Research Article

Smart Lighting System for Efficient Street Lighting

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Abstract

Energy Management is one of the serious concerns all over the world. The Development Plan with respect to the management of Power and Energy has been incorporated in Sri Lanka's development drive as well. The energy management has been identified as one of the key factors that would help the country in becoming an internationally competent middle-income country. In this context, the energy wasted for street lighting is one of the serious issues and the utilization of smart computing could be an optimal solution for this. This paper has proposed an efficient and commercially viable smart lighting system for streetlights in Sri Lanka, which is backed by Internet of Things (IoT), in conjunction with sensors and actuators augmented in lampposts. The proposed system is comprised of modules that assist for proactive monitoring, create alerts for proper maintenance support and cut off energy waste by dimming or switching off on demand. Further, energy usage can also be tracked through embedded intelligent energy meters and it provide the platform for data scientists and authorities to analyze the periodic reports generated based on usage status, lighting performances and run hours. This system would provide a positive economical return on investment.

Keywords: *Smart lighting, energy efficient, internet of things (iot)***,** *sensors and actuators, zigbee module*

1. Introduction

Sri Lanka is the only country in South Asia that has 100% electricity accessibility with 24 hours uninterrupted power supply (Ministry of Power and Renewable Energy, 2017). The annual total electricity demand of Sri Lanka is accounted as 10,500 GWh, comprising of 38% from domestic consumers, 39% from industries and 20% from commercial enterprises, with the balance coming from other sectors such as religious organizations and street lighting says the report (Ministry of power and energy, 2015).

The same report identifies Energy wastage & losses and unsustainable consumption patterns as major challenges to the energy sector in Sri Lanka. Hence, a strategic balance between the national electricity demand and its supply needs to be upheld for the power and energy sector of Sri Lanka to become an energy self-sufficient nation by the year 2030, while addressing the challenges identified strategically.

Street lighting is one of the essential community services. However, the current implementation practices are not energy efficient and leads to more wastages. The improper switching of street lights due to non-optimized scheduling, increased manpower cost resulting from human intervention, cost incurred for operation and maintenance due to reactive monitoring could be identified as potential causes of inefficiency in street lighting. Thus, the electricity demand for street lighting is high and it in turn demands the municipalities to spend nearly 40% of their allocated budget for street lighting alone (Cacciatore *et al.*, 2017).

The Table 1 shows the Electricity Sales categorized by their provinces from year 2014- 2017 (*Economic and Social Statistics of Sri Lanka 2018*, 2018). From the particular table, it can be interpreted that, the amount of electrical energy used by street lighting is considerably greater around 100 GWh and it increases annually.

The demand for electricity is growing at a rate of 6% per year, which means that an additional 100 MW of electricity is needed to be appended to the existing generation capacity annually. (Ministry of Power and Renewable Energy, 2017). On the other hand, the technical and commercial losses of the electricity transmission is being another factor that escalate the electricity demand rate even higher.

Therefore, in order to achieve the target of reducing the technical and commercial losses of the electricity transmission and distribution network from 11% to 8% by the year 2020 as stipulated by the Energy Sector Development Plan for a Knowledge-Based Economy 2015-2025, and to outgrow Sri Lanka as an energy self-sufficient nation by the year 2030, this paper proposes a commercially viable “Smart Lighting System for Efficient Street Lighting” as a Demand Side Management Program.

Table 1: Electricity sales categorized by their provinces from year 2014- 2017

Province & Type of Sale	Units in GWh				Revenue, Rs. Mn.				No. of Consumer Accounts			
	2014	2015	2016	2017	2014	2015	2016	2017	2014	2015	2016	2017
Colombo City												
Domestic	243.06	251.71	268.26	270.46	7,712.54	6,457.80	7,045.00	7,087.00	134,589	136,943	138,838	140,797
Religious	7.74	7.89	8.73	9.01	67.49	70.23	76.62	79.52	870	878	889	899
Industrial	159.71	161.64	180.52	178.00	2,685.54	2,445.63	2,695.97	2,645.02	396	392	384	374
Commercial	869.14	897.81	948.94	992.79	23,401.28	21,046.89	22,534.18	23,338.79	33,741	34,430	35,017	35,523
Street Lighting	9.71	9.71	9.74	9.71	–	–	–	–	–	–	–	–
Total	**1,289.36**	**1,328.76**	**1,416.19**	**1,459.95**	**33,866.85**	**30,020.55**	**32,351.76**	**33,150.33**	**169,596**	**172,643**	**175,128**	**177,593**
Western Province[(a)]												
Domestic	979.37	1,067.75	1,150.72	1,186.88	17,705.36	16,331.87	18,475.56	19,202.42	1,053,449	1,081,055	1,117,146	1,142,260
Religious	11.55	12.32	13.43	14.02	84.66	91.09	99.72	105.53	5,146	5,314	5,470	5,643
Industrial	1,920.31	1,995.55	2,121.36	2,260.84	31,456.09	29,065.59	30,475.93	32,870.36	10,846	10,828	10,854	10,821
Commercial	582.90	614.95	694.88	765.86	15,761.37	14,363.09	16,045.91	17,555.56	131,077	138,485	147,617	157,394
Street Lighting	39.31	39.33	39.44	39.35	–	–	–	–	–	–	–	–
Total	**3,533.43**	**3,729.89**	**4,019.82**	**4,266.96**	**65,007.47**	**59,851.64**	**65,097.12**	**69,733.87**	**1,200,518**	**1,235,682**	**1,281,087**	**1,316,118**
Central Province												
Domestic	506.03	554.06	582.93	605.56	6,209.57	5,832.10	6,322.49	6,669.62	783,624	806,642	847,188	866,266
Religious	8.91	9.53	10.19	10.72	57.86	62.78	67.56	72.29	5,934	6,113	6,343	6,555
Industrial	268.13	285.05	301.51	307.36	4,589.92	4,313.85	4,542.13	4,682.22	3,828	3,904	3,976	4,031
Commercial	252.37	276.66	309.61	334.70	6,708.43	6,287.63	7,015.66	7,549.22	90,209	94,758	99,693	105,282
Street Lighting	7.61	7.61	7.63	7.61	–	–	–	–	–	–	–	–
Total	**1,043.04**	**1,132.91**	**1,211.87**	**1,265.95**	**17,565.78**	**16,496.37**	**17,947.84**	**18,973.34**	**883,595**	**911,417**	**957,200**	**982,134**
Southern Province												
Domestic	393.06	432.64	462.96	477.75	4,762.87	4,541.55	5,114.11	5,317.62	610,186	629,302	654,437	667,344
Religious	6.33	6.81	7.50	7.66	42.85	47.06	52.54	53.46	3,540	3,707	3,895	4,068
Industrial	269.44	263.76	274.06	284.62	4,456.64	3,903.15	4,022.86	4,199.29	4,441	4,594	4,763	4,944
Commercial	198.78	215.86	260.70	283.57	5,112.70	4,785.16	5,696.96	6,188.21	61,149	64,514	68,736	73,562
Street Lighting	10.45	10.47	10.50	10.50	–	–	–	–	–	–	–	–
Total	**878.05**	**929.54**	**1,015.73**	**1,064.10**	**14,375.05**	**13,276.92**	**14,886.46**	**15,758.59**	**679,316**	**702,117**	**731,831**	**749,918**
Northern Province												
Domestic	138.10	162.00	185.01	213.64	1,906.07	1,879.48	2,242.17	2,601.71	207,844	234,393	267,250	295,985
Religious	5.54	6.02	7.05	7.89	37.54	43.09	48.52	54.50	3,675	4,003	4,404	4,726
Industrial	20.67	26.12	29.81	31.85	380.72	421.72	481.80	521.28	3,518	3,764	4,101	4,640
Commercial	93.69	105.03	118.68	128.97	2,506.53	2,426.91	2,734.29	2,956.46	26,682	28,103	30,802	34,069
Street Lighting	1.63	1.63	1.63	1.63	–	–	–	–	–	–	–	–
Total	**259.62**	**300.79**	**342.19**	**383.98**	**4,830.86**	**4,771.20**	**5,506.77**	**6,133.95**	**241,719**	**270,263**	**306,565**	**339,420**
Eastern Province												
Domestic	255.73	294.85	330.71	352.63	3,423.73	3,436.67	4,060.40	4,323.80	370,193	392,297	426,889	459,151
Religious	5.52	6.18	6.99	7.64	37.76	42.75	49.05	54.09	2,942	3,168	3,389	3,612
Industrial	124.81	123.13	136.16	141.09	2,036.71	1,805.15	1,998.68	2,085.15	4,960	5,048	5,081	5,155
Commercial	113.34	127.94	147.60	166.58	2,990.57	2,902.05	3,306.38	3,742.47	39,919	41,934	44,594	48,777
Street Lighting	4.86	4.86	4.87	4.86	–	–	–	–	–	–	–	–
Total	**504.25**	**556.95**	**626.32**	**672.80**	**8,488.76**	**8,186.62**	**9,414.52**	**10,205.51**	**418,014**	**442,447**	**479,953**	**516,695**
North Western Province												
Domestic	430.31	476.62	523.35	552.91	5,704.96	5,428.12	6,269.78	6,688.49	621,905	649,175	687,209	710,384
Religious	7.27	7.84	8.69	9.28	46.97	51.65	58.46	63.08	4,604	4,734	4,874	5,013
Industrial	461.47	468.97	503.04	509.87	7,576.76	6,880.41	7,370.92	7,502.63	16,517	17,696	18,149	19,159
Commercial	167.63	184.23	207.32	230.27	4,582.48	4,278.82	4,785.80	5,314.87	77,445	81,520	86,962	94,362
Street Lighting	27.37	27.37	27.44	27.37	–	–	–	–	–	–	–	–
Total	**1,094.05**	**1,165.03**	**1,269.84**	**1,329.70**	**17,911.17**	**16,639.00**	**18,484.95**	**19,569.07**	**720,471**	**753,125**	**797,194**	**828,918**
North Central Province												
Domestic	202.65	223.43	249.87	262.38	2,309.30	2,229.69	2,615.14	2,762.63	327,480	343,252	372,484	382,469
Religious	4.59	4.38	4.99	5.53	30.01	31.15	35.80	40.02	2,053	2,156	2,243	2,332
Industrial	95.38	100.62	125.84	127.24	1,737.76	1,637.45	2,008.17	2,047.20	6,164	6,378	6,685	6,992
Commercial	99.45	107.48	123.48	132.07	2,631.81	2,442.61	2,798.15	2,998.70	36,970	38,988	41,491	44,381
Street Lighting	2.08	2.08	2.09	2.08	–	–	–	–	–	–	–	–
Total	**404.15**	**437.99**	**506.27**	**529.29**	**6,708.88**	**6,340.89**	**7,457.26**	**7,848.56**	**372,667**	**390,774**	**422,903**	**436,174**
Uva Province												
Domestic	154.48	174.12	188.89	197.10	1,527.02	1,494.43	1,675.68	1,756.52	293,387	308,030	328,683	342,593
Religious	2.62	2.83	3.06	3.09	16.15	17.67	19.24	19.86	2,157	2,290	2,427	2,597
Industrial	52.85	55.03	56.81	61.10	935.98	865.18	887.96	975.38	2,314	2,428	2,673	2,796
Commercial	67.22	68.48	83.01	88.07	1,825.58	1,592.87	1,905.58	2,038.14	27,929	29,265	30,839	33,447
Street Lighting	0.97	0.97	0.97	0.97	–	–	–	–	–	–	–	–
Total	**278.13**	**301.42**	**332.74**	**350.32**	**4,304.73**	**3,970.15**	**4,488.46**	**4,789.89**	**325,787**	**342,013**	**364,622**	**381,433**
Sabaragamuwa Province												
Domestic	218.63	239.23	255.61	265.53	2,416.51	2,297.57	2,537.76	2,659.85	365,572	386,306	403,309	417,811
Religious	3.05	3.20	3.50	3.65	19.28	20.45	22.62	23.72	2,254	2,347	2,448	2,554
Industrial	125.66	127.68	134.99	141.16	2,158.58	1,962.66	2,064.35	2,165.59	1,593	1,649	1,715	1,782
Commercial	75.15	82.51	92.67	98.77	2,037.02	1,906.38	2,135.88	2,275.26	36,428	38,347	40,237	42,579
Street Lighting	4.37	4.37	4.38	4.37	–	–	–	–	–	–	–	–
Total	**426.85**	**457.00**	**491.15**	**513.47**	**6,631.40**	**6,187.06**	**6,760.61**	**7,124.41**	**405,847**	**428,649**	**447,709**	**464,726**
Transmission Bulk Supply to LECO	**1,352.19**	**1,446.00**	**1,553.18**	**1,594.95**	**24,980.67**	**22,295.38**	**24,496.28**	**23,776.33**	**1**	**1**	**1**	**1**
Grand Total	**11,063.11**	**11,786.28**	**12,785.29**	**13,431.46**	**204,671.63**	**188,035.77**	**206,892.04**	**217,063.85**	**5,417,532**	**5,649,132**	**5,964,194**	**6,193,130**

(a) Excluding Colombo city.

Note 1: Transmission Bulk Supply to LECO is accounted as one account.

Note 2: Street Lighting Consumer Accounts are accounted as one account.

Source : Ceylon Electricity Board

2. Related Work

Street lights and city-wide lighting infrastructure could be the backbone for building smart cities, says Barbara Kreissler, the director of professional lighting at connected lighting company Signify (Sam Forsdick, 2019). Various researchers around the world have come up with different solutions to save energy wasted through street lighting.

A street lamp monitoring system has been developed by a group of students of Indian Institute of Science (IISC), Bangalore, India, using Xbee wireless module (Satyan Raj Prakash *et al.*, 2010). This system consists of three modules namely Lamp module, Microcontroller module and the Lamp Status Transmission module. The system is connected to a control center using Xbee wireless module. Figure 1 below shows the simplified block diagram of the developed system.

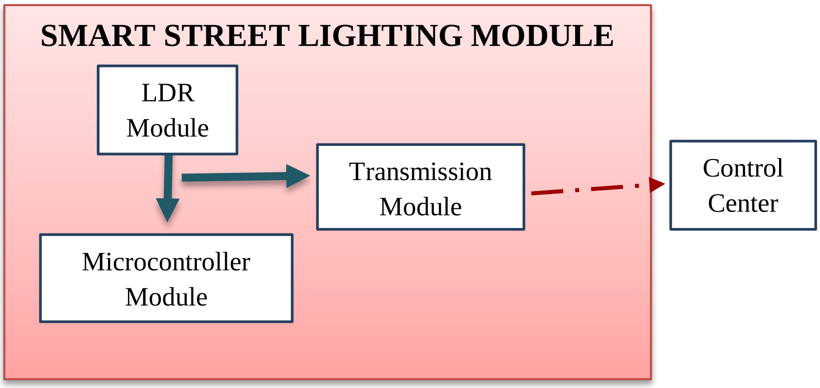

Figure 1: Block diagram of smart street lamp monitoring system

This system used two LDRs, one for detecting whether the time of the day is either day or night and this is placed above the street lamp. The second LDR is placed below the street lamp to monitor the health status of the lamp. The voltages obtained from both the LDRs are sent to the Microcontroller Module, which is converted into digital values using an ADC converter. These digital values are then compared with the reference values predefined in the microcontroller to check the health status of the lamp. If the lamp is found to be faulty, the ID of the respective lamp is sent to the Transmission Module.

A wireless Xbee module is used for transmitting the data received from the microcontroller module to the control center via a wireless network. Based on the data received from the transmission module, the control center monitors the health status of the street lamps and prepares a list of faulty lamps which is later sent to a computer at the control station (Satyan Raj Prakash *et al.*, 2010). This system only aims to monitor and identify the health status of the lamps whereas it fails the feature of automatic switching on and off of street lamps.

Hu *et al.*, (2012) propose an architecture of a smart lighting system for a daylit office. They have used lighting controller, A/D and D/A converter, dimmable LED lights and the lighting management software. In the year 2013, Majlis Bandaraya Shah Alam (MBSA) together with WSN Company in Malaysia has deployed a smart street lighting system (Yusoff *et al.*, 2013), to save electrical energy and the system is controlled using a kinetic sensor. An intelligent street lighting system using two types of sensors, wireless sensor network (WSN) and pyroelectric infrared sensors (PIR) has been developed by researchers in India. It also uses the ZigBee device (Chetna & Palak, 2013).

Another smart street lighting system has been implemented in the center of the Luxembourg city of an area of 1.11 km^2, comprising of 537 lampposts. The Dimming methodology along with the LED technology has been deployed and this has resulted in a higher energy savings in the city (Cacciatore *et al.*, 2017). A street lighting system for urban and rural areas with less traffic has been implemented to avoid unnecessary usage of electricity. This system automatically switches on and off street lights depending on the intensity of the sunlight of the environment (Kokilavani & Malathi, 2017). Majority of the systems have been implemented using LED lamps compared to the HPS lamps due to its low power consumption, high luminous efficiency, long lifespan and less light pollution (*Comparison Chart HPS Light vs LED Street Light - Street Lighting - Outdoor LED Lighting*, no date). Different technologies with different approaches for system implementations have been carried out in order to obtain an efficient and a cost-effective smart street lighting system.

Few real-world examples for cities, which have implemented smart streetlights, are Dutch city of Tilburg, Nuenen city in Netherland, Copenhagen in Denmark, Smart City Barcelona in Spain, New York City in USA, and Shanghai in China and so on.

2.1 Smart Lighting Solution/Methodologies

The world is moving towards smart energy management, which in turn require changes in the system not only on how the energy is supplied, but also on also how it could be efficiently consumed. A number of recent research works have been carried out to automate the streetlights since lighting national highways to small streets consumes a large amount of electrical energy. Accordingly, there are several smart lighting solutions presented by researchers which could be implemented either in distributed or centralized manner. In a centralized system, the lamp posts use a coordinator unit to control lighting which is determined by the feedback on the presence of users around the lampposts (Viani *et al.,* 2016) whereas in a distributed system, each lamppost operate independently. Occupancy is an important factor in the context of automatic switching on/off or dimming of lights and distributed systems are highly preferable as they are capable of saving higher energy (Cacciatore *et al.,* 2017). Delay-Based (DEL), Encounter-based (ENC) and Dimming (DIM) are the three new heuristics proposed as smart lighting solutions (Cacciatore *et al.,* 2017) as an alternative to the currently employed methodology (CUR), which is letting the lampposts remain active continuously for an average of 10 to 12 hours a day.

2.1.1 Delay-based (DEL)

The lamp is off when no one is sensed by a motion sensor at a defined vicinity and during a time window W when nobody passes nearby. But, whenever the presence of user is sensed within a predefined distance R, the lampposts re-activate and operates at full intensity. Both LEDs and HPSs lamps could be used for this methodology. But LED lamps are highly preferable for DEL methodology since HPSs lamps take around 15 minutes to reach the maximum brightness from the time it turns on (García *et al.,* 2014).

2.1.2 Encounter-based (ENC)

This methodology is similar to DEL with a little modification in it. Here, the lampposts turn on when the motion sensor senses the presence of a user who comes first and remains active during a predefined active period in the morning. It does not require the switching on and off of lamps frequently, but comparatively this methodology is only medium efficient.

2.1.3 Dimming (DIM)

Here, the amount of light of lampposts is dimmed in proportion to the number of users available in the vicinity distance predefined. A minimum level for the light intensity is defined in the system, and when the proportion of the users nearby the lampposts distance R increases, the level of light intensity of lampposts also increases up to a maximum of 100%. This method also concerns about the light intensity level for any obstacles present on the path or any animals crossing by. Only LEDs could be employed for this methodology as HPSs lamps do not support dimming (Pinto *et al.,* 2015).

Table 2 summarizes the comparison of efficiency between the currently adopted approaches to the smart street lighting solutions proposed.

Table 2: Smart lighting solutions efficiency comparison

Methodology	Acronym	Efficiency
Current methodology	CUR	Low
Delay-Based	DEL	High
Encounter-Based	ENC	Medium
Dimming	DIM	High

3. Methodology

3.1 Architectural Description

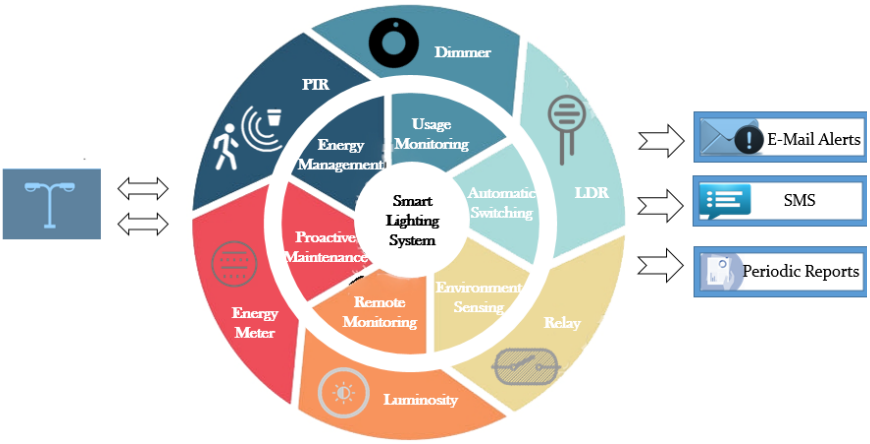

Figure 2: Architectural diagram of proposed system

3.1.1 The System

The system consists of a smart web server that is capable of producing reports periodically, send email notifications on any faulty detection and monitors the amount of consumption of electricity and the lifetime of the street lamps. The system includes environmental sensing, proactive maintenance, electrical energy management, proactive monitoring and automatic switching On/Off of street lamp modules.

The switching On/Off of lamps depend on a scheduled timing either single schedules or multiple schedules. The environmental weather, and the light intensity is also considered as one of the factors in scheduling lights. The lights also become active when a motion of a person is detected within a certain radius from the location of the street lamp.

3.1.2 Sensors and Actuators

3.1.2.1 Dimmer

Dimmers are used in the system to control the brightness of the LED lights during the off-peak hours. The brightness would increase when any vehicles or users passes by. This will reduce the amount of electrical energy consumed by the streetlights.

3.1.2.2 Light Dependent Resistor (LDR)

An LDR consists of a variable resistor that varies depending on the intensity of light falling on it. LDR senses the lighting in the environment, measures the amount of light and based on the measurement obtained, it automatically switches ON/OFF the lights.

3.1.2.3 Energy Meter

It measures the consumption of electrical energy to track the real-time usage.

3.1.2.4 Relay

A relay is used in the smart street lighting system to control the switching ON and OFF of lights remotely. It functions as an electrical switch operated by an electromagnet to open and close the circuit. Relay consumes smaller current to operate high current circuits. Sensors produce only smaller amount of currents and relay acts as a bridge between the sensor and the system to activate larger currents. In this way, relays work as switch (Chris Woodford, 2019).

3.1.2.5 Passive Infrared Sensor (PIR)

A PIR sensor is a device used to measure the amount of infrared light emitted from the objects in its detection range. It is used in smart street lighting system to sense the motion of the human or vehicle within a defined distance range.

3.1.2.6 Temperature Sensor

Temperature sensor is used as the source to detect the motion of a human in the vicinity of the streetlight using PIR sensor. The temperature of the filed changes to human body temperature at the detection of a person movement by the infrared radiation in the PIR sensor. The change in the temperature triggers the detection of motion.

3.1.3 Gateway

The system and the sensors are separately placed, and it needs a bridge to feed the data obtained from sensors and actuators into the system. This is carried out by the component called the Gateway. Gateway use several internet protocols in order to send information from the sensors to the smart system. The main protocols used are explained below.

3.1.3.1 Hyper Text Transfer Protocol (HTTP)

HTTP is one of the most important protocols used by the World Wide Web (WWW). These protocols define the format in which the messages are transmitted over the internet. It also defines the actions to be taken by web servers and browsers when several commands are executed.

Another protocol, HTTPS, HyperText Transfer Protocol Secure is similar to HTTP, except that HTTPS is more secure than HTTP. The Transport Layer Security (TLS) or Secure Sockets Layer (SSL) encrypts the communication between the web server and browsers (Vangie Beal, no date).

3.1.3.2 Message Queuing Telemetry Transport (MQTT)

MQTT is an internet protocol for messaging and designed for devices with low bandwidth. This protocol is used for communication from one machine to another machine and therefore, this is applicable for systems involving Internet of things (IoT). Smart street light system uses MQTT protocol to send commands to control outputs, read and publish data from the sensor nodes in the system (*The lightweight IoT Protocol MQTT: How to get started*, no date).

3.1.3.3 Modbus

Modbus is a communication protocol with a Master/Slave architectural technique to communicate between devices. It is an open serial protocol used for Automation Systems. This protocol is easy to use and more reliable. Modbus transmits data retrieved form control devices such as sensors to the smart system (*Modbus RTU Protocol Overview*, no date).

4. Discussion and Conclusion

It is widely expected that smart lighting systems will have a huge impact in the upcoming years as a result of the availability of the LED drivers, sensors and connected LED platforms. In this paper, a smart street lighting system has been proposed considering the energy saving that is consumed by streetlights in the current scenario. A smart server has been introduced that is capable of managing the energy, maintain the usage, sense and react to the environmental sensors, and turn the streetlights ON and OFF remotely. A gateway using the IoT technology is suggested to be implemented as the pathway between the sensors and the system to retrieve sensor data.

Further, LED bulbs has been proposed as the most suitable luminaires to be used for streetlights compared to HPS bulbs. Now a days, developed countries are on the process of implementing the smart street light system and they have found this to be an efficient way to save energy and hence, it would be more suitable for countries like Sri Lanka too, as, it also spends more of its electrical energy produced for street lighting.

In the future, this system can be further extended in a way that the city maps with the location of each street lamps could be integrated with the smart system. This will be useful for real time monitoring of the system to be even more efficient. XBee/Zigbee module also could be embedded into the system, as they are very easy to use for wireless modules.

5. Acknowledgement

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6. References

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