Smart Street Light System using Wi-SUN and oneM2M

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***Abstract*—As urbanization continues to accelerate, the demand for energy-efficient and sustainable urban infrastructure has become paramount. Street lights are an elemental part of any city because they facilitate better night visibility, secured roads, and luminescence in public areas. Also, because street lights are present homogeneously on city roads, if they are used for wireless communication, other smart nodes can make use of their backhaul. In this paper, we present a smart street lighting system based on Wi-SUN (Wireless Smart Ubiquitous Network), which offers excellent redundancy owing to its use of a mesh topology. Wi-SUN is based on the IEEE 802.15.4g standard and uses license-free sub-GHz bands. We have used oneM2M as the middleware platform to enable possible interoperability with other smart city data verticals such as weather stations, environmental monitoring, crowd monitoring and so on. The proposed system provides a robust and low-cost method for controlling street lighting in any area, providing IP-addressable lighting. The proposed system additionally aims to provide consistent Wi-SUN coverage for future nodes in the area of deployment.**

***Keywords*—oneM2M, Smart street lighting, Smart city, Urban deployment, Wi-SUN**

I. INTRODUCTION

As the concept of smart cities has gained considerable momentum in recent years. The urban areas face the challenges of rapid population growth, resource constraints, and environmental concerns. The rapid urbanization and increasing energy demands have led to the development of innovative solutions for sustainable and smart urban infrastructure as well as smart homes [1], [2]. In recent years, smart street lighting systems (SSLS) have gained significant attention as a promising solution to address the challenges faced by traditional street lighting. Smart street lights apart from providing remote monitoring and control, adaptive lighting, energy efficiency and data analytics also provide a networking capability for a dense network of IOT sensors like pollution monitoring [3]–[5], environmental parameters [6]–[8], traffic management [9], and so on. This paper aims to provide a smart street lighting solution with Wi-SUN based communication and oneM2M as the backhaul server. We explore the technologies and components involved in smart street lighting systems and discuss their potential to revolutionize urban lighting, improve public safety, and provide energy efficiency. Additionally, we highlight the key considerations for successful implementation, including connectivity, data management, and integration with existing urban infrastructure. Overall, this paper can serve as a valuable resource for policymakers, urban planners, and researchers interested in the deployment of smart street lighting systems.

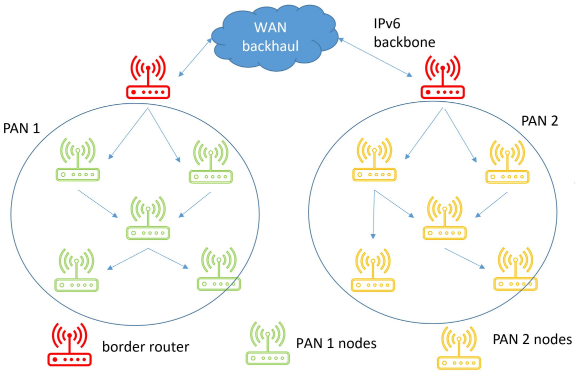


Fig. 1. A typical Wi-SUN mesh network with two Personal Area Networks (PANs).

Wireless Smart Ubiquitous Network (Wi-SUN) uses a mesh topology that can self heal, where each device can act as a data forwarder for other devices in the network. Wi-SUN is a good choice for communication using street lights owing to its license-free sub-GHz frequency range. It provides signal penetration through obstacles like buildings and trees catering to its long range capability [10], [11]. In this paper, we present the fabrication and deployment of 30 smart street lights systems in the IIIT-Hyderabad campus. These street lights are controlled through Wi-SUN based mesh network protocol, and provide cloud connectivity to any Wi-SUN device in their vicinity. The data from this network is posted and retrieved from oneM2M, a middleware platform. We also present the Relative Signal Strength Index (RSSI) levels reported by the nodes in the network.

II. RELATED WORKS

Saifuzzaman *et al.* developed a street lighting solution, with 3 stages, either ON/OFF or dim, where the luminous control decisions were based upon the data provided from a Light Dependent Resistor (LDR) fixed atop the pole [12]. For connectivity, a cloud-based system dependent on Wi-Fi was used, which may hinder the scalability of such a

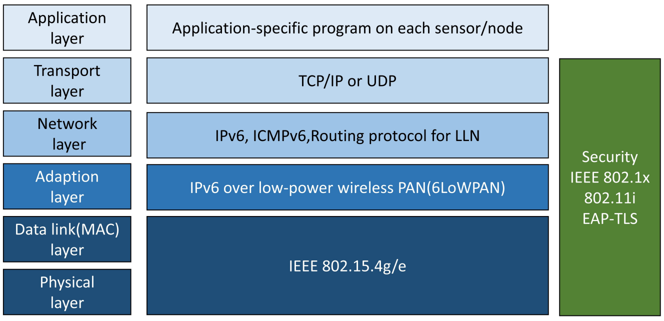


Fig. 2. OSI layer structure of the Wi-SUN network protocol.

model. Chen *et al.* deployed a smart street light solution with communication of multiple poles on NB-IoT protocol with data being posted on the cloud [13]. Mathew *et al.* installed an IoT-enabled street light management system with LED lamps and an additional calibrated DHT 11 temperature/humidity sensor using LoRaWan network [14]. A lack of such works on the Wi-SUN protocol and the potential of such a deployment are the main motivations for this paper.

III. WI-SUN ARCHITECTURE

The Wi-SUN standard specifies three different PHYs, Multi Rate (MR) - Orthogonal Frequency Division Multiplexing (OFDM), Frequency Shift Keying (FSK), Quadrature Phase Shift Keying (QPSK) and with data rates ranging from 50 kbps to 300 kbps [15]. The network layer uses RPL (Routing Protocol for Low-Power and Lossy Networks) that is optimized for multiple hops,long range and low power under the MAC layer uses Carrier Sense Multiple Acess with Collision Avoidance (CSMA/CA) [16], [17].

The RPL protocol defines the mechanism for forming the Destination Oriented Directed Acyclic Graph (DODAG). The algorithm works with metrics and constraints to compute the most optimized path for sending data packets from the source to the destination. The DODAG has a root node (border router) such that all the edge nodes have their path oriented towards the root node. Once the DODAG is formed, if a node is shut down, the DODAG initiates a local repair to heal and changes itself accordingly. In some cases, it may initiate a global repair and the entire DODAG forms all over again. However, this leads to a long network reconfiguration time which is considered one of the drawbacks of the Wi-SUN network protocol [18]. An example Wi-SUN mesh network is shown in Fig. 1 and its OSI layers detailed in Fig. 2.

Wi-SUN Personal Area Network (PAN) links the cluster of smart devices deployed to the cloud by enabling interoperable, multi-service and secure IPv6 communication. Once the Wi-SUN devices are powered, they have the ability to self organize into a mesh network and transmit data via multi-hop routing which enlarges the range of the entire network by using other nodes as relays. Each node in the Wi-Sun PAN assumes one of three roles [19]:

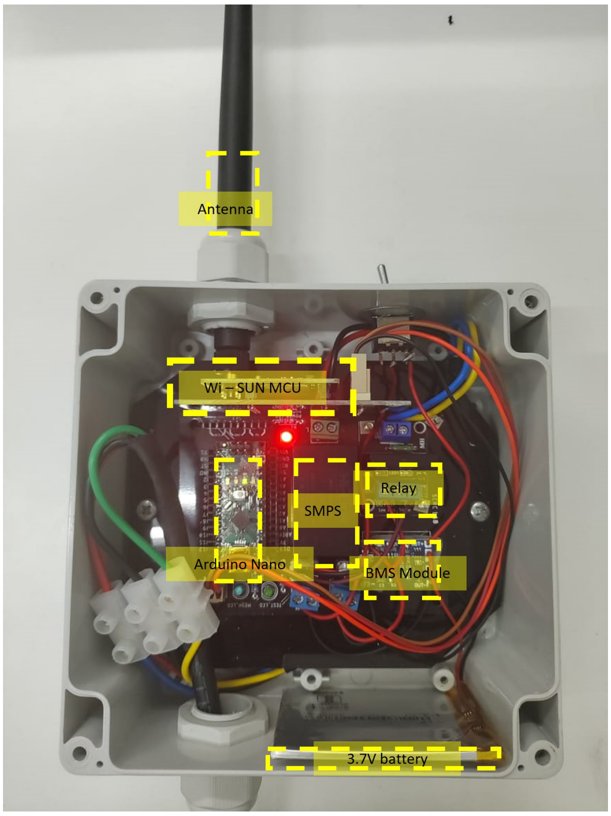


Fig. 3. The internal circuitry for the Wi-SUN node.

1) *Border Router* behaves as a gateway between the internet and the Wi-SUN PAN. It maintains and upgrades the source routing table for all the nodes within the PAN.
2) *Router nodes* provide both up-link and down-link data packet forwarding and behave as intermediate nodes for the mesh network.
3) *Leaf nodes* have the ability to discover and join the PAN and send/receive packets and act as the edge.

IV. SYSTEM ARCHITECTURE

We used an integrated radio transceiver module based on the EFR32MG12 microcontroller from Silicon Laboratories Inc., as part of the Silicon Labs Wi-SUN Wireless Starter Kit. The module was programmed to transmit at 868 MHz with a 200 kHz channel bandwidth at a data rate of 150 kbps and a modulation index of 0.5 using a 3-FSK modulation scheme. The Wi-SUN transceiver was part of the system consisting of an Arduino Nano board, a solid state relay to control the street light, a switch mode power supply (SMPS) for in-situ AC to DC conversion, a battery module comprising of a battery and a TP4056 battery management system in case AC power is lost. A double layered PCB (110 mm×50 mm) was designed to house all the components, and was placed in an IP65 waterproof casing. The antenna was connected outside the box to avoid signal attenuation from the box itself. An image of the circuit box with its components is shown in Fig. 3.

Fig. 4. a) One of the smart lamp posts deployed in the IIIT-H campus b) The design of the fabricated smart lamp post. Several compartments has been provided at the bottom and midway to house nodes with sensors. All measurements are in inches.

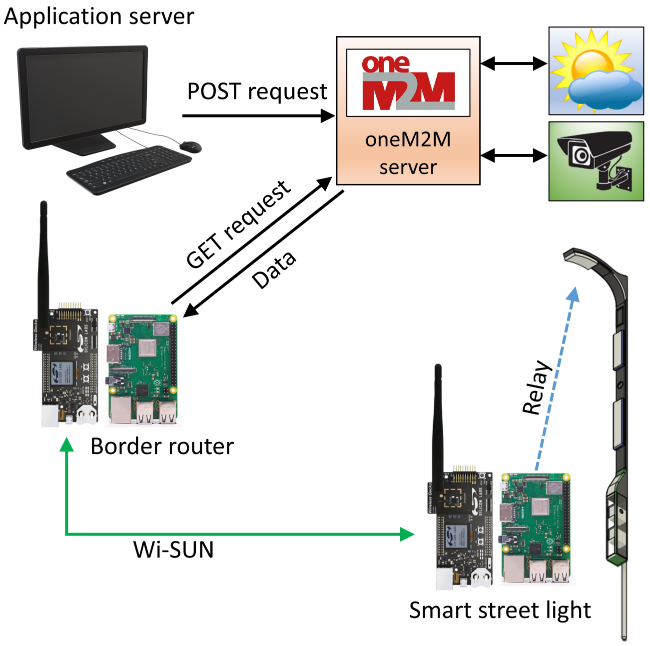


Fig. 5. The data flow diagram for the Wi-SUN smart street lights integrated with the oneM2M platform.

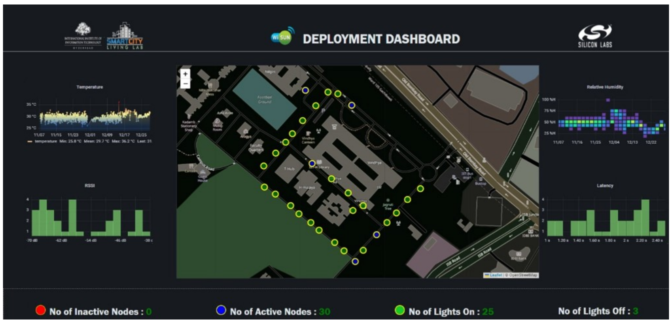
V. RESULTS

A smart street lamp was specifically fabricated to contain a compartment for this box as shown in Fig. 4. However, this is not a requirement for Wi-SUN based street lighting solutions. In this study, several Wi-SUN nodes were integrated onto existing infrastructure. The pole was provided with a single-phase AC supply, which was used to power the communication circuitry using the SMPS based AC to DC converter as well as the LED light. The Wi-SUN transceiver receives a string signal from the border router via UDP over Wi-SUN protocol, which it then forwards to the microcontroller, which decodes the incoming signal and triggers the relay accordingly. Once the trigger signal has been sent, the microcontroller, with a five second delay, confirms through a luminous sensor if the status of the light matches with the expectation and sends an acknowledgement signal back to the border router. This closed-loop feedback can help with the maintenance in case the light malfunctions. The acknowledgement packet contains the unique identifier IP of that specific node, the previous state of the light, the current state of the light, and the timestamp of the last change. In case of a power failure, to avoid a reformation of the Wi-SUN mesh network, which is time consuming, the node is powered through the battery until the AC power is restored.

To provide cloud connectivity and to control the network, a border router node is designed and connected to the cloud server using a Raspberry Pi controller board. The server pulls up the sunset and sunrise time from the internet and sends the node the data packets which contains the strings for turning "ON" or "OFF" the lights. This switching can also be manually overridden to directly send the packets from the border router in case of an unexpected event.

To test the robustness of the system, the border router periodically initiates a test, to fetch the RSSI values of the nodes as received by the node from its adjacent connecting node in the mesh. Each exchanged packet consists of an ICMPv6 (Internet Control Message Protocol for IPv6) payload corresponding to 2 bytes of dummy data. Every transmission in the Wi-SUN mesh is done at 19 dBm of power. The received RSSI values are noted and averaged out for ten data packets and a round trip latency from the border router to each node and back is also obtained. At the server end, the Wi-SUN network is integrated into an an open-source (OM2M) implementation of the oneM2M middleware platform as a separate <container> within an application entity (<AE>). The latter denoting the prospective "smart street light" vertical. OM2M is an open-source service platform compliant with the oneM2M standards [20]–[22]. The desired status (ON/OFF) of the light is posted to the appropriate <container> as a <contentInstance>. The border router polls the OM2M server periodically using the inbuilt latest data API, receiving the desired status of each smart light. This data is forwarded to the appropriate nodes over Wi-SUN, where the microcontroller powers the light ON/OFF through a relay. The data flow diagram is detailed in Fig. 5.

We created a dashboard to visualize the deployment locations and the status of the lights (Fig. 6). The dashboard was created using Grafana visualization platform, and the data was sourced from the OM2M server. The dashboard also provides information about the RSSI and latency values for the network. We observed that the RSSI values of the nodes were between -38 to -70 dB (Fig. 7), depending on the distance and obstacles, and the round trip latency varied from 0.8 to 3 s.



No of Inactive Nodes : 0
No of Active Nodes : 30
No of Lights On : 25
No of Lights Off : 3

Fig. 6. The dashboard of the Wi-SUN deployment shows the status of each node and the histogram of RSSI and latency values.

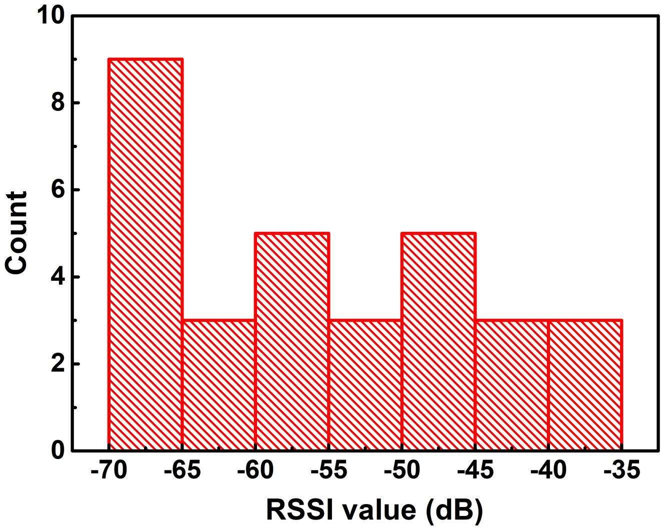


Fig. 7. Histogram of the snapshot of RSSI values for all the nodes deployed in the network.

VI. CONCLUSION

As more and more smart cities evolve, it is imperative to have such scaled deployments in dense urban landscapes. The deployment in this work can serve as a test-bed to collect information about the robustness, durability and reliability of the Wi-SUN protocol before deploying them in a larger area. Some other modalities can also tried, for example, to switch the lights based on activity using a Passive Infrared (PIR) sensor, which can provide further opportunities for energy saving. oneM2M integration also provides unique opportunities in terms of applications and control. For example, a digital luminescence sensor can be deployed on the rooftop building which posts the data on oneM2M. These values can be fetched by the street light nodes connected to the Wi-SUN border router gateway, to make a decision whether the lamp should be off or at a specific brightness depending on the local weather conditions. Further, information related to pedestrians or large crowds can be obtained from the oneM2M platform, which can then be used to for light switching.

REFERENCES

[1] S. E. Bibri and J. Krogstie, “Environmentally data-driven smart sustainable cities: Applied innovative solutions for energy efficiency, pollution reduction, and urban metabolism,” *Energy Informatics*, vol. 3, pp. 1–59, 2020.

[2] J. Yang, H. Zou, H. Jiang, and L. Xie, “Device-free occupant activity sensing using WiFi-enabled IoT devices for smart homes,” *IEEE Internet Things J.*, vol. 5, no. 5, pp. 3991–4002, Oct 2018.

[3] K. Zheng, S. Zhao, Z. Yang, X. Xiong, and W. Xiang, “Design and implementation of LPWA-based air quality monitoring system,” *IEEE Access*, vol. 4, pp. 3238–3245, 2016.

[4] C. R. Reddy *et al.*, “Improving spatio-temporal understanding of particulate matter using low-cost IoT sensors,” in *Proc. IEEE 31st Annu. Int. Symp. Pers. Ind. Mob. Rad. Commun. (PIMRC)*, Aug 2020, pp. 1–7.

[5] D. Zhang and S. S. Woo, “Real time localized air quality monitoring and prediction through mobile and fixed IoT sensing network,” *IEEE Access*, vol. 8, pp. 89 584–89 594, 2020.

[6] S. D. T. Kelly, N. K. Suryadevara, and S. C. Mukhopadhyay, “Towards the implementation of IoT for environmental condition monitoring in homes,” *IEEE Sensors J.*, vol. 13, no. 10, pp. 3846–3853, Oct 2013.

[7] S. Fang *et al.*, “An integrated system for regional environmental monitoring and management based on internet of things,” *IEEE Trans. Ind. Informat.*, vol. 10, no. 2, pp. 1596–1605, May 2014.

[8] L. G. Manzano *et al.*, “An IoT LoRaWAN network for environmental radiation monitoring,” *IEEE Trans. Instrum. Meas.*, vol. 70, pp. 1–12, Jun 2021.

[9] S. Misbahuddin, J. A. Zubairi, A. Saggaf, J. Basuni, S. A-Wadany, and A. Al-Sofi, “Iot based dynamic road traffic management for smart cities,” in *2015 12th International Conference on High-capacity Optical Networks and Enabling/Emerging Technologies (HONET)*, 2015, pp. 1–5.

[10] A. Gupta, M. Ruthwik, A. Saxena, and A. M. Hussain, “Non line of sight (nlos) path loss evaluation of wi-sun in an urban landscape,” in *2023 IEEE Applied Sensing Conference (APSCON)*. IEEE, 2023, pp. 1–3.

[11] W. Anani, A. Ouda, and A. Hamou, “A survey of wireless communications for iot echo-systems,” in *2019 IEEE Canadian Conference of Electrical and Computer Engineering (CCECE)*. IEEE, 2019, pp. 1–6.

[12] M. Saifuzzaman, N. N. Moon, and F. N. Nur, “IoT based street lighting and traffic management system,” in *Proc. IEEE Region 10 Humanitarian Technol. Conf.*, Dec 2017, pp. 121–124.

[13] S. Chen, G. Xiong, J. Xu, S. Han, F.-Y. Wang, and K. Wang, “The smart street lighting system based on NB-IoT,” in *Proc. Chin. Autom. Congr. (CAC)*, Nov 2018, pp. 1196–1200.

[14] J. Mathew, R. Rajan, and R. Varghese, “Iot based street light monitoring & control with lora/lorawan network,” *International Research Journal of Engineering and Technology (IRJET)*, vol. 6, no. 11, 2019.

[15] H. Harada, K. Mizutani, J. Fujiwara, K. Mochizuki, K. Obata, and R. Okumura, “IEEE 802.15. 4g based Wi-SUN communication systems,” *IEICE Trans. Comm.*, vol. 100, no. 7, pp. 1032–1043, Jul 2017.

[16] E. Callaway *et al.*, “Home networking with IEEE 802.15.4: a developing standard for low-rate wireless personal area networks,” *IEEE Commun. Mag.*, vol. 40, no. 8, pp. 70–77, Aug 2002.

[17] J. Gutierrez *et al.*, “IEEE 802.15.4: a developing standard for low-power low-cost wireless personal area networks,” *IEEE Netw.*, vol. 15, no. 5, pp. 12–19, Sep. 2001.

[18] G. Iyer *et al.*, “Performance analysis of wireless mesh routing protocols for smart utility networks,” in *Proc. IEEE Int. Conf. Smart Grid Commun. (SmartGridComm)*, Oct 2011, pp. 114–119.

[19] T. Junjalearnvong *et al.*, “Performance evaluation of multi-hop network configuration for Wi-SUN FAN systems,” in *Proc. 16th IEEE Annu. Consum. Commun. Netw. Conf. (CCNC)*, Jan 2019, pp. 1–6.

[20] M. B. Alaya *et al.*, “OM2M: Extensible ETSI-compliant M2M service platform with self-configuration capability,” *Procedia Comput. Sci.*, vol. 32, pp. 1079–1086, 2014.

[21] S. Mante, “Iot data processing for smart city and semantic web applications,” *arXiv preprint arXiv:2306.16728*, 2023.

[22] S. Mante, S. S. S. Vaddhiparthy, M. Ruthwik, D. Gangadharan, A. M. Hussain, and A. Vattem, “A multi layer data platform architecture for smart cities using onem2m and iudx,” in *2022 IEEE 8th World Forum on Internet of Things (WF-IoT)*. IEEE, 2022, pp. 1–6.