Jurnal Ilmiah Teknik Elektro Komputer dan Informatika (JITEKI)
Vol. 8, No. 1, March 2022, pp. 51-63
ISSN: 2338-3070, DOI: 10.26555/jiteki.v8i1.22535

Multi-hop ESP-Mesh Network and MQTT Protocol for Smart Light Systems in High-Rise Buildings

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ARTICLE INFO

Article history:

Received December 17, 2021
Revised February 17, 2022
Accepted April 15, 2022

Keywords:

ESP-Mesh;
Protocol MQTT;
Smart Light;
cloud MQTT;
IoT MQTT Panel;
Painless Mesh

ABSTRACT

When a high-rise building's lights are not required because they are frequently left on, electrical energy is wasted as a result of this. The smart light is one of the effective ways to energy saving in a building. This study aims to create a smart light system using the ESP-Mesh network and the MQTT protocol to control the turn on/off of all lights in all rooms of a high-rise building. The ESP-Mesh network is a mesh of ESP8266 devices that are designed for multi-hop transmission. The MQTT is one of the widely used IoT protocols that allows a smartphone to control the lights in every room in a mesh topology via the internet remotely. The performance evaluation shows that a multi-hop ESP-Mesh is better than that a Single-hop ESP8266 in signal strength. The signal strength of the ESP8266 single-hop is bad. Meanwhile, the signal strength of the multi-hop ESP-Mesh is good in all rooms. Furthermore, The functional tests of the multi-hop ESP-Mesh show that although there are various broken paths caused by several disconnected nodes, all lights can be turned on or off suitably through the command from the smartphone switch. Turning off the not-required lights by smart light systems can help save energy.

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1. INTRODUCTION

Electricity is a vital need in everyday life. One of the most basic human requirements is lighting, both for public and private lighting. In general, lighting strives to increase people's security and safety, as well as the attractiveness of their surroundings, mobility, and quality of life [1]. However, both public and private lighting requires a significant amount of electricity. Lighting systems in a home or office environment consume more electricity than other types of lighting. It is critical to limit the amount of electricity used for lighting. The most crucial thing to construct is the ability to monitor and report the value of electricity use [2]–[4]. Furthermore, a smart system that can monitor and control the usage of superfluous room lighting throughout the day and at night is required. The lights are frequently left on all day or night when the people of the house or business forget to turn them off or leave the room without turning them off. As a result, electrical energy is wasted. This problem can be solved with a smart lighting system that uses internet of things technology to monitor and control lights remotely.

Several types of research on smart lighting for energy savings have been conducted using various approaches for public (outdoor) and personal (indoor) lighting. The authors in [5] and [6] created an intelligent system for monitoring, controlling, and energy-saving street lighting to dynamically control lighting levels for public (outdoor) lighting. Lighting for airport operations consumes more than 70% of the port's energy consumption, with rigorous controls in place to assure user safety and comfort. Furthermore, The author of [7] presented a new replicable architecture for smart-controlling outdoor lighting infrastructure for airport operations lighting.

Smart lighting is used for personal lighting (indoor) to provide comfort and energy savings through lighting settings depending on desired varied lighting conditions. It was likewise created by a group of researchers. The photodetector detects the room's lighting level and is integrated with the neural network to alter the luminaire's dimming level, as developed by [8] and [9]. Moreover, the research in [10] created a self-calibrating lighting control system for intelligent lighting for energy consumption. Weather data, room dimensions, window sizes, user requirements, lighting requirements, and working hours—are used to save energy using three forms of intelligent control based on switches and dimmers, illumination meters, and irradiation detectors [11]. Energy-efficient LED lamps can also be increased in terms of savings by adjusting the illumination based on the dimming principle using Pulse Width Modulation (PWM) [12] and Fuzzy logic controller [8].

Other smart lighting applications are being explored, such as smart table lamps, mobile gaming applications, and reducing CO pollution produced by cigarette smoke. The author of [13] created a practical application that incorporates a smart object into a table light to enhance room temperature comfort while also conserving energy. On the other hand, D-TOX [14] is used in smart lighting and mobile applications for gamification to limit children's smartphone use at night by altering light colors and intensities. In a different case, the titaneon smart lamp [15] was utilized to minimize the CO pollution created by cigarette smoke for 20 minutes.

ESP8266 or ESP32 WiFi devices can provide connectivity between nodes in a mesh network. These devices have been utilized by several researchers to create mesh networks for internet of things applications. IoT applications are employing ESP8266 to connect numerous NodeMCU devices via a Wireless-Local-Area-Network (WLAN) between different nodes in a mesh network topology [16]. ESP32 module and ESP-WiFi-Mesh protocol were used to construct the internet of things with a low-cost wireless sensor network with dependable communication capacity [17]. ESP8266 configured a mesh network to create an IoT-based smart street lighting system by creating a PWM signal, providing the dimmer value, and reading the sensor data. The ESP8266 is trained (programmed) to regulate the light intensity [18]. A webserver is being used to access our system wirelessly.

Because it works lightly on Transmission Control Protocol / Internet Protocol (TCP/IP), the Message Queuing Telemetry Transport (MQTT) protocol has been widely employed in many IoT-based applications for sharing data via machine-to-machine (M2M) [19]. On the other hand, MQTT needs to be assessed for vulnerability to secret network channels and also requires more bandwidth than Constrained Application Protocol (CoAP) due to TCP overhead [20]. As a result, MQTT 5.0 has been released to provide secure services [21]. The benefits of MQTT as a lightweight protocol for balancing the gateway to gateway load in wireless sensor cluster networks, as described by [22]. Furthermore, the author of [23] uses MQTT to create interoperable IoT-based systems that increase redundancy and fault tolerance. Also, the research in [24] used MQTT to provide various communication service models for the Internet of Things (IoT). A new lightweight authentication and authorization framework based on Elliptical Curve Cryptography (ECC) and MQTT is ideal for remote IoT situations suggested by [25]. A method for efficiently transferring data using the MQTT path routing mechanism is presented by [26]. Meanwhile, the author of [27] designed and built a robot control system for Human-Robot Collaboration based on the IEC-61499 standard and the MQTT protocol. Likewise, the Internet of Drones Things (IoDT) concept by employing the MQTT protocol to boost the packet sending rate proposed by [28]. In a different case, the research in [29] uses MQTT to improve WiFi distribution network and terminal connectivity.

This research offers a smart lighting system for high-rise buildings that uses the ESP8266 as a node to create ESP-Mesh network topology and the MQTT protocol to remotely control the smart lighting in each room. The goal of this study is to improve network coverage in places where WiFi signals are difficult to reach all rooms in the building. There are multiple paths to approach the gateway with a multi-hop mesh topology, allowing all lights in high-rise buildings to be controlled remotely via the internet.

This study contributes to the development of a mesh network protocol capable of multi-hop transmission. The multi-hop ESP-mesh network protocol, which is embedded in the ESP8266 wireless communication device, is the name of this protocol. Furthermore, the multi-hop ESP-mesh network protocol is integrated with the MQTT protocol, allowing lights in high-rise buildings to be remotely monitored and controlled using internet of things technology.

2. METHOD

An ESP-mesh network, an ESP8266 smart lighting node (hence referred to as a node), a gateway, an MQTT broker, and a smartphone interface make up the smart lighting system used in high-rise buildings. The following is a description of all the devices that make up the smart lighting system.

2.1. Multi-hop ESP-Mesh Network

Due to the requirement that each node is within range to connect directly to the Access Point (AP), single-hop Wi-Fi networks have area limits. Furthermore, because the maximum number of nodes allowed in the network is restricted by the AP's capacity, classic Wi-Fi networks are prone to overload. The ESP-Mesh network, on the other hand, has a far wider reach because nodes can still acquire interconnectivity without having to be within range of the central node (gateway). ESP-Mesh is a network technology that is based on Wi-Fi. ESP-Mesh allows several nodes to be connected to one other over a vast physical area (both indoors and outdoors) using a single WLAN (Wireless Local Area Network) [30].

As illustrated in Fig. 1, a multi-hop ESP-Mesh topology is utilized in this study, in which each node can transfer packets to other nodes in the network over one or more wireless hops. In the ESP-MESH network, nodes not only send their own packets but also act as an intermediary for other nodes. This protocol works by allowing two nodes to interact if there is a path between them at the physical layer that is either through one or more wireless hops [31]. Using the PainlessMesh library [32], which is integrated into each node, create an ESP-Mesh network topology. The ESP8266 can automatically generate a mesh topology structure with the PainlessMesh. The exchange of data in the library is based on JSON.

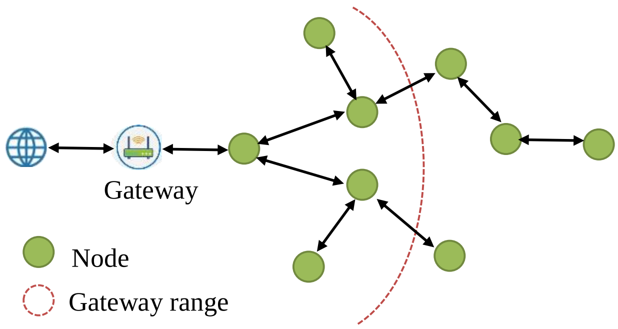

Fig. 1. Multi-hop ESP-Mesh network topology

2.2. ESP8266 Smart Light Node

The ESP8266 module used in this work is WebMos D1 Mini ESP8266-based WiFi board [33]. This device is low profile and powerful as any NodeMCU or microcontroller. The advantage of WeMos D1 Mini ESP8266-based WiFi is that its small size allows the device to be easily installed in a light fitting, as shown in Fig 2. The smart light node is made up of a WebMos D1 Mini ESP8266 and an AC switch. The AC switch is made up of a MOC3041 optocoupler and a BTA16 Triac that acts as a breaker and connecter to the electric current of the lamp. Fig. 3 depicts the smart lamp circuit's schematic.

Fig. 2. Design of smart light

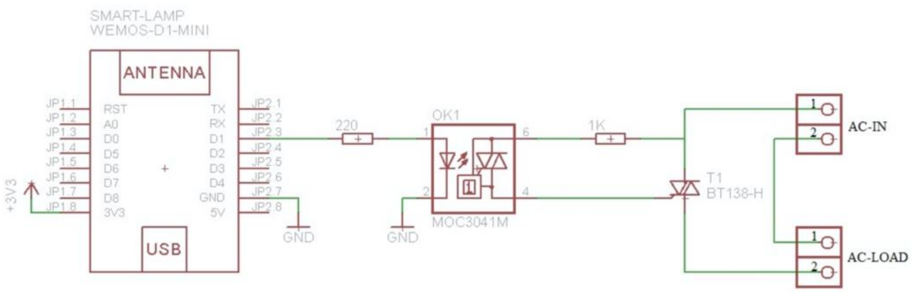

Fig. 3. Schematic of the smart lamp circuit

2.3. Gateway

The MQTT protocol is used in this study to communicate data between smart lights and smartphones. This lightweight protocol runs on Transmission Control Protocol / Internet Protocol (TCP/IP) [8] and uses a broker-based publish-subscribe mechanism. The gateway is made up of a mesh gateway and an MQTT gateway that are linked via serial communication. The Wemos D1 microcontroller is used in both devices. The mesh gateway serves as a connection point between the network's nodes and the MQTT gateway [18]. Meanwhile, the MQTT gateway forwards publish-subscribe messages sent over the internet to the MQTT broker. Fig. 4 and Fig. 5 depict the gateway device and schematic, respectively.

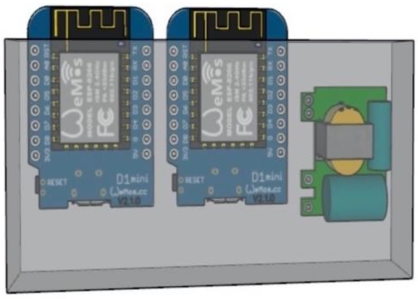

Fig. 4. Mesh gateway and MQTT gateway

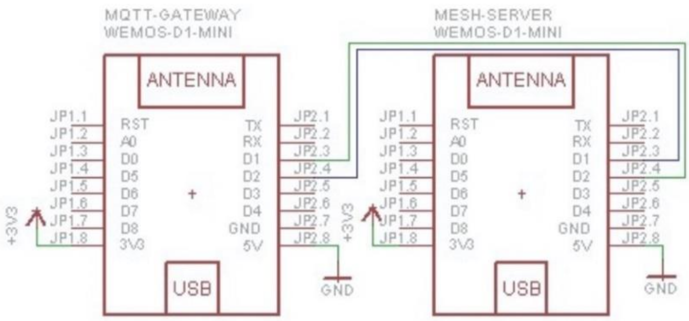

Fig. 5. Schematic of gateway circuit

2.4. MQTT Broker

As an MQTT publisher, the smartphone controls the light ON/OFF command. It sends the topic and data to the MQTT broker. On the other hand, MQTT Gateway as a subscriber, sends the topic to the MQTT broker. The MQTT broker replied to the request by publishing topics and data from the MQTT publisher. The node ID and the ON/OFF command are included in the data published by the MQTT publisher. According to the destination node ID, the MQTT gateway will send an ON/OFF instruction to the node via the mesh server. Fig. 6 depicts the procedure of using a smartphone to turn off and on lights with the help of an MQTT Broker.

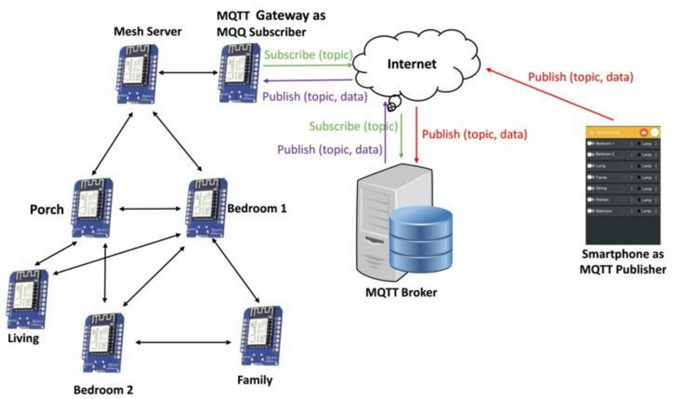

Fig 6. Working as an MQTT broker in the smart light system

In the MQTT protocol mechanism, communication between the node and the MQTT broker must match the user and port settings for both the node and the MQTT broker. CloudMQTT [34] is used as a broker in this work, and the user and port settings on cloud MQTT are presented in Fig. 7.

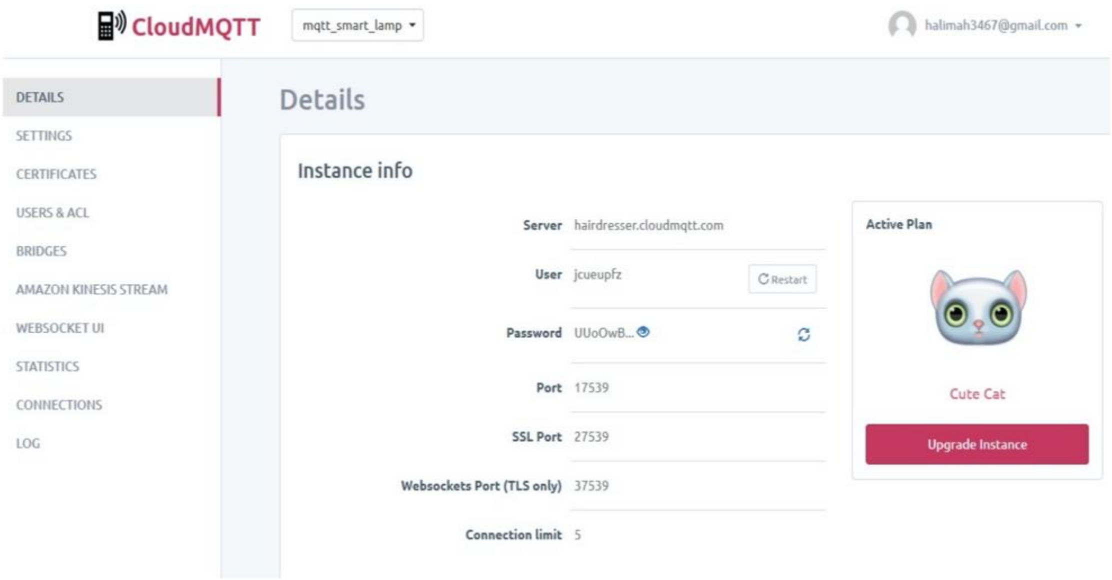

Fig. 7. CloudMQTT acting as an MQTT broker [34]

2.5. Smartphone Interface

The IoT MQTT Panel application [35] is used by the smartphone interface. This app contains an on/off switch as well as a light indicator. By touching a button on the intended widget, the ON/OFF feature can be utilized to turn off or on the lights. The app's switch widget indicates whether or not a control message has been transmitted to the MQTT cloud. Fig. 8 shows the on/off switch widgets for each lamp on the MQTT IoT panel interface.

Fig. 8. IoT MQTT Panel as the interface in the smartphone [35]

3. RESULTS AND DISCUSSION

The smart light system's performance was evaluated in a two-floor building with a total area of 90m2. Fig. 9 depicts the plan of light placement in each room on the 1st and 2nd floors, with the 1st floor having 8 rooms and the 2nd floor having 2 rooms. The gateway is installed on the stairwell so that the Wi-Fi signal can be connected to the room on the 2nd floor.

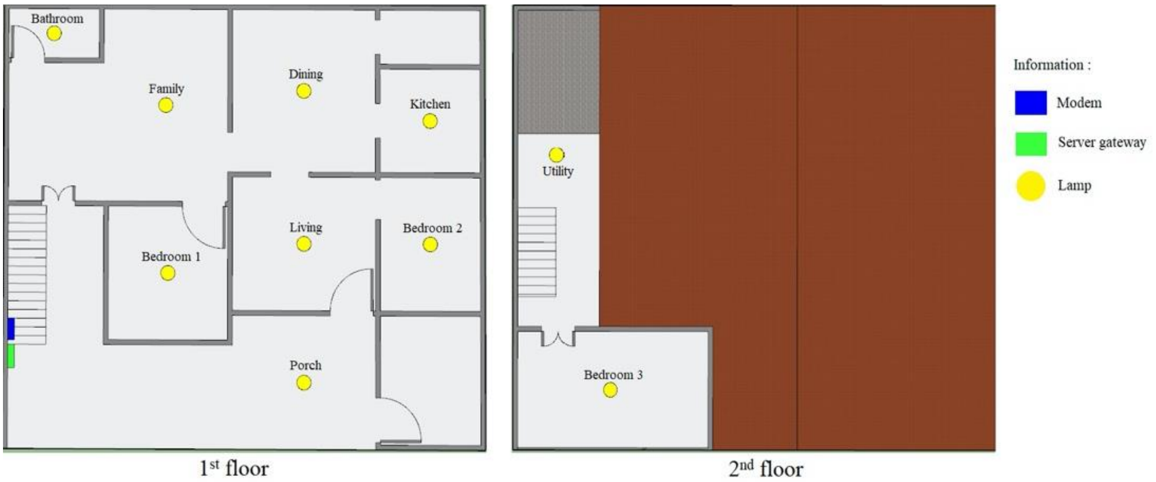

Fig. 9. The layout of the lamp placement

3.1. Range of Wi-Fi Signal

A single-hop Wi-Fi network coverage test is performed in this part without the use of the ESP-Mesh topology. The coverage of this single-hop Wi-Fi signal is determined by the quality of the Wi-Fi signal received by the node, as shown in Table 1, using a typical Wi-Fi signal strength level scale. The strength of the Wi-Fi signal received is expressed in decibels (dBm) by the Receiver Signal Strength Indicator (RSSI).

Table 1. WiFi signal strength category

Signal strength category	Strength signal level (dBm)
Very good	0 to -60
Well	-61 to -70
Pretty good	-71 to -80
Bad	-81 to -90
Very bad	-91 to -100

The mesh network must take into account the allowable maximum and minimum ranges. As seen in Fig. 10, the difference between them establishes a tolerance factor that allows connections to all nodes in the network. As a result, the tolerance factor has a direct impact on the range of admissible signals. According to the measurement results, the permitted range of the ESP8266 signal is at a distance of 8 meters, as shown in Table 2. Thus, the maximum distance for the ESP8266 smart light node can be placed 8 meters.

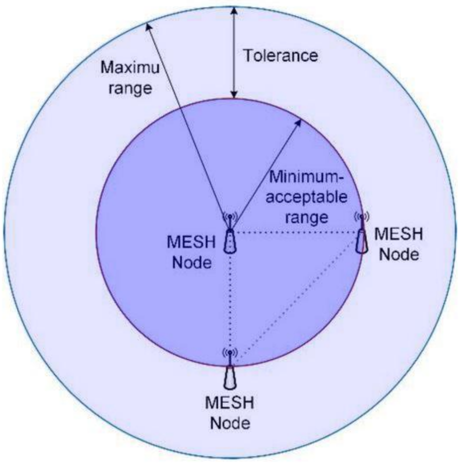

Fig. 10. Acceptable Wi-Fi signal tolerance

Table 2. ESP8266 Range

ESP8266 Range	Distance (m)	RSSI (dBm)	Signal Strenght
Minimum	1	-65	Good
	2	-68	Good
	3	-70	Good
	4	-76	Pretty good
Tolerance	5	-82	Bad
	6	-86	Bad
	7	-89	Bad
	8	-90	Bad
Maksimum	9	-92	Very bad

3.2. Distance and Barrier of Node to Gateway

The condition of each room on the first and second floors needs to be identified before conducting the test. Several nodes are obstructed by walls to the gateway, as seen in Fig. 11. There are also a few nodes that have a distance of 8 to 10 meters away from the gateway, which gateway is indicated by two blue and green colored boxes that are located above the stairwell. This problem can prevent the gateway from communicating with the obstructed and distant nodes. Table 3 illustrates this condition.

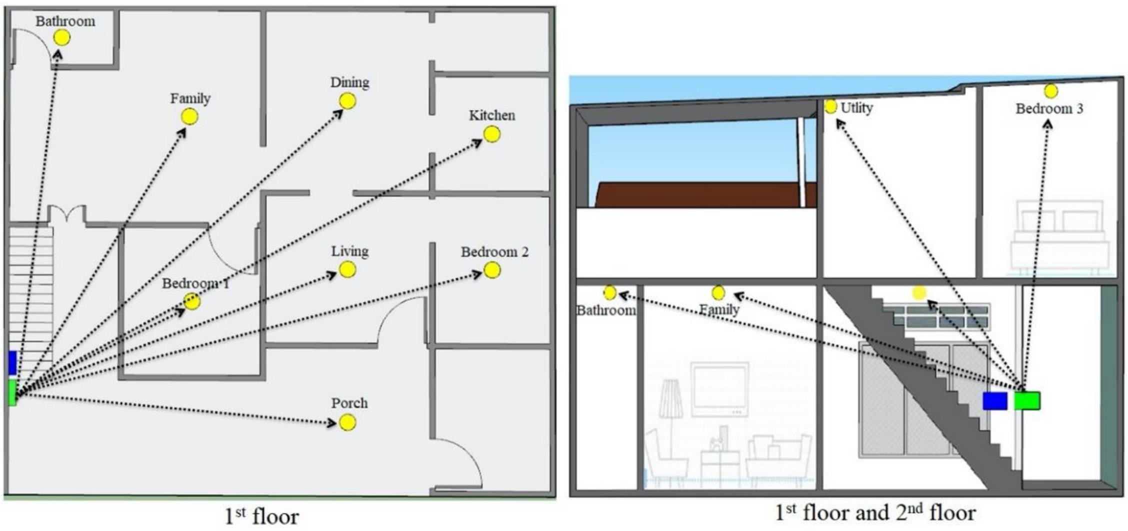

Fig. 11. Nodes' barrier against the gateway

Table 3. Direct distance and obstruction of nodes to the gateway

Room		Distance (m)	Barrier
1st Floor	2nd Floor		
Bedroom 1		3.6	2 Walls
Bedroom 2		9.2	2 Walls
Family		6.1	1 Wall
Living		6.6	1 Wall
Dining		8.3	2 Walls
Porch		6.1	Nothing
Kitchen		10.5	3 Walls
Bathroom		3.6	2 Walls
	Bedroom 3	6	1 Wall
	Utility	3.4	Nothing

3.3. Signal Strength of the Single-hop ESP8266 and Multi-hop ESP-Mesh Network

The signal quality of the single-hop ESP8266 and the Multi-hop ESP-Mesh were assessed for each room in the circumstances depicted in Fig. 11 and detailed in Table 3. Except in bedroom 1, the signal quality of the single-hop ESP8266 network falls into the bad category, as illustrated in Table 4. This issue arises as a result of some obstructions and a greater distance from the gateway. Otherwise, the signal in bedroom 1 is good because it is in the gateway's coverage area. The ESP-Mesh network can improve signal quality in the good category, as illustrated in Table 5. The quality is improved by employing a multi-hop network, as shown in Fig. 12, which allows obstacles to be avoided and nodes to be closer together.

A solid black line and a dotted red line distinguish two types of routes in Fig. 12. The shortest path from a node to the gateway is indicated by the black line. Meanwhile, if there are any dead nodes, the red dotted line provides an alternate route to the gateway. The multi-hop technique, as illustrated in Table 5, improves signal quality by breaking up the long direct route from a node to the gateway into several hops. As a result, the distance between the pieces of the route shortens, resulting in a greater RSSI value. For instance, a direct route from the GW to the node of the family room with an RSSI of -85 dBm will be categorized as good since it passes through bedroom 1, which has two short paths with RSSI of -69 and -79 dBm. Although, those two paths result in a longer delay.

Table 4. The signal quality of the single-hop ESP8266 network

Room	RSSI (dBm)	Delay (second)	Signal Quality
Bedroom 1	-68	27	Good
Bedroom 2	-90	70	Bad
Family	-85	50	Bad
Living	-85	49	Bad
Dining	-90	67	Bad
Porch	-70	29	Bad
Kitchen	-83	48	Bad
Bathroom	-96	-	Very bad
Bedroom 3	-82	48	Bad
Utility	-68	25	Bad

Table 5. The signal quality of the multi-hop ESP-Mesh network

Room	RSSI (dBm)	Delay (second)	Signal Quality
Bedroom 1	-69	27	Good
Bedroom 2	-60	70	Good
Family	-75	50	Pretty good
Living	-77	49	Pretty good
Dining	-60	67	Good
Porch	-70	29	Good
Kitchen	-71	48	Pretty good
Bathroom	-69	-	Good
Bedroom 3	-62	48	Good
Utility	-62	25	Good

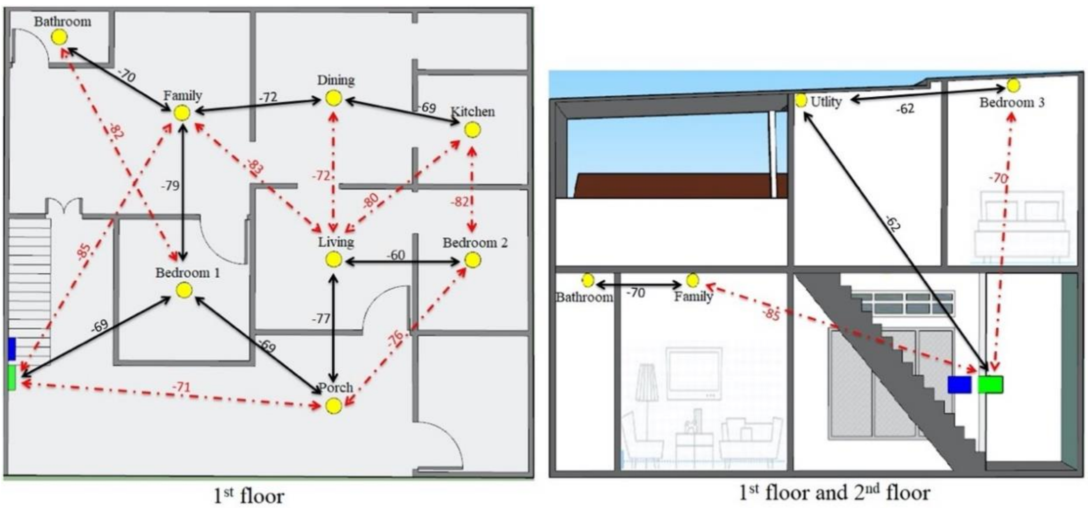

Fig. 12. Path of the gateway signal to all light nodes in the ESP-Mesh network

3.4. Functional Evaluation of the Multi-hop ESP-Mesh Network

3.4.1. Switch ON/OFF Testing of All Light Nodes

To check that everything can be controlled from a smartphone, the initial scenario in the on/off test for all nodes in the network is to activate all nodes. The path from the gateway to all nodes is depicted in Fig. 12. Alternative paths are denoted with a red dotted line, while main paths are marked with a solid black line. The test is conducted by pressing each widget switch in the smartphone IoT MQTT Panel application for all of the lights (Table 6). A toggle is used to change the state of the widget switch from off to on and vice versa. The results of the tests demonstrate that all nodes can succeed to be turned on and off in response to commands of the widget switch on the smartphone, with a fast response time in the delay range of 27 – 49 seconds for turn-on. Meanwhile, the response time for turn-off is 24 – 44 seconds. Furthermore, the signal quality of the rooms is included in the good category.

Table 6. Switch ON/OFF testing for all light nodes

Room	RSSI (dBm)	On/Off Testing			
		Condition node	Delay (second)	Condition node	Delay (second)
Bedroom 1	-69	On	27	Off	24
Bedroom 2	-60	On	40	Off	36
Family	-75	On	34	Off	31
Living	-77	On	40	Off	36
Dining	-60	On	49	Off	44
Porch	-70	On	34	Off	31
Kitchen	-71	On	28	Off	25
Bathroom	-69	On	48	Off	44
Bedroom 3	-62	On	41	Off	31
Utility	-62	On	29	Off	24

3.4.2. Switch ON/OFF Testing of All Active Light Nodes when Two Disconnected Light Nodes

The second scenario involves testing the lights that pass through the nodes in the two rooms using two disconnected nodes, specifically the node in bedroom 1 and the node in the living room. The path from the gateway to the porch light node should go through the light node at bedroom 1, but the node is disconnected. Thus, the path goes straight to the porch light node, as shown in Fig. 13. Similarly, the path to bedroom 2 passes through the porch light node rather than the living room node. In normal condition testing, RSSI and delay are shown in Fig. 14, along with two disconnected nodes. Fig. 14 depicts the difference in the decreasing RSSI values before and after several broken paths caused by two disconnected nodes. Likewise, the delay increases after the path are interrupted both when the switch is on and when it is switched off. The decrease in the RSSI value and the increase in the delay value are caused by longer paths due to dead nodes. After two disconnected nodes, the range of response time in the delay is 44 - 50 seconds for turn-on and 42 – 50 seconds for the turn-off. The decrease in the RSSI value, along with the increase in the distance between the gateway and the node, is consistent with the results obtained by [36].

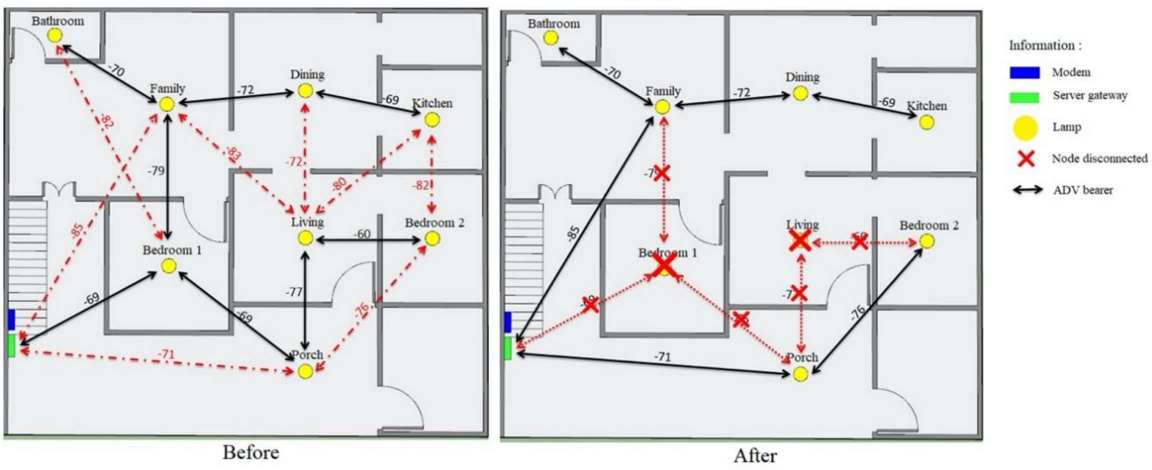

Fig. 13. Disconnected path due to two disconnected light nodes

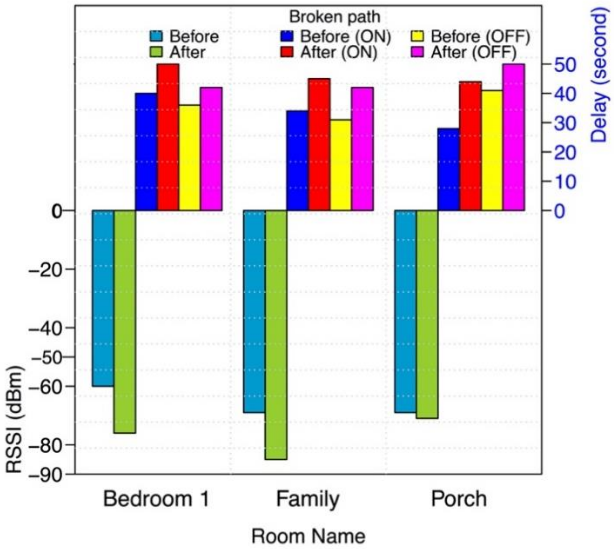

Fig 14. Switch ON/OFF testing for all light nodes when two disconnected light nodes

3.4.3. Switch ON/OFF Testing of All Active Light Nodes when Three Disconnected Nodes

Three disconnected nodes, namely bedroom 1, porch, and utility room, are used in the third scenario to test the path on floors 1 and 2, as shown in Fig. 15. On the first path, nodes will be tested in bedroom 2, the family room, and the living room, and on the second floor, nodes will be tested in bedroom 3. Fig. 16 shows that all of the nodes are tested for the lights can be turned on and off easily, although the response time is slower than when all nodes are in a connected condition or when two disconnected nodes are. The range of response time in delay after three disconnected nodes is 47 – 60 seconds for turn-on and 43 – 56 seconds for the turn-off. Furthermore, the received signal strength indicator (RSSI) is lower than it would be under normal circumstances. The results are also in line with the results obtained by [36].

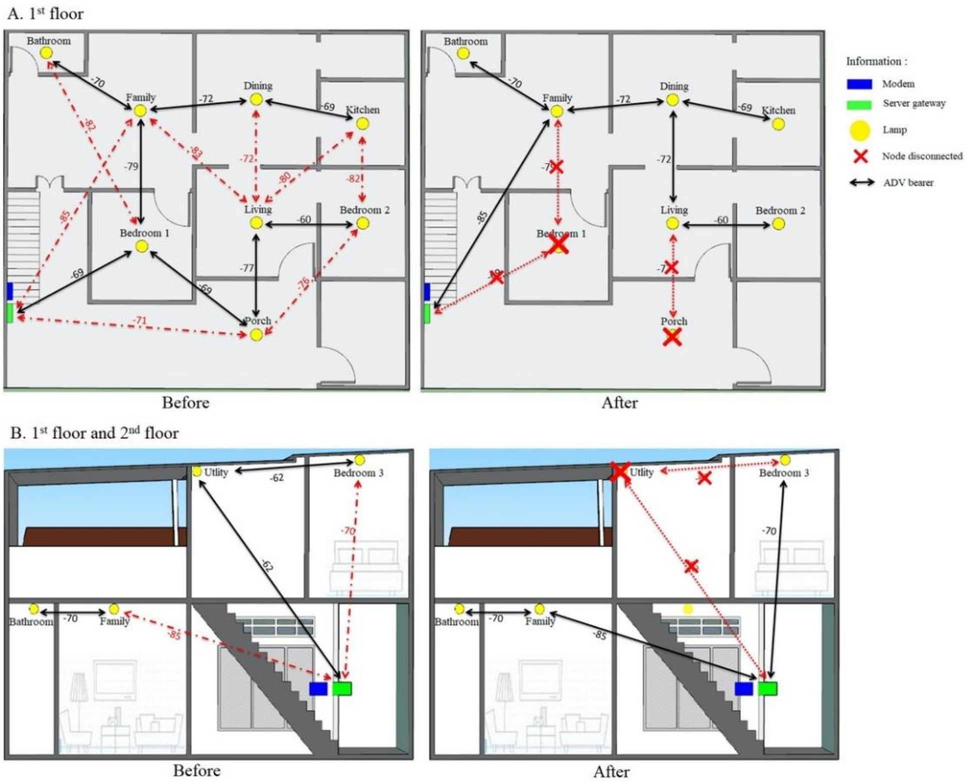

Fig. 15. Disconnected path due to 3 disconnected light nodes

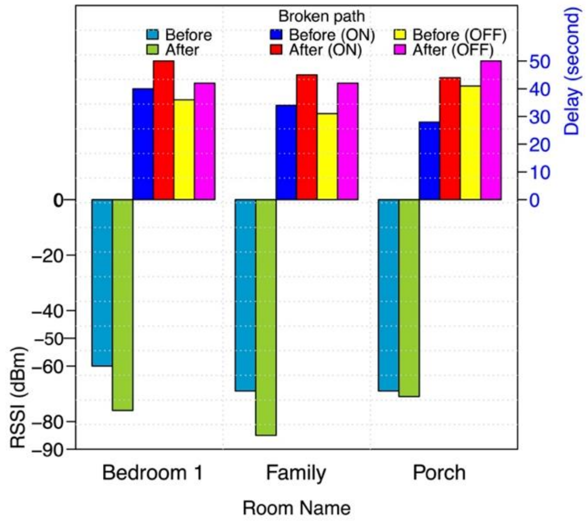

Fig. 16 Switch ON/OFF testing for all light nodes when three disconnected lights node

4. CONCLUSION

A Multi-hop ESP-Mesh with an RSSI of -77 to -60 dBm is better than that of a Single-hop ESP8266 with an RSSI of -96 to -68 dBm in signal strength. Except for bedroom 1, the signal strength of the ESP8266 Single-hop is bad. At the same time, the signal strength of the Multi-hop ESP-Mesh is good in all rooms. Furthermore, the function of multi-hop ESP-Mesh was evaluated in three different scenarios: first in which all nodes are active, second in which there are two disconnected nodes and third scenario in which there are three disconnected nodes. Although the range of response time in delay after two disconnected nodes is 44 – 50 seconds when switching ON and 42 – 50 seconds when switching OFF. Also, after three disconnected nodes, the range of response time in the delay is 50 - 60 seconds for switch ON and 43 – 56 seconds for switch OFF. The response time in both scenarios is slower than when all nodes are active. The results of the ON/OFF functional test for the three scenarios show that all lights on the active nodes can be turned on or off suitably through the command from the widget switch.

REFERENCES

[1] F. Pardo-Bosch, A. Blanco, E. Sesé, F. Ezcurra, and P. Pujadas, "Sustainable strategy for the implementation of energy efficient smart public lighting in urban areas: case study in San Sebastian," *Sustain. Cities Soc.*, vol. 76, p. 103454, 2022, https://doi.org/10.1016/j.scs.2021.103454.

[2] T. L. Webb, Y. Benn, and B. P. I. Chang, "Antecedents and consequences of monitoring domestic electricity consumption," *J. Environ. Psychol.*, vol. 40, pp. 228–238, 2014, https://doi.org/10.1016/j.jenvp.2014.07.001.

[3] N. Brown, R. Bull, F. Faruk, and T. Ekwevugbe, "Novel instrumentation for monitoring after-hours electricity consumption of electrical equipment, and some potential savings from a switch-off campaign," *Energy Build.*, vol. 47, pp. 74–83, 2012, https://doi.org/10.1016/j.enbuild.2011.11.023.

[4] Y. Yang, J. Yuan, Z. Xiao, H. Yi, C. Zhang, W. Gang, and H. Hu,, "Energy consumption characteristics and adaptive electricity pricing strategies for college dormitories based on historical monitored data," *Energy Build.*, vol. 245, p. 111041, 2021, https://doi.org/10.1016/j.enbuild.2021.111041.

[5] F. Sanchez-Sutil and A. Cano-Ortega, "Smart regulation and efficiency energy system for street lighting with LoRa LPWAN," *Sustain. Cities Soc.*, vol. 70, p. 102912, 2021, https://doi.org/10.1016/j.scs.2021.102912.

[6] E. Juntunen, E.-M. Sarjanoja, J. Eskeli, H. Pihlajaniemi, and T. Österlund, "Smart and dynamic route lighting control based on movement tracking," *Build. Environ.*, vol. 142, pp. 472–483, 2018. https://doi.org/10.1016/j.buildenv.2018.06.048.

[7] N. Sifakis, K. Kalaitzakis, and T. Tsoutsos, "Integrating a novel smart control system for outdoor lighting infrastructures in ports," *Energy Convers. Manag.*, vol. 246, p. 114684, 2021, https://doi.org/10.1016/j.enconman.2021.114684.

[8] A. Seyedolhosseini, M. Modarressi, N. Masoumi, and N. Karimian, "Efficient photodetector placement for daylight-responsive smart indoor lighting control systems," *J. Build. Eng.*, vol. 42, p. 103013, 2021, https://doi.org/10.1016/j.jobe.2021.103013.

[9] A. N. Cihan and G. N. Güğül, "An Indoor Smart Lamp For Environments Illuminated Day Time," in *2020 IEEE East-West Design & Test Symposium (EWDTS)*, 2020, pp. 1–5, https://doi.org/10.1109/EWDTS50664.2020.9224900.

[10] Y. Aussat, A. Rosmanis, and S. Keshav, "A Power-Efficient Self-Calibrating Smart Lighting System," *Energy Build.*,

p. 111874, 2022. https://doi.org/10.1016/j.enbuild.2022.111874.
[11] M. Á. Campano, I. Acosta, S. Domínguez, and J. López-Lovillo, "Dynamic analysis of office lighting smart controls management based on user requirements," *Autom. Constr.*, vol. 133, p. 104021, 2022, https://doi.org/10.1016/j.autcon.2021.104021.
[12] Y. Gao, Y. Cheng, H. Zhang, and N. Zou, "Dynamic illuminance measurement and control used for smart lighting with LED," *Measurement*, vol. 139, pp. 380–386, 2019, https://doi.org/10.1016/j.measurement.2019.03.003.
[13] Y. E. Wang, J. Bergman, and J. Sachs, *Cellular Internet of Things*. 2020. https://doi.org/10.1016/c2018-0-01131-7.
[14] J. Lee, J. Y. Lee, S. W. Kim, and J. D. Cho, "D-TOX: Inducing Digital Detox for Nighttime via Smart Lamp Applied Gamification," in *Proceedings of the 2017 Conference on Interaction Design and Children*, 2017, pp. 497–502, http://dx.doi.org/10.1145/3078072.3084315.
[15] Y. F. Lathif, P. Marwoto, and R. S. Iswari, "Titaneon: the eco smart lamp to degrade cigarette smoke pollutants," in *Journal of Physics: Conference Series*, 2020, vol. 1567, no. 4, p. 42099, https://doi.org/10.1088/1742-6596/1567/4/042099.
[16] M. Kumari, V. Kumar, and D. C. Sati, "Establishing a Wireless-Local-Area-Network (WLAN) Connectivity between Multiple Nodes using ESP-Mesh Network Topology for IoT Applications," *Int. Res. J. Eng. Technol.*, vol. 7, no. 8, pp. 1053–1057, 2020, https://www.irjet.net/archives/V7/i8/IRJET-V7I8174.pdf.
[17] W. Marwan and T. Wiklom, "Prototype Development and Performance Evaluation of ESP-WIFI-Mesh Sensor Networks for IoT," *Proc. Asia Pacific Conf. Robot IoT Syst. Dev. Platf.*, no. 2020, pp. 63–64, 2021, http://id.nii.ac.jp/1001/00210226/.
[18] S. Fuada, T. Adiono, and L. Siregar, "Internet-of-Things for Smart Street Lighting System Using ESP8266 on Mesh Network," *Int. J. Recent Contrib. from Eng. Sci. IT*, vol. 9, no. 2, pp. 73–78, 2021, https://doi.org/10.3991/ijes.v9i2.22877.
[19] G. C. Hillar, *MQTT Essentials - A LightWeight IOT Protocol*, Packt Publishing Ltd, 2017, https://books.google.co.id/books?id=40EwDwAAQBAJ.
[20] V. Seoane, C. Garcia-Rubio, F. Almenares, and C. Campo, "Performance evaluation of CoAP and MQTT with security support for IoT environments," *Comput. Networks*, vol. 197, p. 108338, 2021, https://doi.org/10.1016/j.comnet.2021.108338.
[21] A. Mileva, A. Velinov, L. Hartmann, S. Wendzel, and W. Mazurczyk, "Comprehensive analysis of MQTT 5.0 susceptibility to network covert channels," *Comput. Secur.*, vol. 104, p. 102207, 2021, https://doi.org/10.1016/j.cose.2021.102207.
[22] D. Guha Roy, B. Mahato, D. De, and R. Buyya, "Application-aware end-to-end delay and message loss estimation in Internet of Things (IoT) — MQTT-SN protocols," *Futur. Gener. Comput. Syst.*, vol. 89, pp. 300–316, 2018, https://doi.org/10.1016/j.future.2018.06.040.
[23] A. Schmitt, F. Carlier, and V. Renault, "Dynamic bridge generation for IoT data exchange via the MQTT protocol," *Procedia Comput. Sci.*, vol. 130, pp. 90–97, 2018, https://doi.org/10.1016/j.procs.2018.04.016.
[24] M. Kashyap, V. Sharma, and N. Gupta, "Taking MQTT and NodeMcu to IoT: Communication in Internet of Things," *Procedia Comput. Sci.*, vol. 132, pp. 1611–1618, 2018, https://doi.org/10.1016/j.procs.2018.05.126.
[25] A. Lohachab and Karambir, "ECC based inter-device authentication and authorization scheme using MQTT for IoT networks," *J. Inf. Secur. Appl.*, vol. 46, pp. 1–12, 2019, https://doi.org/10.1016/j.jisa.2019.02.005.
[26] P. Arivubrakan and K. Prema, "The routing based protocol technique for enhancing the performance metrics using MQTT in the Internet of Things," *Mater. Today Proc.*, 2020, https://doi.org/10.1016/j.matpr.2020.11.070.
[27] C. A. Garcia, W. Montalvo-Lopez, and M. V Garcia, "Human-Robot Collaboration Based on Cyber-Physical Production System and MQTT," *Procedia Manuf. C. A. Garcia, W. Montalvo-Lopez, M. V Garcia, "Human-Robot Collab. Based Cyber-Physical Prod. Syst. MQTT," Procedia Manuf., vol. 42, pp. 315–321, 2020.*, vol. 42, pp. 315–321, 2020, https://doi.org/10.1016/j.promfg.2020.02.088.
[28] A. Mukherjee, N. Dey, and D. De, "EdgeDrone: QoS aware MQTT middleware for mobile edge computing in opportunistic Internet of Drone Things," *Comput. Commun.*, vol. 152, pp. 93–108, 2020, https://doi.org/10.1016/j.comcom.2020.01.039.
[29] X. Liu, T. Zhang, N. Hu, P. Zhang, and Y. Zhang, "The method of Internet of Things access and network communication based on MQTT," *Comput. Commun.*, vol. 153, pp. 169–176, 2020, https://doi.org/10.1016/j.comcom.2020.01.044.
[30] K. Monika, K. Vivek, and C. S. Dayal, "Establishing a Wireless-Local-Area-Network (WLAN) Connectivity between Multiple Nodes using ESP-Mesh Network Topology for IoT Applications," *Int. Res. J. Eng. Technol.*, vol. 7, no. 8, pp. 1053–1057, 2020, https://www.irjet.net/archives/V7/i8/IRJET-V7I8174.pdf.
[31] R. Kashyap, M. Azman, and J. G. Panicker, "Ubiquitous Mesh: A Wireless Mesh Network for IoT Systems in Smart Homes and Smart Cities," in *2019 IEEE International Conference on Electrical, Computer and Communication Technologies (ICECCT)*, 2019, pp. 1–5, https://doi.org/10.1109/ICECCT.2019.8869482.
[32] M. German, V. L. Doanh, and V. D. Costyn, "Intro to painlessMesh," [Online]. Available: https://github.com/gmag11/painlessMesh.
[33] G. Marques, C. Roque Ferreira, and R. Pitarma, "A system based on the internet of things for real-time particle monitoring in buildings," *Int. J. Environ. Res. Public Health*, vol. 15, no. 4, p. 821, 2018, https://doi.org/10.3390/ijerph15040821.
[34] Anonim, "Cloud MQTT," [Online]. Available: https://www.cloudmqtt.com.

[35] R. Kundu, “IoT MQTT Panel,” [Online]. Available: https://play.google.com/store/apps/details?id=snr.lab.iotmqttpanel.prod&hl=pt.
[36] S. Barai, D. Biswas, and B. Sau, “Estimate distance measurement using NodeMCU ESP8266 based on RSSI technique,” in *2017 IEEE Conference on Antenna Measurements & Applications (CAMA)*, 2017, pp. 170–173, https://doi.org/10.1109/CAMA.2017.8273392.

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