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DEVELOPING OF BLUETOOTH MESH FLOODING BETWEEN SOURCE-DESTINATION LINKING OF NODES IN WIRELESS SENSOR NETWORKS

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Bluetooth uses 2.4 GHz in ISM (industrial, scientific, and medical) band, which it shares with other wireless operating system technologies like ZigBee and WLAN. The Bluetooth core design comprises a low-energy version of a low-rate wireless personal area network and supports point-to-point or point-to-multipoint connections. The aim of the study is to develop a Bluetooth mesh flooding and to estimate packet delivery ratio in wireless sensor networks to model asynchronous transmissions including a visual representation of a mesh network, node-related statistics, and a packet delivery ratio (PDR). This work provides a platform for Bluetooth networking by analyzing the flooding of the network layers and configuring the architecture of a multi-node Bluetooth mesh. Five simulation scenarios have been presented to evaluate the network flooding performance. These scenarios have been performed over an area of 200 200 meters including 81 randomly distributed nodes including different Relay/End node configurations and source-destination linking between nodes. The results indicate that the proposed approach can create a pathway between the source node and destination node within a mesh network of randomly distributed End and Relay nodes using MATLAB environment. The results include probability calculation of getting a linking between two nodes based on Monte Carlo method, which was 88.7428 %, while the Average-hop-count linking between these nodes was 8. Based on the conducted survey, this is the first study to examine and demonstrate Bluetooth mesh flooding and estimate packet delivery ratio in wireless sensor networks

Keywords: Bluetooth, mesh flooding, packet delivery ratio, wireless sensor networks, network simulation, node position allocator (NPA), Monte Carlo algorithm

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1. Introduction

It is essential to pay more attention to Bluetooth networking issues as it uses 2.4 GHz in ISM (industrial, scien2 tific, and medical) band applications, which it shares with other wireless operating system technologies like ZigBee and WLAN. The Special Interest Group (SIG) defines two PHY modes in the Bluetooth core design [1]; the mandatory BR and the optional enhanced data rate (EDR). The Bluetooth BR/EDR radio uses a frequency hopping spread spectrum (FHSS) method with a hop rate of 1,600 hops per second. On 79 selected Bluetooth channels, the radio jumps in a pseudo-random manner. Each Bluetooth channel has a 1 MHz bandwidth. Each channel has a central frequency of 2402+k MHz, with k ranging from 0 to 78. Differential phase-shift keying (DPSK) and Gaussian frequency-shift keying (GFSK) are the modulation techniques used on the payload in the BR and EDR modes, respectively with 1 M Symbol/s is the baud rate. The Bluetooth BR/EDR radio employs a Time-Division Duplex (TDD) system, which allows data to be transmitted in only one way at a time. In many cases, Bluetooth and WLAN radios coexist in the same physical environment and on the same device. As a result, Bluetooth and WLAN broadcasts may interfere with one another, affecting both networks' performance and dependability. The IEEE 802.15.2 Task Group [2] proposes adopting the AFH approach with Bluetooth and WLAN coexistence to reduce interference [3].

Flooding in Bluetooth wireless mesh network is a straightforward routing method in which a data source or a node sends packets via each outgoing connection. Flooding is similar to a broadcast that occurs when data packets of the source are transmitted (without routing data) to all nodes of the network. Every received packet is routed through every outgoing link excluding the one it arrived on, which is known as flooding. The flooding mechanism is investigated by tracing a path from source to destination nodes via intermediate relay nodes. Bluetooth Low Energy (BLE) was introduced to the low-power standard devices that generate a modest quantity of data, for instance, warning alerts of home automations, Internet of Things (IoT), fitness, and health care. The profile of the Bluetooth mesh network specifies the specifications for implementing a BLE mesh networking solution.

The importance of Bluetooth mesh networking applications appears as providing large-scale device networking for industrial automation, smart lighting, sensor networking, asset monitoring, and a variety of additional IoT applications. Some common Bluetooth logical transport types are listed in Table 1.

Table 1

Bluetooth logical transport types

Bluetooth type		Logical transport supports		Reference
Synchronous connection-oriented (SCO)	The Master and Slave exchange SCO packets at regular intervals in the reserved slots	Exchange periodic data such as audio streaming	does not support retransmissions	[4]
Extended (eSCO)	–	exchange periodic data such as audio streaming	retransmissions	[5]
ACL	Master polls the ACL logical transport of a Slave at least once	exchange asynchronous data such as a file transfer protocol (FTP)	–	[6, 7]
Active slave broadcast (ASB)	send messages from the Master to all of the Slaves in a piconet	unidirectional traffic	no acknowledgments	[8]
Connectionless slave broadcast (CSB)	A master node sends profile broadcast data to multiple Slaves	unidirectional traffic	no acknowledgments	[9]

The basic network configuration in Bluetooth is the piconet, where a master node can cater up to seven slave nodes. The group of a piconet is called the scatternet, where a master in one piconet can be a slave in another piconet. A scatternet of three piconets is shown in Fig. 1.

The Bluetooth protocol has various layers like the physical layer, data link layer, middleware layer, and finally the application layer. These layers are listed in Fig. 2.

The physical radio layer achieves modulation and demodulation of data into radio signals. It identifies the physical features of the Bluetooth transceivers. It classifies two kinds of physical links, connectionless and connection-oriented. Bluetooth mesh implements managed flood message-related transmit information from a source to a destination. Managed flood message relay is a modified version of traditional flood networking. One of the exclusive elements of a managed flood is the identification of a counter of time-to-live messages. When a source node sends out a message, there's an associated counter value. That value is decreased by 1 every time a relay node retransmits messages. This ensures messages only have a set time to live to minimize network congestion.

The connectionless services data will take any path whereas in connection-oriented services data will take the predefined path. The baseband layer performs connection establishment within a piconet. If one device wants to communicate with another device, the connection has to be established between these two devices. Then, this base bar layer is going to take care of these connection establishments within a peak on it now. The link manager protocol layer is in charge of managing links that have previously been established. This means that if the link between two nodes is already established, the supervision of these recognized associations is handled by this link manager protocol or link manager layer. This link manager layer also concentrates on security services. It also includes authentication and encryption processes. Authentication means ensuring that the right entity is involved in the transactions or the network. Encryption means that if one Bluetooth device is sending the data to another Bluetooth device, and if it is encrypted, then no other nodes can see the data, only the receiver knows what data is being transmitted between them, so this layer focuses on the management part as well as the security services. The logical link control adaptation layer or the adaptation protocol is also known as the heart of the Bluetooth protocols because this is going to be the interface between the upper layers and the lower layers. It enables the communication between the Bluetooth protocol's upper and lower layers, and it packages data packets received from the upper layers in the format anticipated by the lower tiers. It also conducts multiplexing segmentation. From the upper layer, only data and these data have to be converted into the form which the lower layers can understand. This logical link control and operation layer, also known as the adaption protocol, handles all of the conversion.

Therefore, research devoted to the development of Bluetooth mesh networks including layer flooding and estimate packet delivery ratio of a Bluetooth mesh in a wireless sensor network (WSN) is relevant to provide large-scale device networking for industrial automation.

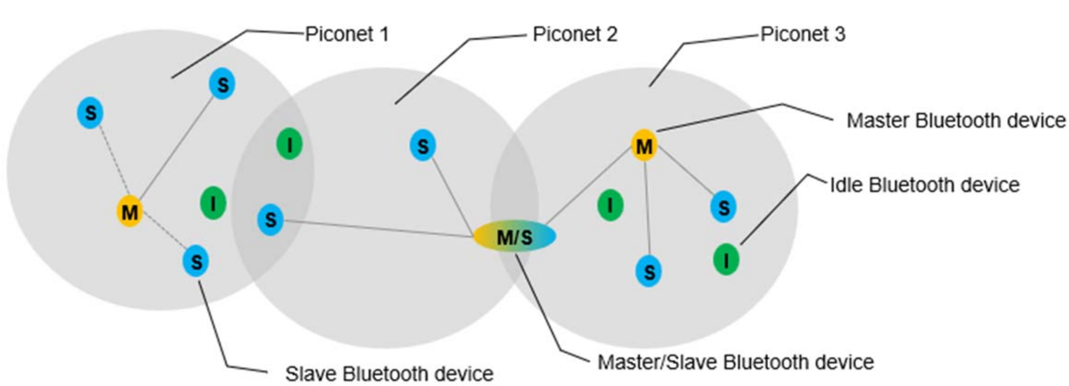

Fig. 1. A scatternet of three piconets [10]

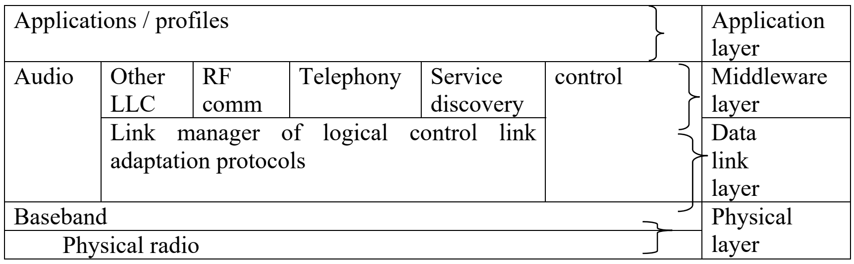

Fig. 2. The physical layer of the Bluetooth protocol

2. Literature review and problem statement

The paper [11] proposed a system for transmitting both data and voice via a 250-meter communication link. The optical source was a 100 mW, 808 nm DPSS LASER. The data transmission unit employs an ON-OFF keying modem, with a data rate of 2 Mbps achieved. For voice communication, a pulse width modulation technique was used. However, there were unresolved issues related to the full-duplex optical wireless communication solution that can link two IoT networks together. A methodology for communicating digital speech data for small groups was given in the study [12], which used the TDMA approach to transfer data or speech to other nodes via multi-hop retransmission and to add ad-hoc functionality. Although the study partitioned a network cycle into 17 tiny time slots with the first slot designated as a contention slot and the maximum number of full-duplex nodes that can communicate with each other is sixteen, the full-duplex backscatter system with a carrier source is not discussed. This issue is resolved in [13], where a monostatic full-duplex backscatter system with a carrier source co-located with a commercial Bluetooth chipset was demonstrated for the first time in the publication. The system allows for the co-location and simultaneous functioning of a commercial Bluetooth chipset and a carrier source, allowing for the usage of specially developed BLE-Backscatter tags to convey data to the commercial Bluetooth chipset without requiring any software changes. The reason for the companionable backscatter communication problem may be objective difficulties associated with BLE devices. The study [14] demonstrated an ultralow-power BLE v5.0 companionable backscatter communication uplink. This backscatter technique works with BLE devices that haven't been modified, such as PCs, cell phones, and tablets, and uses less than 200 pJ/bit of energy, which is more than 50 percent not as much as a commercially accessible BLE transmitter. A way to overcome these difficulties can be backscatter-based data uplinks in [15] that proposed a dual-band, which has energy efficiency with the BLE backscatter method. This approach was used in [16], which is one of the most popular and robust routing protocols for wireless ad hoc networks, enhanced for Bluetooth Low-Energy communication. However, the study [17] offered a rigorous measurement-based evaluation of two mesh techniques that can be used with BLE flooding and connection-oriented networking. Flooding can sacrifice a shorter end-to-end delay for larger power consumption as compared to linked mesh for equivalent performance in terms of overhead and PDR.

The paper [18] described a method for improving the packet delivery ratio by involving only a few nodes, or relays, in packet forwarding. The authors looked at three different relay selection processes and developed extensions that could work in a distributed environment. The paper [19] suggested a unique BLE-based overlay mesh (BOM) that adds mesh capabilities to existing beacon networks without requiring the installation of new equipment to control beaconing and flooding situations. However, all these studies still do not discuss mesh flooding and estimate packet delivery ratio in wireless sensor networks.

All this suggests that it is advisable to conduct a study on providing a demonstration and analysis for a Bluetooth mesh of the network layer flooding and estimate the packet delivery ratio in wireless sensor networks using Bluetooth Protocol in the MATLAB environment. The mechanism of network flooding is studied by categorizing a path between source-destination nodes throughout transitional relay nodes.

3. The aim and objectives of the study

The aim of the study is to develop a Bluetooth mesh flooding between source-destination links of nodes in wireless sensor networks to model asynchronous transmissions including a visual representation of a mesh network.

To achieve this aim, the following objectives are accomplished:

– to configure a Bluetooth mesh network and create mesh visualization of two source-destination pairs with some out-range nodes of the Bluetooth network;

– to examine the dropping of several Relay/End nodes from the Bluetooth network by disabling the relay label of some nodes within a configuration of some out-range nodes in the network;

– to visualize source-destination pair of nodes with unregulated distribution of Relay/End nodes;

– to show the effect of an unregulated distribution of Relay/End nodes on the path connection between source-destination nodes;

– to identify and visualize three overlapped source-destination links between nodes with a regulated range among them;

– to obtain the statistical data of each node in the Bluetooth mesh network and the node pair probability using the Monte Carlo method.

4. Materials and methods

This work discusses network layer flooding in a Bluetooth mesh and estimates the packet delivery ratio in a wireless sensor network (WSN) using Bluetooth Protocol in the MATLAB environment. Three simulation scenarios include performance evaluation of the network flooding carried out over an area of 200×200 meters including 81 randomly distributed nodes as demonstrated in Fig. 3, while the BLE Mesh Flooding Simulation algorithm is shown in Fig. 4.

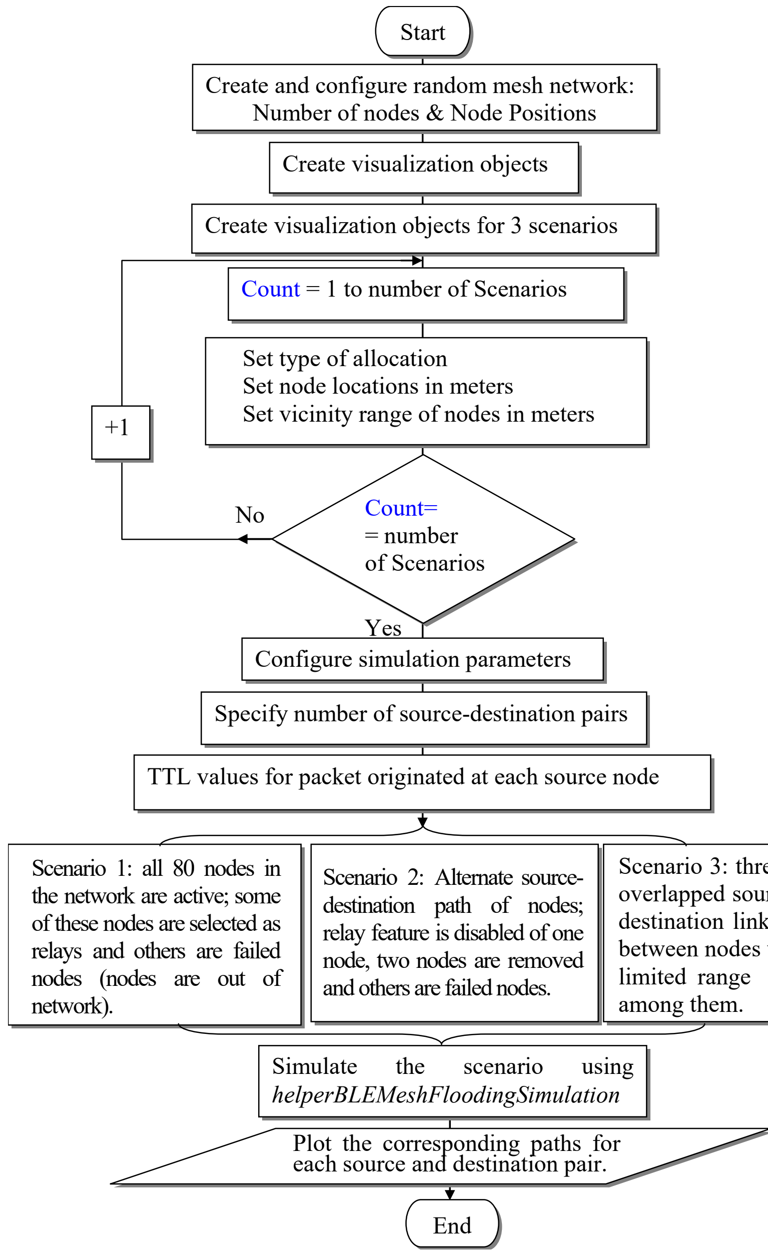

Fig. 3. Methodology flowchart of the proposed Bluetooth mesh network

The developed approach discusses three scenarios for configuring source-destination paths over an area of 200×200 meters including 80 nodes distributed randomly addressing the following issues:

– scenario 1 identifies and visualizes the source-destination path of nodes including selection of some relay middle nodes. Two source-destination links between End nodes are satisfied with some out-range nodes in the network;

– scenario 2 consists of dropping several Relay/End nodes by disabling the relay label of some nodes. Two source-destination links between End nodes are satisfied despite removing two nodes from the primary path. This is done with randomly distributed configuration with some out-range nodes in the network;

– scenario 3 visualizes linking between source-destination nodes with random distribution of Relay/End nodes;

– scenario 4 shows the effect of the wrong distribution of Relay/End nodes on the path connection between source-destination nodes;

– scenario 5 identifies and visualizes three overlapped source-destination links between nodes that are satisfied with a limited range among them.

This work also provides the main network statistics of the first five nodes that includes: Network-Layer parameters of all nodes, the number of node transmitted messages, the number of node received messages, the number of *Rx* messages to consider for more processing, the number of Relay node messages, and the number of Dropped node messages. These configuration parameters are used for further exploration, where the Monte Carlo algorithm is utilized for getting numerical results averaging through several simulations on the Bluetooth mesh network to obtain the probability of delivering messages. All the source-destination links among the nodes of the Bluetooth mesh network have been conducted on more than 80 nodes distributed randomly over an area of 200×200 meters.

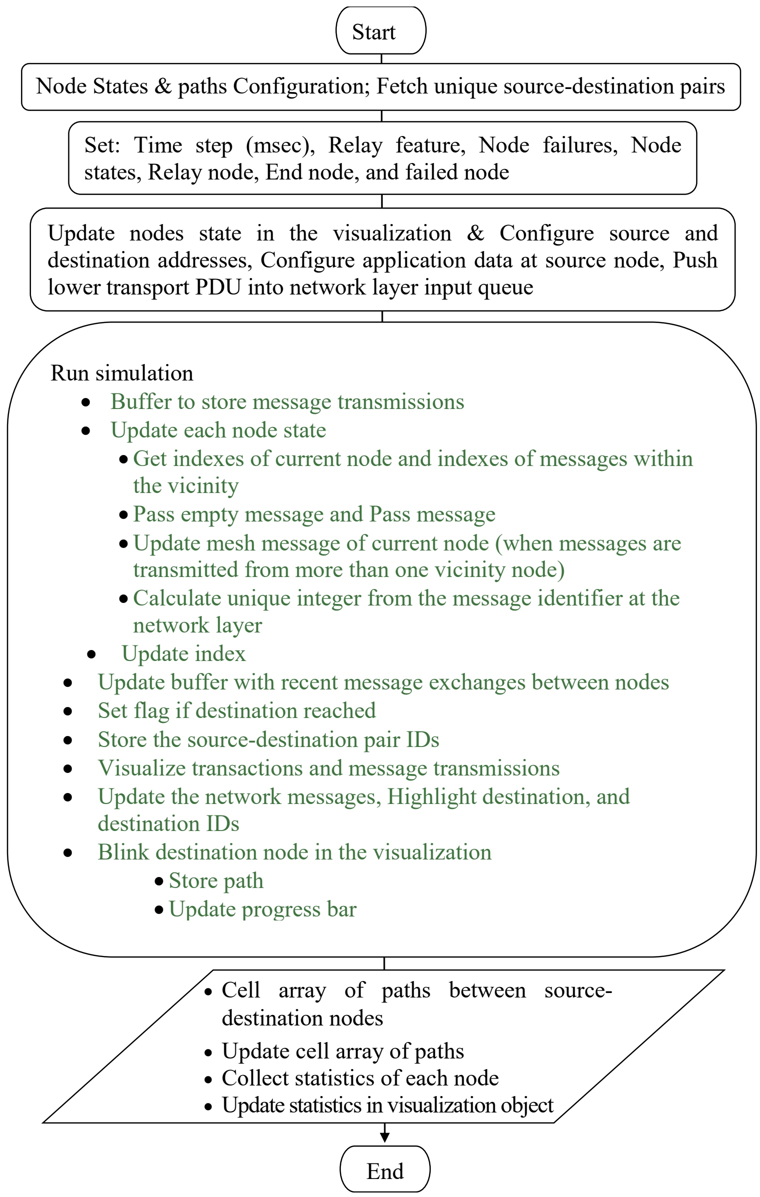

Fig. 4. BLE Mesh Flooding Simulation algorithm

5. Results of developing a Bluetooth mesh flooding between source-destination pair nodes in a network

5. 1. Mesh visualization of two source-destination pairs with some out-ranging nodes of the Bluetooth network (Scenario 1)

The mesh of the Bluetooth network in XY-position (meters) for 81 nodes is shown in Fig. 5.

Two source-destination links between End nodes are satisfied over an area of 200×200 meters including 80 nodes distributed randomly with some out-ranging nodes in the network.

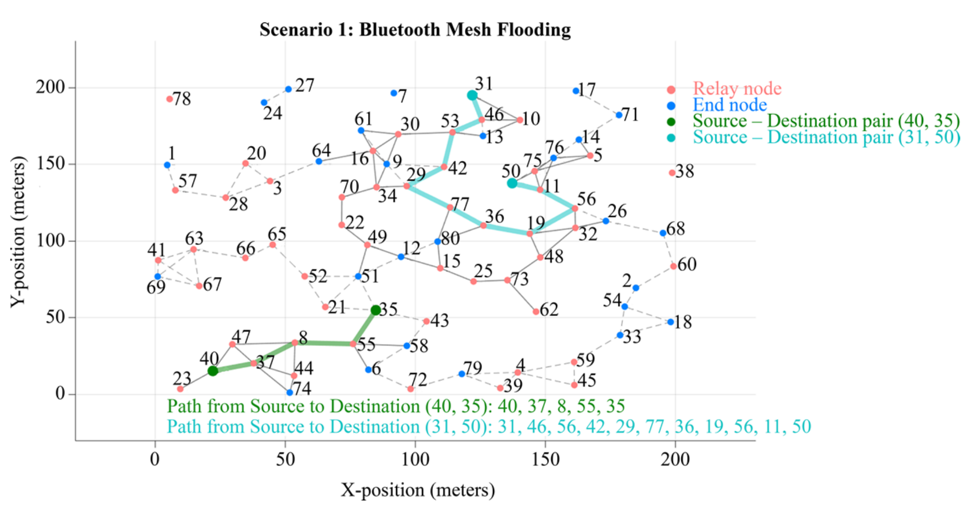

Fig. 5. Visual representation of the mesh network scenario 1

5. 2. Mesh visualization of source-destination pair nodes when removing two nodes from the primary path of Bluetooth mesh network (Scenario 2)

The mesh of the Bluetooth network in XY-position of 81 nodes is shown in Fig. 6.

Two source-destination links between End nodes are satisfied despite removing two nodes (37 and 42) from the primary path. This is done over an area of 200×200 meters including 80 nodes distributed randomly with some out-ranging nodes in the network.

5. 3. Mesh visualization of source-destination path nodes with random End nodes in Bluetooth mesh network (Scenario 3)

The mesh of the Bluetooth network in *XY*-position of 80 nodes is shown in Fig. 7.

Linking between source-destination nodes is satisfied even with random distribution of End nodes since the route of data is free of End nodes.

5. 4. Mesh visualization of wrong distribution of Relay/End nodes in Bluetooth mesh network (Scenario 4)

The mesh of the Bluetooth network in *XY*-position of 80 nodes is shown in Fig. 8.

Wrong distribution of relay/end nodes causes disconnection between source-destination nodes because the node with ID 35 ends the flow of data.

5. 5. Mesh visualization of three overlapped source-destination paths between nodes (Scenario 5)

The mesh of the Bluetooth network in *XY*-position of 80 nodes is shown in Fig. 9.

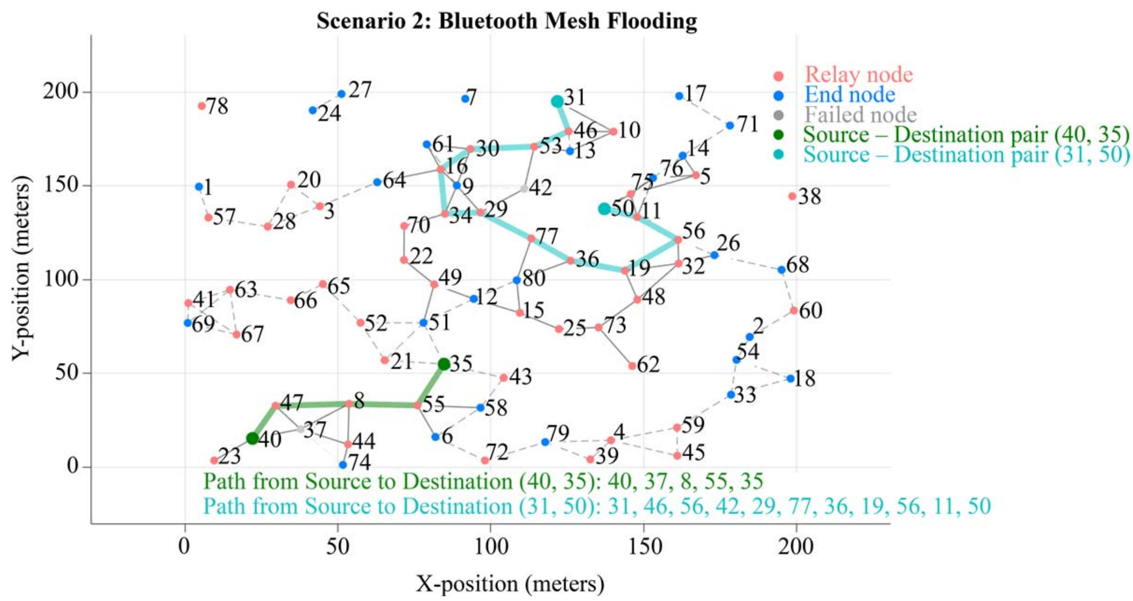

Fig. 6. Visual representation of the mesh network scenario 2

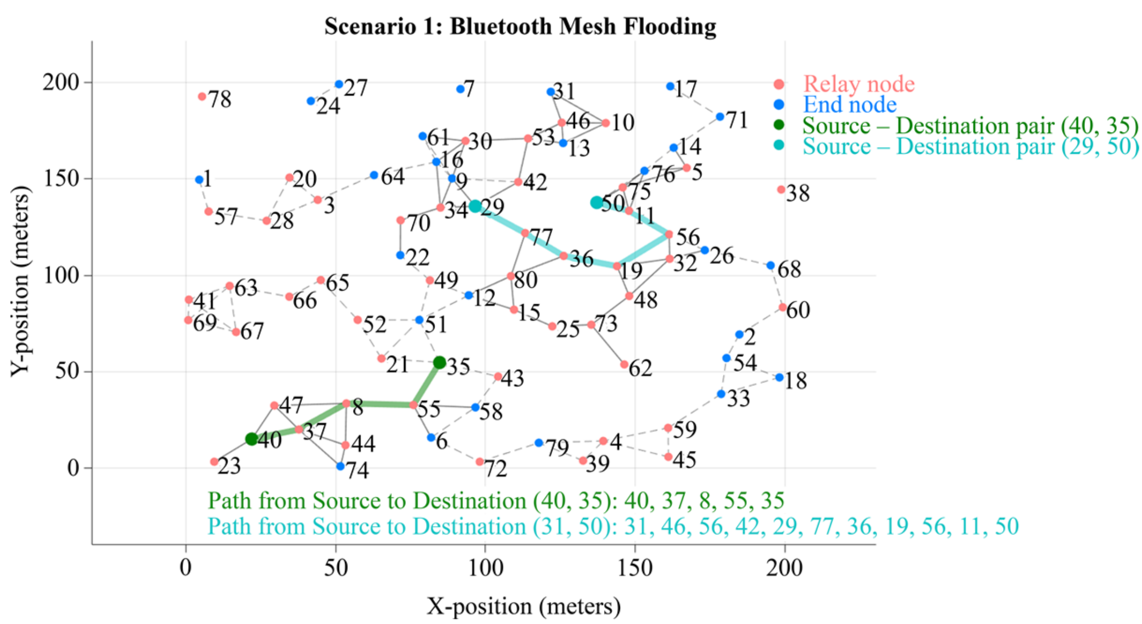

Fig. 7. Visual representation of the mesh network scenario 3

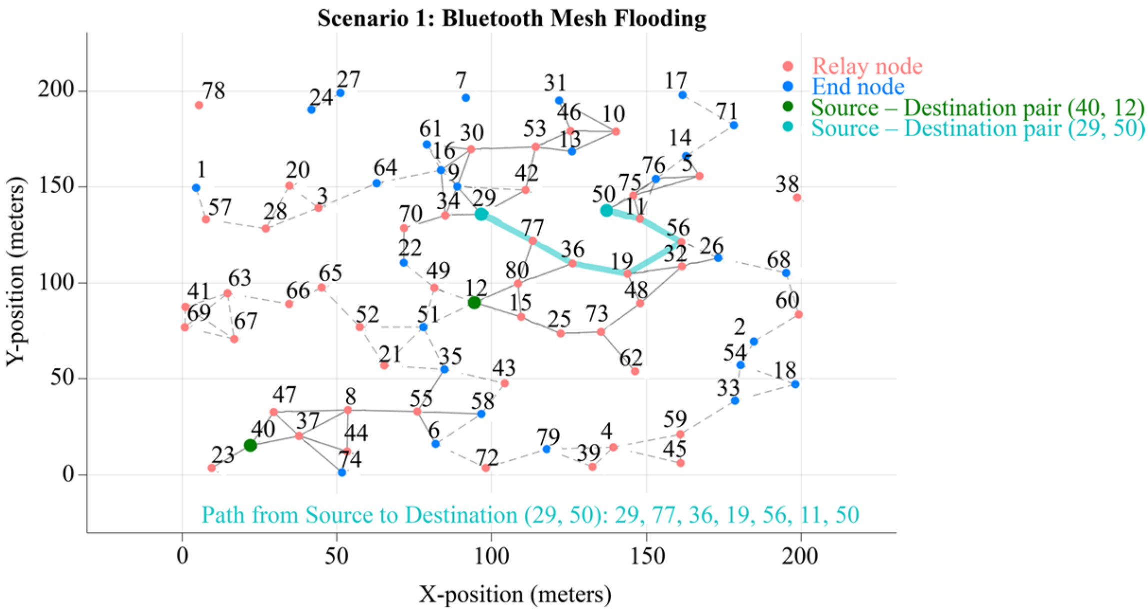

Fig. 8. Visual representation of the mesh network scenario 4

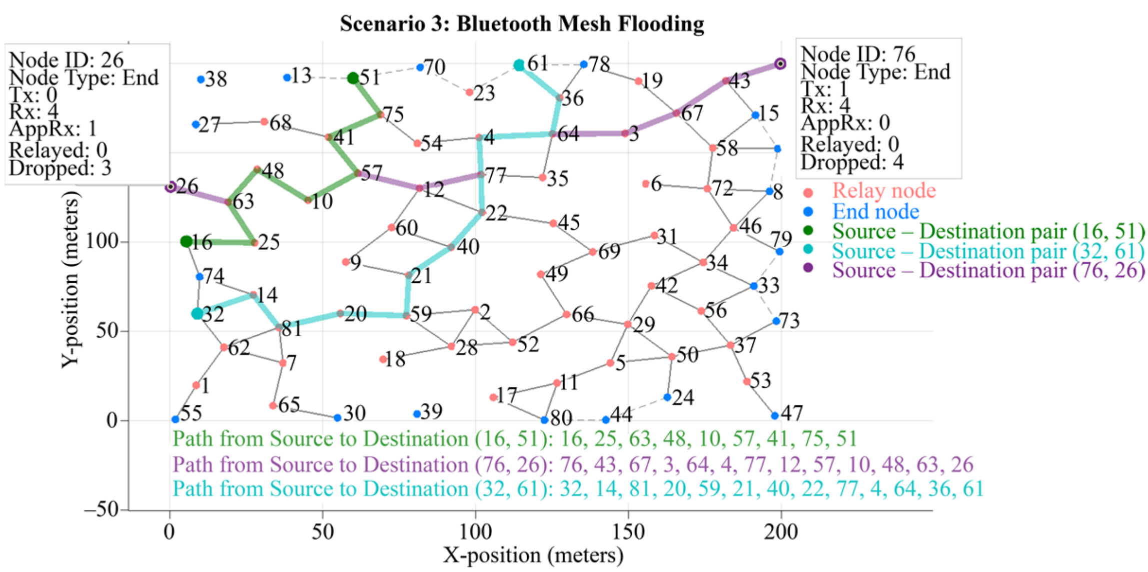

Fig. 9. Visual representation of the mesh network, in which between nodes (scenario 5)

Three overlapped source-destination links between nodes are satisfied over an area of 200×200 meters including 81 nodes distributed randomly with a limited range among them.

5. 6. Statistical data of each node and using the Monte Carlo method for a node pair probability

The developed model provides statistical data for each node in the workspace variable. The statistical data captured for each node includes the number of received and transmitted messages on PHY, received and transmitted messages on LL, messages received by CRC failures, transmitted, received, and dropped messages on the network layer, messages relayed on the network layer, received application messages on the network layer. As an example, for the three overlapped source-destination pairs (Scenario 5), the numerical presentation of the source-destination paths including the number of Hops is listed in Table 2, while the list of the first 5 nodes of these data can be listed in Table 3.

Table 2

Relative paths among each source-destination pair of Scenario 5

Source	Destination	Path	Number of Hops
16	51	{1×9 double}	8
32	61	{1×13 double}	12
76	26	{1×13 double}	12

Table 3

Statistical data for the first 5 nodes of Scenario 5

Node. ID	Total-TxMsg	Total-RxMsg	Total-AppRxMsg	Total-RelayedMsg	Total-DroppedMsg
1	0	5	0	4	1
2	0	11	0	4	7
3	0	9	0	5	4
4	0	9	0	4	5
5	0	11	0	4	7

These statistical data of each node in the workspace variable are essential to understand the Bluetooth mesh flooding, which is obtained in the next section.

Based on the Monte Carlo method, the probability of getting a pair of nodes 12 and 16 is 88.7428 %, and the average-hop-count linking of the nodes 12 and 16 is 8. In addition, separately from the neighborhood nodes of nodes (39, 37.8, 38, and 4) and node 12 and node 16 are the peak five critical relays of getting a linking between them.

6. Discussion of the results of developing a mesh flooding between source-destination links of nodes

This work conducted two source-destination links between arbitrary End nodes that are satisfied over an area of 200×200 meters including 80 nodes distributed randomly with some out-ranging nodes in the network. This simulation represents a mesh Bluetooth visualization of two source-destination pairs with some out-ranging nodes of objective 1. However, these two source-destination links between End nodes are also satisfied despite removing two nodes (37 and 42) from the primary path with some out-ranging nodes in the network, which verify objective 2 of this work. The linking between source-destination nodes is satisfied even with random distribution of End nodes since the route of data is free of End nodes. This represents the mesh visualization of random End nodes in the Bluetooth mesh network, which achieves objective 3 of this work. The unregulated/wrong distribution of relay/end nodes causes disconnection between source-destination nodes because the node with ID 35 ends the flow of data. This shows the mesh visualization of wrong distribution of Relay/End nodes in the Bluetooth mesh network of objective 4. Three overlapped source-destination links between nodes are satisfied with a limited range among them, which represents the satisfaction of objective 5.

The most important advantage of this work is that the number of source nodes can be set to two or five. It is also feasible to run simulations for any particular network scenario to determine the best source-destination path value.

The study limits some characteristics of the mesh network paradigm, which future studies could include altering any of these characteristics to further explore the mesh network paradigm. Numerical values averaged for the Bluetooth mesh network along with several iterations can be obtained by performing Monte-Carlo simulations.

7. Conclusions

1. The developed simulation displayed and created a Bluetooth mesh network of two source-destination pairs with some out-ranging nodes of the Bluetooth network by placing the nodes in a network in *XY*-position (meters) for 81 nodes.

2. The dropping of several Relay/End nodes from the Bluetooth network by disabling the relay label of some nodes didn't affect the node pair in the network within a configuration of some out-range nodes.

3. The developed simulations succeeded to display Bluetooth mesh flooding messages for the source-destination pair of nodes with unregulated distribution of Relay/End nodes.

4. This work shows the effect of an unregulated distribution of Relay/End nodes on the path connection between source-destination nodes.

5. This study identified and visualized three overlapped source-destination links between nodes with a regulated range among them with all related statistics.

6. The developed scheme obtained statistical data of each node, which includes the number of received and transmitted messages on PHY, received and transmitted messages on LL, messages received by CRC failures, transmitted, received, and dropped messages on the network layer, messages relayed on the network layer, received application messages on the network layer.

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