standard natively supports quality of service and real-time two-way broadband communications between nodes [41]. This makes WiMAX a good candidate for smart city applications, including smart streetlighting, smart meter readings, traffic light management, and backhaul to public Wi-Fi networks, remote link to video surveillance cameras, and more. WiMAX technology can also provide a backhaul network infrastructure to transfer communication data from end users or nodes to the central network for such communication technologies, e.g., Wi-Fi and ZigBee [42].

Cellular is a radio network technology using a large number of transmitters to create cells. Cellular systems allow reusing frequencies to increase both coverage and capacity. Telecommunications industry divides cellular technologies into four generations that are labeled 1G, 2G (GSM), 3G (UMTS), and 4G (WiMAX and LTE) with intermediate versions labeled 2.5G (GPRS and EDGE) and 3.5G (HSPA). Cellular systems commonly operate in 850, 900, 1800, and 1900 MHz frequency bands. 3G/4G cellular is a high-speed, low latency, secure and long distance wireless communication technology. Availability of existing cellular communication infrastructure provides fast installation and cost-effectiveness. Cellular services are shared with mobile customers, which may lead to congestion and reduction the network performance [41]. Cellular systems can be a good candidate to provide communication for smart city applications, such as smart metering, smart street lighting, traffic control, and video surveillance, etc.

IV. Network Requirements of Various Smart Stretlighting Applications

Understanding network requirements of different smart streetlighting applications provides a guideline to which solution(s) are suitable for each application in the smart city environment. These applications include basic streetlighting control, advanced streetlighting (motion/traffic-based and weather-based) control, performance monitoring, environmental and traffic monitoring, signage and alerts, emergency response, and public safety monitoring. Specific network requirements of smart street lighting applications in terms of their data rate, latency, reliability and security are summarized in Table III. These requirements vary from applications to applications, and influence choices of communication technologies selected.

For basic streetlighting control and motion/traffic-based control with low data rate and latency requirements, LPWAN communication technologies, including SigFox, LoRa, Weightless N/P, Symphony Link, RPMA, NB-IoT, are the most suitable. This is in addition to PLC, ZigBee and wireless mesh communication technologies.

For weather-based control, performance and environment monitoring, and signage and alerts, communication technologies offering medium data rate and latency requirements are required. These are Weightless N/P, Symphony Link, RPMA, NB-IoT, LTE-Cat-1/M PLC, ZigBee, and wireless mesh.

The traffic monitoring, emergency response, and public safety applications are more critical than the other applications. Therefore, they require communication networks that have higher data rate and lower latency than the others. Such communication technologies as LTE-Cat-0/1/M, WLAN, wireless mesh, WiMAX and cellular, can meet these network requirements. In addition, the mesh topology of WLAN can be considered as one of the suitable technologies, which can provide low cost, easy-to-deploy backhaul infrastructure for those applications, especially public safety.

TABLE III.
NETWORK REQUIREMENTS OF SMART SREETLIGHITNG APPLICATIONS AND COMMUNICATION TECHNOLOGIES THAT CAN MEET THE REQUIREMENTS

Application	Data rate	Latency Require-ment	Reliability	Security	Communication technologies												
					SigFox	LoRa	Weightless N/P	Symphony Link	RPMA	NB-IoT	LTE-Cat0/1/M	PLC	ZigBee	WLAN	Wireless Mesh	WiMAX	Cellular
Basic (ON/OFF/DIM)	Low	Low	High	High	X	X	X	X	X	X		X	X		X		
Motion/traffic-based control	Low	Low	High	High	X	X	X	X	X	X	X	X	X		X		
Weather-based control	Medium	Medium	High	High			X	X	X	X	X	X	X		X		
Performance monitoring	Medium	Medium	Medium	Medium			X	X	X	X	X	X	X		X		
Environmental monitoring	Medium	Medium	Medium	Medium			X	X	X	X	X	X	X		X		
Signage and alerts	Medium	Medium	High	High			X	X	X	X	X	X	X		X		
Traffic monitoring	High	High	High	High							X			X	X	X	X
Emergency response	High	High	High	High							X			X	X	X	X
Public safety monitoring	High	High	High	High							X			X	X	X	X

V. CONCLUSION

Selection of suitable communication technologies to support various smart streetlighting applications is crucial to the successful implementation of a smartligting project. This paper compares various communication technologies and identifies their suitability to support such applications, including basic streetlighting control, advanced streetlighting (motion/traffic-based and weather-based) control, performance monitoring, environmental and traffic monitoring, signage and alerts, emergency response, and public safety monitoring. Communication technologies under discussion are Sigfox, LoRa, Weightless N/P, Symphony Link, RPMA, NB-IoT LTE-Cat-0/1/M, PLC, ZigBee, WLAN, Wireless Mesh, WiMAX and Cellular. These technologies are compared in terms of their data rate and coverage range. Network requirements of various smart streetlighting applications based on data rate, latency, reliability and security, are also discussed.

Low-power wide area network (LPWAN) communication technologies are suitable for most of the smart streetlighting applications, especially basic streetlighting control, advanced streetlighting (motion/traffic-based and weather-based) control, performance and environmental monitoring, signage and alerts. This is because these applications have low/medium data rate and latency requirements. However, such communication technologies offering high speed at very low latency can be used for other non-lighting applications, such as, traffic monitoring, emergency response and public safety monitoring, which have higher data rate/latency requirements.

It is expected that this paper will benefit researchers and engineers working in smart city applications, in particular smart streetlighting, by providing an insight into how various communication technologies fit into the smart city context.

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