Computer Networks and Communications
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Article

Zigbee Based Mobile Sensing for Wireless Sensor Networks

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Received: 14 November 2023; **Revised:** 4 December 2023; **Accepted:** 11 December 2023

Abstract: Wireless sensor networks, have drawn a lot of interest because of their adaptability and range of uses in different industries. WSNs face significant challenges when it comes to energy efficiency because sensor nodes are usually battery-powered and have limited resources. Several energy-efficient methods and protocols, such as duty cycling, data aggregation, and topology management, have been put forth to address this problem. Moreover, new potential for mobile wireless sensor networks are presented by the integration of WSNs with mobile and static devices, such as drones, tablets, and smartphones. In this study, we suggest utilizing Zigbee technology to establish a robust and flexible monitoring system for both stationary and mobile sensors. Numerous industries, including healthcare, smart agriculture, asset tracking, energy management, smart home automation, and industrial monitoring and control, have made extensive use of Zigbee. By leveraging Zigbee's capabilities, we hope to improve the protocol's performance while establishing dependable communication links between nodes, analyzing the communication range, and assessing the influence of environmental conditions. In this study, a system model for Zigbee deployment in mobile robots will be presented. It will address the basics of Zigbee, communication difficulties, networking with Zigbee, and simulations or real-world outcomes. We will learn about the strengths and weaknesses of Zigbee-based systems in terms of creating reliable communication links in mobile wireless sensor networks by looking at their architecture and functionality. The results of this study will help us comprehend Zigbee's potential to improve monitoring systems and make better decisions across a range of industries. The study's emphasis on mobile monitoring systems signifies a step forward in addressing the evolving needs of wireless sensor networks in dynamic environments.

Keywords: wireless sensor networks (WSNs), Zigbee, Zigbee protocol, communication range analysis, challenges

1. Introduction

Because wireless sensor networks (WSNs) have so many applications across multiple industries, they have been the subject of substantial research. WSNs are made up of a vast number of tiny sensor nodes that can communicate with one another and gather information from their environment. These networks are perfect for applications in industries like healthcare, agriculture, and environmental monitoring since they can function in a variety of locations, including dangerous or isolated ones [1–3].

Due to the fact that the majority of sensor nodes are battery-powered and have limited energy resources, energy efficiency is one of the main issues facing WSNs. To extend the network's lifespan, energy-efficient

DOI: https://doi.org/10.37256/cnc.1220233923

methods and protocols are therefore required. Duty cycling, data aggregation, and topology control are a few strategies that have been put forth to increase energy efficiency in WSNs [4–6].

WSNs have been integrated with both stationary and mobile devices in recent years, including laptops, tablets, smartphones, and drones for mobile use. fixed appliances for static, sensors, actuators, gateways, and routers. Each has sparked a lot of curiosity. Because of this integration, mobile wireless sensor networks, which offer greater mobility and flexibility than traditional WSNs—can be developed [7,8].

Without a doubt, adding mobile and static sensors to a monitoring system can improve network performance and monitoring capabilities to a great extent. It is possible to create a comprehensive and flexible monitoring solution by combining the advantages of each type of sensor. Numerous benefits can result from this, such as enhanced spatial coverage, fault tolerance, dynamic network configuration, comprehensive data collection, and the ability to adapt to changing conditions for monitoring systems. The requirements of the application, the goals of the monitoring, and the features of the monitored environment determine the precise deployment strategy and sensor choice [9,10].

Based on our research, we believe that implementing Zigbee for Static and Mobile Sensors will produce a robust and flexible monitoring system. We will be able to collect rich and varied data with this system, which will enhance our comprehension of the surroundings and open the door to better decision-making and efficient management techniques.

Amidst these advancements, the proposed research introduces a novel approach by advocating for the implementation of Zigbee technology for Static and Mobile Sensors. The motivation behind this approach is to establish a robust and flexible monitoring system capable of leveraging Zigbee's capabilities to gather rich and diverse data. This data not only enhances the understanding of environmental dynamics but also provides a foundation for informed decision-making and efficient management techniques. We will consult pertinent research papers, industry publications, and scientific journals that examine the use of Zigbee in wireless sensor networks, the Internet of Things, and environmental monitoring in order to bolster this theory and obtain additional understanding. These resources will offer insightful information and act as references to support and improve the results of our research. Understanding Zigbee's capabilities and limitations in order to create dependable communication links between nodes is the main goal. analysis of communication range and among the significant issues that will be examined are the effects of environmental variables, the assessment of the Zigbee protocol, and performance optimization [11,12].

Numerous industries, including healthcare, senior care, smart agriculture, asset tracking, smart home automation, industrial monitoring, and energy management, have found numerous uses for Zigbee technology [13].

There are various sections that make up the research structure. While Section 3 discusses the formulation of the current research problem, Section 2 presents the System Model with Zigbee deployment for Mobile Robots. In Section 4, we scope the comparative analysis of zigbee technology compared to the other technologies. Node Mobility is covered in Section 5. Simulations and Results in Section 6, which present the carried out simulations and analyze the results, round out the research. This thorough study sheds light on the system model, principles, difficulties, networking features, routing protocols, node mobility, and performance assessment of Zigbee technology.

2. System Model

A combination of mobile and stationary sensors are positioned strategically throughout the environment in Figure 1's system model. Static sensors are fixed nodes that are positioned at predefined intervals to keep an eye on particular regions or parameters of interest. On the other hand, the mobile sensors possess the ability to move around and investigate various areas of their surroundings [14,15].

Within their communication range, the mobile sensors make use of Zigbee technology to enable data exchange. Zigbee's ad hoc networking capabilities allow mobile sensors to create wireless connections when they are in close proximity. The mobile sensors can easily exchange data, such as sensor readings, location information, and observations of their surroundings, thanks to this dynamic network formation. Among the mobile sensors, this peer-to-peer communication facilitates cooperative data sharing and improves situational awareness [16,17].

The system comprises base stations or central controllers that are placed strategically throughout the environment to ensure effective data transmission. The nearest base station acts as a central hub for all of the mobile sensors within its coverage area, and the mobile sensors communicate with it. By receiving data from the mobile sensors and enabling its further distribution, the base station serves as a gateway. This may entail processing and making decisions locally, sending the data to other linked systems, or relaying it to a central server [18,19].

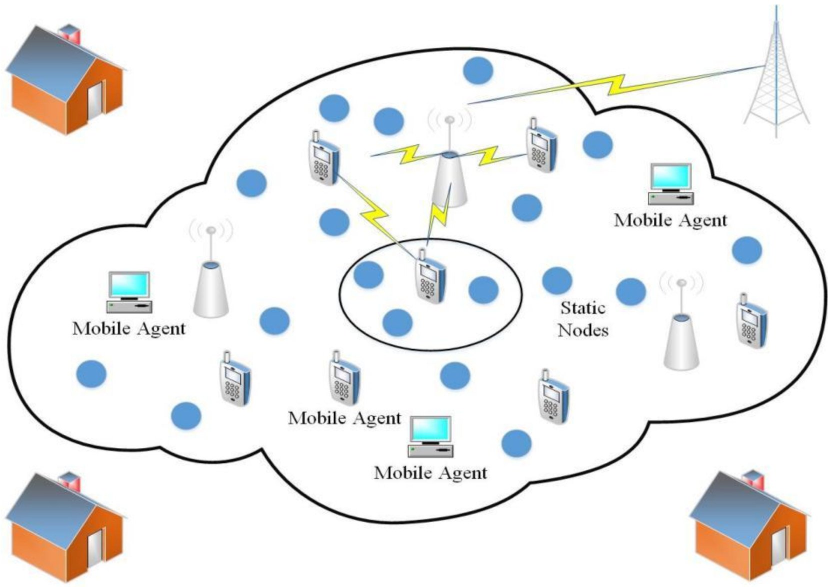


Figure 1. System Design of Mobile Wireless Sensor Networks.

By giving the mobile sensors information, the stationary sensors also aid in the data exchange. Static sensors gather information about the surrounding environment or keep an eye on particular parameters at their assigned sites. Zigbee-based communication is used by the static sensors when pertinent data has to be sent to the mobile sensors. When the distance between a static sensor and a mobile sensor is greater than the direct communication range, this can be accomplished by making direct connections with neighboring mobile sensors or by utilizing Zigbee's multi-hop routing capabilities. Static sensors can efficiently relay data through intermediate nodes to the intended mobile sensors by utilizing Zigbee's mesh networking capabilities [20,21].

Zigbee's mesh networking feature allows nodes to function as routers to increase the network's coverage and get around obstacles, ensuring dependable communication even in difficult environments. Zigbee devices' low power consumption extends the battery life of mobile sensors that run on batteries, allowing for extended use between battery changes [22,23].

3. Problem Formulation

Through the use of Zigbee technology for both stationary and mobile sensors, this research aims to address the challenge of developing a robust and flexible monitoring system in wireless sensor networks. The aim is to collect rich and varied data, enhance comprehension of the environment, and support improved management and decision-making techniques. The goal of the study is to examine Zigbee's potential and constraints for establishing dependable communication links between nodes while taking into account environmental effects, protocol evaluation, performance optimization, and communication range. The research questions cover a wide range of subjects, including mesh networking benefits, node mobility effects, deployment strategies, communication range analysis, and the impact of environmental factors. The study intends to contribute to the creation of an energy-efficient and flexible monitoring system by addressing these issues and offering insights into the system model, foundations, networking aspects, routing protocols, node mobility, and performance evaluation of Zigbee technology.

Static and mobile sensors that are placed strategically throughout the environment make up the system model used in the study. While mobile sensors are able to move around and explore different areas of the environment, static sensors are fixed nodes that are placed in specific locations to monitor predefined areas or parameters. Within the range of the mobile sensors, Zigbee technology is used for communication, allowing them to connect wirelessly and share data, including readings from the sensors and observations of their surroundings. In order to enable effective data transmission, base stations, also known as central controllers, are positioned in strategic locations to act as hubs for the mobile sensors that fall under their coverage areas. Furthermore, the stationary sensors make a contribution by utilizing Zigbee-based communication to transfer data to the mobile sensors, either directly or through multi-hop routing when the distance is too great for direct connections to range of communication. Zigbee's mesh networking feature makes communication dependable, and its low power consumption prolongs the life of mobile sensors that run on batteries.

4. Comparative Analysis of Zigbee Technology

In light of the aforementioned comparison, Zigbee's distinct feature set justifies its choice for communication technologies in networks. One of Zigbee's most notable features is its exceptional energy efficiency, which makes it especially useful for devices that run on batteries [24]. Zigbee's mesh networking architecture adds to its scalability by allowing for the construction of large, robust networks. This scalability is essential, particularly in applications like smart homes and industrial settings where a lot of devices need to communicate with each other without any problems. Zigbee has moderate data transfer rates, but in situations like home automation and healthcare, where robust connectivity and real-time responsiveness are critical, the trade-off for reduced latency and reliability is frequently favorable, this can be found in Table 1, where is compared Zigbee and other techologies. Zigbee's interoperability is improved by using the 2.4 GHz frequency band, which harmonizes with common international standards. Furthermore, Zigbee's security features [25], such as AES-128 encryption, make it even more appealing to apps that value data security. All things considered, Zigbee proves to be a flexible and well-rounded solution, performing exceptionally well in situations where a harmonious combination of scalability, dependability, and energy efficiency is crucial.

Scrutinized real-world scenarios highlight Zigbee's potential to create resilient and scalable networks. The performance part explores reliability, latency, and data transfer rates and compares Zigbee to Wi-Fi and newer protocols like Thread. Through navigating through these complexities, the goal of this comparative analysis is to give readers a comprehensive understanding of the benefits and drawbacks of Zigbee, enabling them to make well-informed decisions when choosing the best wireless communication solution for a variety of applications [26].

Table 1. Comparative Analysis of Zigbee Technology [27,28].

Feature	Zigbee	Bluetooth Low Energy (BLE)	Wi-Fi	Z-Wave	Bluetooth Mesh
Energy Efficiency	Low power consumption	Low power, but can vary	Higher power consumption	Moderate to low power	Varies based on application
Scalability	Excellent mesh networking	Limited scalability	Highly scalable	Good scalability	Mesh networking
Data Transfer Rates	Moderate	Low to moderate	High data rates	Moderate	Varies based on application
Latency	Low latency	Varies, can be low to high	Varies, can be low to high	Low mderate	Varies based on application
Reliability	Robust mesh network	Can vary based on environment	Reliable, but subject to interference	Reliable	Mesh architecture for reliability
Frequency Band	2.4 GHz	2.4 GHz	2.4 GHz, 5 GHz	900 MHz (varies by region)	2.4 GHz
Use Cases	Home automation, industrial control, healthcare	Wearables, short-range IoT	High-speed data transfer, multimedia streaming	Home automation, security	Large-scale IoT applications
Standardization	IEEE 802.15.4	Bluetooth SIG	IEEE 802.11	Z-Wave Alliance	Bluetooth SIG
Security Features	AES-128 encryption	Encryption options available	WPA2/WPA3 security	AES-128 encryption	Encryption options available

5. Node Mobility

The ability of a network node a device or entity to move about a network while staying connected and adjusting to altered network conditions is known as node mobility. It entails the smooth movement of a node between locations, frequently requiring modifications to base stations or network access points [28].

Every node sets out from its current location to travel towards its selected destination at the beginning of the simulation. The nodes' velocities exhibit uniform distribution, and their random selections are made from the interval [0, Vmax], which denotes the highest speed at which a node can operate [29]. and Figure 2 illustrates this movement's methodology.

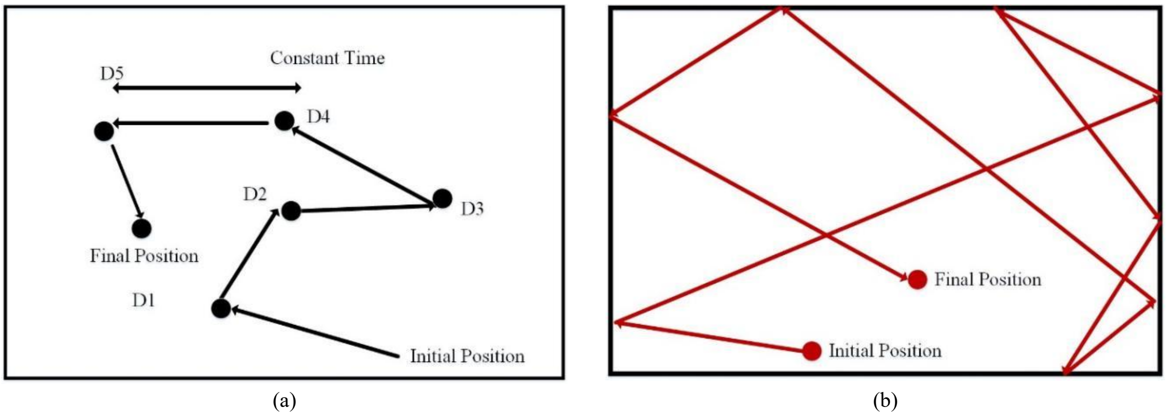


Figure 2. (a) Node movement in Random Way Point Mobility Model and (b) Node movement in Random Direction Mobility Model.

When nodes arrive at their destinations, they pause for a predetermined amount of time, called the pause time, which is chosen at random from the interval [0, Tpause]. The node stays still during this pause, generating stable intervals before continuing on its way to a new location [29].

5.1 *Network Architecture of a Mobile Wireless Sensor Network*

A mobile sink, shown in Figure 3, is a particular kind of mobile device that can travel through a wireless sensor network and collect data. Mobile sinks can move throughout the WSN, collect data, and send it to a distant base station or server, in contrast to traditional sink nodes, which are immobile and positioned at a specific location [30].

In Wireless Sensor Networks, Sink Assistants are a kind of mobile device that helps stationary sinks. SAs are affixed to static sinks and assist them in carrying out their duties more effectively, in contrast to Mobile Sinks, which travel throughout the network area to gather data. By distributing the workload evenly among the sinks and lowering their energy usage, SAs can enhance network performance [31,32].

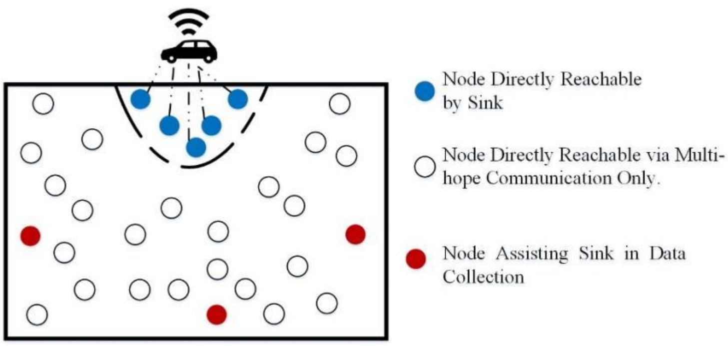


Figure 3. Network architecture of a mobile wireless sensor network.

5.2 *Data Gathering Methods in WSNs*

The methods and approaches used to gather data from the underwater environment using a network of underwater sensors are known as WSN data gathering methods. These techniques, which optimize network performance and efficiency while reducing energy consumption and communication overhead, involve a variety of algorithms and protocols for data transmission, aggregation, and storage [33].

Void handling algorithms, cluster-based techniques, mobility-based approaches, opportunistic routing, geographical routing, and mobility-based methods are the five main categories into which the WSN data gathering methods can be broadly divided [33]. Additional cluster and mobility-based techniques based on routing strategies are also included. As a result, the Mobility Models in WSNs will be the main topic of this work [34].

5.3 *Mobility Models in Mobile Wireless Sensor Network*

The nodes in a mobile wireless sensor network are movable and subject to frequent location changes. The movement patterns of the network's nodes are described by mobility models (Figure 4), which is crucial for forecasting network behavior and optimizing performance [35].

Mobility models are intended to mimic the ways in which nodes move within mobile wireless networks and to capture the ways in which their mobility parameters, such as position, acceleration, and speed, change over time. The goal of these models is to faithfully capture the patterns of displacement that exist in actual environments. MMs can offer insights into the behavior of mobile wireless networks and aid in performance optimization by precisely recording the movement patterns of nodes [36,37].

Numerous mobility models have been created to accommodate various network scenarios, including temporal, spatial-dependency, and random models. However, new and sophisticated mobility models are being developed to accommodate various use cases and network statuses in response to the growing demand for mobile wireless networks in a variety of applications. By precisely capturing the dynamic movement patterns of nodes in mobile wireless networks, these incoming and advanced mobility models hope to shed light on their performance and behavior [38].

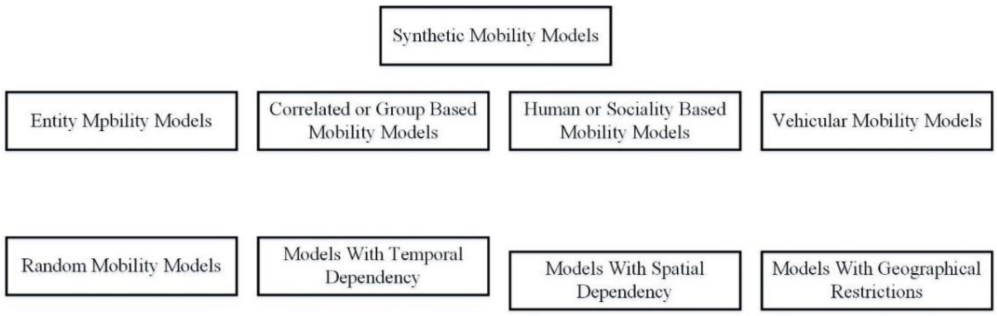


Figure 4. Mobility Models in mobile wireless sensor network.

5.4 *Synthetic Mobility Models*

For testing and simulation, nodes in mobile wireless networks can move in synthetic ways thanks to the use of synthetic mobility models. Usually, these models use mathematical and statistical methods to create movement patterns that resemble the actions of actual mobile nodes. Additionally, these methods can be separated into three categories: human mobility models, correlated mobility models, and entity mobility models [36].

5.4.1 Entity Mobility Models

Random Waypoint Mobility Model (RWPMM): A well-liked synthetic mobility model that produces random node movements is the RWP model. Nodes travel straight ahead to an arbitrary location, stop for an arbitrary period of time, and then move on to another destination [39].

Random node movements with intervals between direction and/or speed changes are produced by this model. A node chooses a random destination in the simulation region and a speed that is uniformly distributed between a minimum and maximum value at the beginning of the simulation after remaining motionless for a predetermined amount of time (the pause time). The node then proceeds at the chosen speed in the direction of the destination until it reaches it, at which time it pauses once more before starting the process over [39].

Manhattan Grid Mobility Model (MGMM): Nodes are positioned on a two-dimensional grid by the Manhattan Mobility Model, and they travel along the vertical and horizontal lines. This pattern of movement is very similar to how cars and pedestrians move through cities. Nodes have the ability to randomly choose a new direction when they are turning or changing directions at intersections. This gives nodes some flexibility to explore different streets while maintaining adherence to the city's underlying geographic structure [40].

The Manhattan Mobility Model can simulate node movements in urban environments more accurately by including high spatial and temporal dependencies. It might not work well in all situations, though, such as ones with erratic traffic patterns or pedestrian traffic. Other mobility models, like the Reference Point Group Mobility model or the Random Waypoint model, might be more suitable in these circumstances [40].

5.4.2 Correlated Mobility Models

Reference Point Group Mobility Models (RPGMM): One kind of mobility model used in wireless networking simulations is the Reference Point Group Mobility Model (RPGMM). Based on the notion that mobile devices travel in groups and that these groups move between reference points, RPGMM is implemented [41]. Every mobile device is assigned to a reference point group (RPG) in an RPGMM; an RPG is a collection of devices that move together. A collection of parameters that regulate movement speed and direction are applied to each RPG [42]. The selection of reference points ensures that every RPG moves independently of every other RPG.

When simulating scenarios where a group of mobile devices moves together, like in a pedestrian network or a vehicular ad hoc network, RPGMMs are helpful [41]. Additionally, they are helpful in assessing how well location-based services like location-based multicast or routing perform [42]. Researchers can examine how mobile devices behave and how mobility affects network performance in a controlled setting by employing RPGMMs.

The Nomadic Community Mobility Model (NCMM): is a kind of mobility model that takes into account nomadic communities' movements in WSN. A nomadic community, according to this model, is a collection of mobile devices that travel together. The community's movements are controlled by a set of guidelines that imitate the behavior of actual nomadic communities [43]. According to the NCMM, nomadic communities follow a cyclical pattern of movement, with each cycle consisting of a specific sequence of waypoint visits by the community [44]. The NCMM also has controls for the community's speed, how long it spends at each waypoint, and how likely it is that it will veer off the cyclic path.

The NCMM is a helpful tool for modeling situations in which a collection of mobile devices moves in unison in a cyclical manner, as in military, disaster relief, and wildlife tracking applications [43]. Researchers can examine how mobile devices behave and how mobility affects network performance in a controlled setting by utilizing the NCMM.

5.4.3 Human Mobility Model

Human mobility modeling has a wide range of possible uses. Traces that are generated from these kinds of models can be used to simulate a variety of things, such as epidemics, urban planning, transportation systems, wireless ad hoc networks, and disaster response [45,46].

These models attempt to capture the essential elements of human mobility, including directionality, acceleration, and velocity. They are based on statistical analyses of real-world data, such as GPS traces [47,48].

The stop-and-go behavior of vehicles in urban settings is simulated by the SLAW model, whereas the smooth model mimics the smooth movement of vehicles on highways and other high-speed roads. Applications for both models include the simulation of vehicular ad hoc networks, the assessment of emergency warning and collision avoidance systems, and the investigation of the effects of traffic congestion on network performance [47,48].

In order to better understand the intricate patterns of human movement and to enhance the design of transportation systems, emergency response procedures, and urban planning, scientists are still working to improve and develop models of human mobility [47,48].

5.5 *Static Sensors vs Mobile Sensors in WSNs*

Numerous tiny, inexpensive, low-power devices known as sensor nodes make up a typical wireless sensor network. Typically immobile, these nodes interact with one another to acquire information about the surroundings [49]. To track moving objects or enhance network coverage, these nodes might need to be made mobile in specific situations [50].

To create a static WSN mobile, there are multiple methods. One method is to fasten the sensor nodes to moving objects within the network, like cars or robots [51]. Using drones or other flying objects with sensors to collect data from various locations within the network area is an additional method [52].

The network protocol needs to be built with node mobility handling in mind in order to support mobility in a WSN. Using a hierarchical routing protocol, in which nodes are arranged into clusters and cluster heads are in charge of forwarding data to the base station, is one method to accomplish this. In order for the network to adjust to changes in node locations, the cluster heads can be dynamically chosen based on their mobility [53,54].

Using a location-based routing protocol, in which nodes share location data and utilize it to forward data to the base station, is an additional strategy. In this scenario, the position of each node needs to be determined by a location sensor, like a GPS receiver [55].

Overall, network coverage and data accuracy can be greatly improved by integrating mobility into a WSN. It also brings up new issues that need to be carefully considered in the network protocol design, such as energy consumption, data routing, and network topology maintenance [56].

Static nodes are first placed in a two-dimensional environment in Figure 5, where they have to figure out where they are. A stationary node sends a message to a mobile robot node in response to detecting an event. The mobile robot determines a path to the target node by using the estimated locations of the static nodes [57].

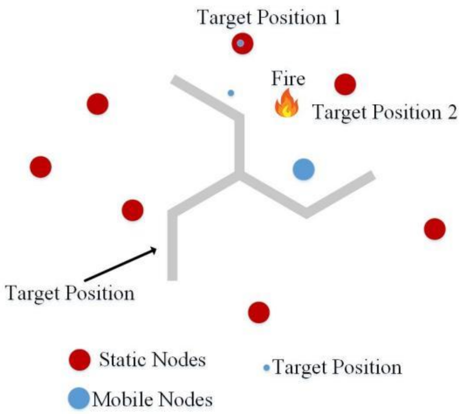


Figure 5. Static vs Mobile in WSN.

5.5.1 Sensing and communication range in WSNs

a) The sensing ranges

As seen in Figure 6, Sensing range, which describes the greatest distance a sensor node can travel to detect an event or phenomenon, is a crucial parameter in wireless sensor networks (WSNs). Numerous variables, including transmit power, antenna gain, noise level, and ambient conditions, affect the sensing range. To increase the sensing range and coverage in WSNs, a number of studies have proposed novel techniques like probabilistic sensing, energy-based sensing, and signal strength-based sensing [58,59].

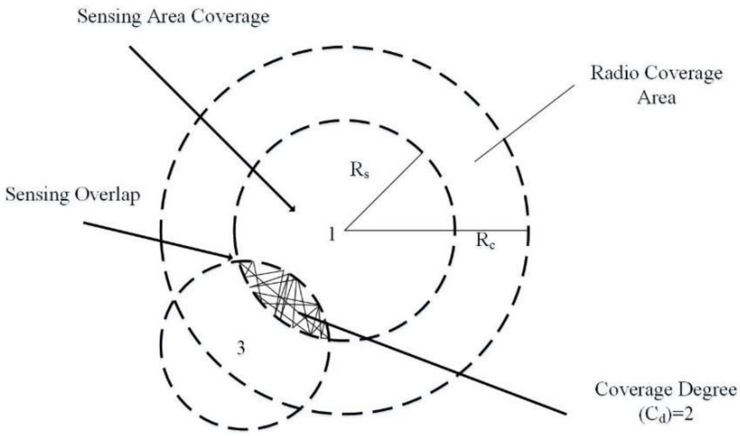


Figure 6. Sensing and communication range in WSNs.

b) The communication ranges

Is the greatest distance that two sensor nodes can have dependable communication over. Numerous elements, including the modulation scheme, transmit power, receiver sensitivity, and channel conditions, affect the communication range. To increase the communication range and quality in WSNs, several studies have suggested various strategies, including relay nodes, directional antennas, and adaptive transmission power [60,61].

Euclidean distance

A measurement of the straight-line distance in a Euclidean space between two points is called the Euclidean metric. Figure 7 shows how we computed the two-dimensional Euclidean distance and the nodes' communication range using the Pythagorean theorem [62].

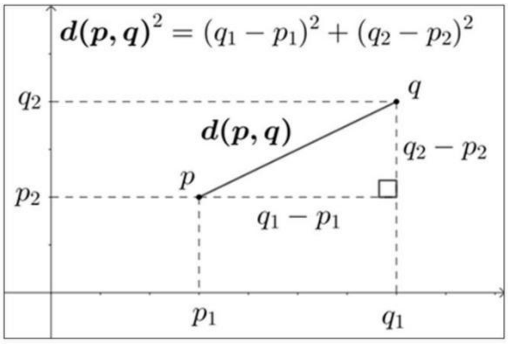


Figure 7. Using the Pythagorean theorem to compute two-dimensional Euclidean distance.

c) Sensing coverage area

In wireless sensor networks, the geographic area that a single sensor node can provide sensing coverage over is referred to as the sensing coverage area. Numerous elements, including the network topology, deployment density, and sensing range, have an impact on it. The sensing coverage area can be mathematically modeled through a variety of methods, including grid-based methods, Delaunay triangulation, and Voronoi diagrams. To increase the sensing coverage and efficiency in WSNs, a number of studies have suggested various techniques, including mobility-assisted schemes, clustering algorithms, and convex hull-based approaches [63,64].

d) The radio area coverage

Is used to describe the area in which wireless signals can be sent and received by network devices. Numerous variables, such as the transmitting power, antenna gain, frequency, and ambient conditions, affect the radio coverage area. Several studies have suggested various approaches to increase the radio coverage and capacity in wireless networks, including multi-hop communication, power control, and interference management [65,66].

The radio area coverage is assumed to be larger than the sensing coverage area.

e) Sensing overlap

This is the region where the sensing coverage of several sensor nodes overlaps. It is the area inside the WSN where multiple sensor nodes are able to detect and gather information about the same occurrence or phenomenon [67,68].

5.6 *Stationary or Static in Wireless Sensor Network*

Energy efficiency, data aggregation, and network scalability can all be optimized in a stationary WSN (Figure 8) that does not experience node failure. The network's lifespan can be increased by implementing energy-efficient protocols like duty cycling and sleep scheduling, which reduce energy consumption. In order to decrease redundant data transmission and increase bandwidth utilization, data aggregation techniques can be applied. Additionally, scalability can be supported in the network design, making it simple to add or remove nodes in accordance with the needs of the application.

When a node fails in a stationary WSN (Figure 8), fault tolerance and recovery mechanisms must be taken into account. The network should be built to support graceful node failures and guarantee ongoing data gathering and communication. This can be accomplished by implementing redundancy via multi-hop routing, which uses backup routes to send data in the event that a node fails. Furthermore, methods such as fault detection, error correction codes, and network reconfiguration can be implemented to lessen the effects of node failures and preserve dependable network communication.

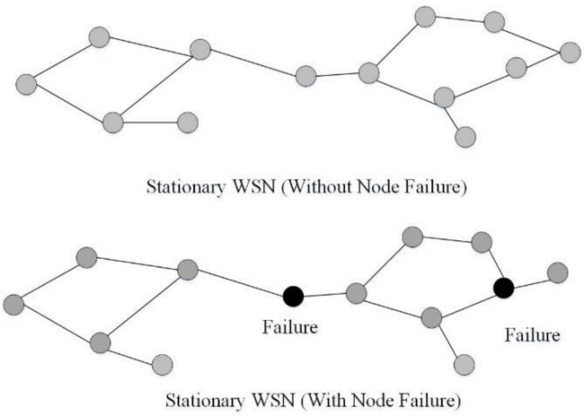


Figure 8. Stationary (Static) in WSNs.

6. Simulation Results

We will explain the network's behavior in terms of message passing and connectivity based on the communication range and node positions in this section of simulations and results. In particular, how adjusting the communication range impacts the quantity of messages that are passed between nodes and the number of neighbors that each node has. In order to achieve this, we looked at the following four scenarios:

- Scenario 1: Interface Zigbee Static to Static Nodes;
- Scenario 2: Interface Zigbee Mobile to Mobile Nodes;
- Scenario 3: Simulating the Number of Communication vs the Communication Range;
- Scenario 4: Zigbee Static to Mobile Nodes.

6.1 *Scenario 1: Random Zigbee Static to Static Sensors*

A wireless sensor network with ten static nodes that communicate via the Zigbee protocol is shown in scenario number 1 (Figures 9 and 10). The communication range between nodes is set to 30 meters, and the nodes are randomly placed within a 100 by 100 meter area. This means that if two nodes are closer than the communication range, they are added to each other's neighbor lists and are deemed to be neighbors. A blue circle surrounds each Static Node, which is depicted as a tiny black circle with its communication range shown around it.

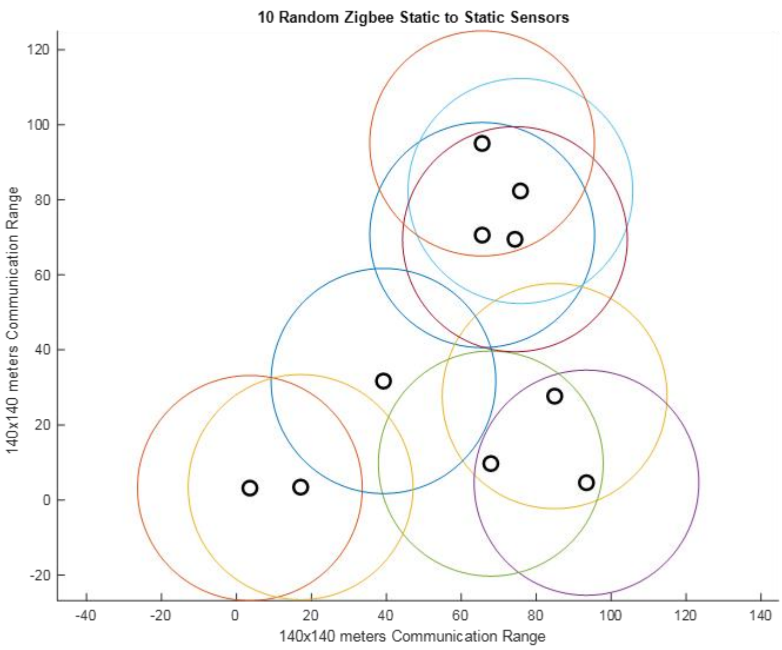


Figure 9. 10 Random Zigbee Static to Static Sensors.

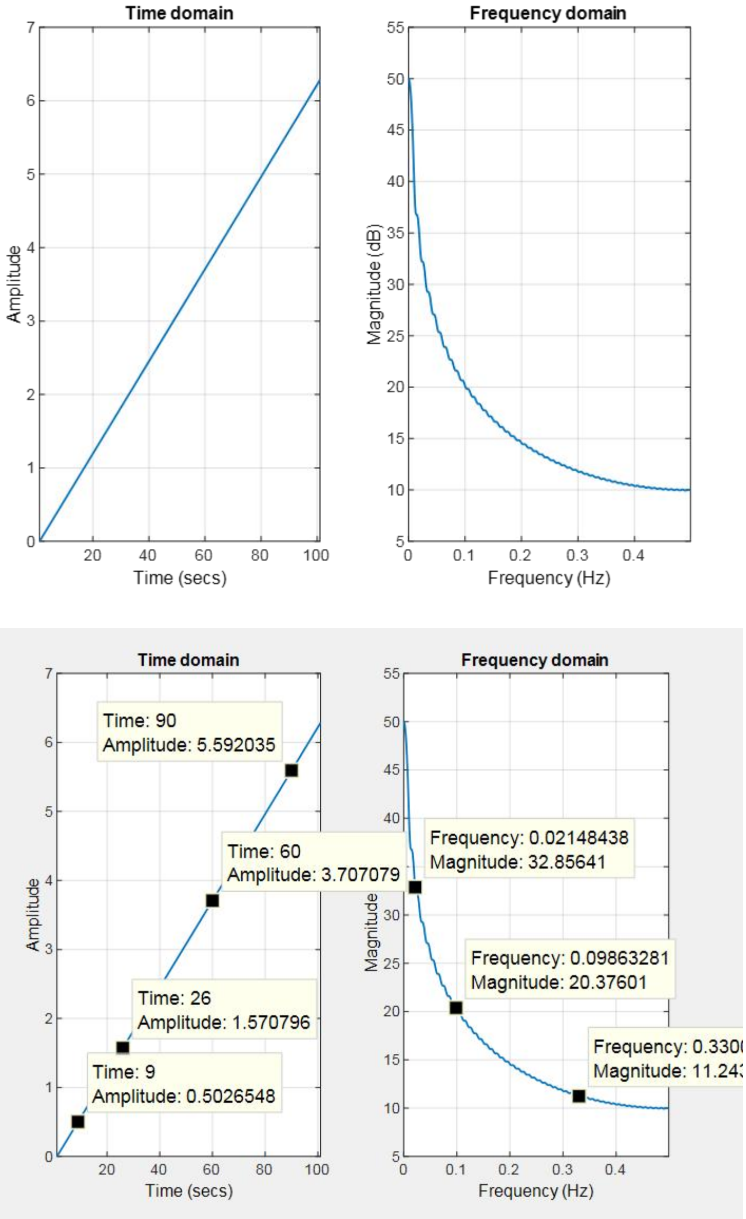


Figure 10. Time domain and Frequency Domain for Static to Static Nodes in seconds.

In order to store network data for every node, the simulation first creates a cell array to initialize the network. Next, it determines each node's neighbors by determining whether the Euclidean distance between them is smaller than the Communication Range. Plots the nodes and their communication range after the network has been initialized and the neighbors have been located. Each node then transmits a message to its nearby neighbors.

6.2 *Scenario 2: Random Zigbee Mobile to Mobile Sensors*

Since many of the parameters from scenario 1 (Figures 11, 12 and 13) are also from scenario 2, where we studied mobile to mobile, this scenario differs from the previous one in that the nodes are constantly moving. As a result, we must determine the precise time and velocity at which the nodes are moving.

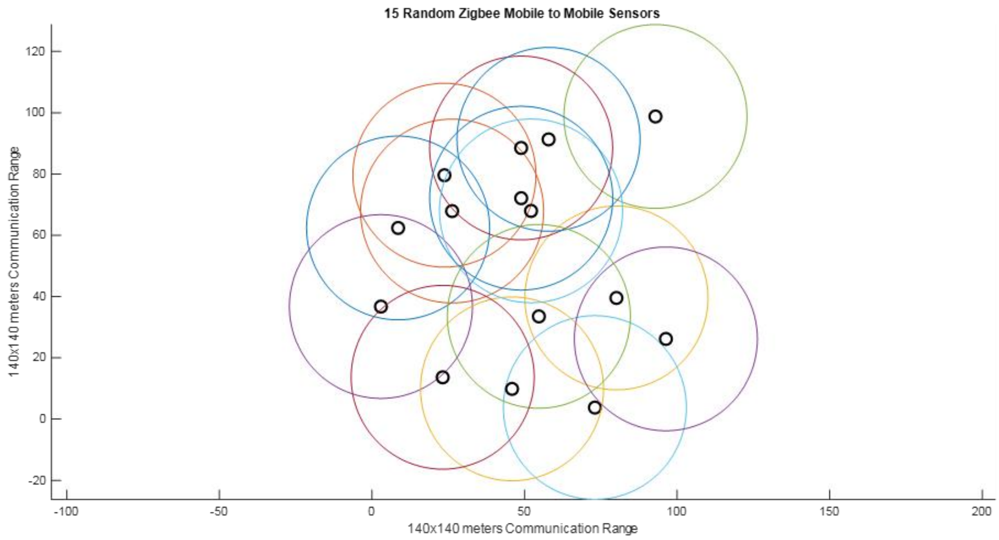


Figure 11. 15 Random Zigbee Mobile to Mobile Sensors.

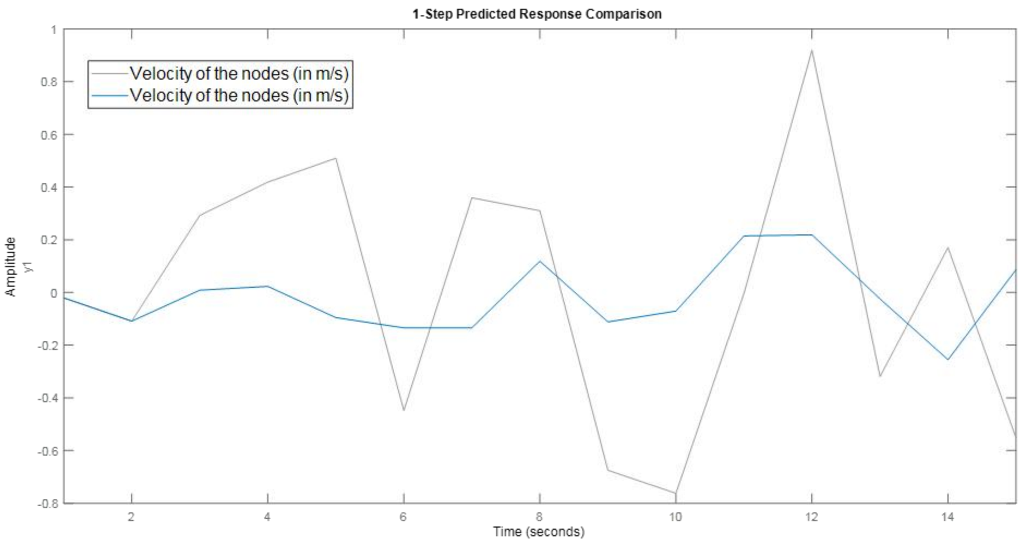


Figure 12. Velocity of the nodes (in m/s).

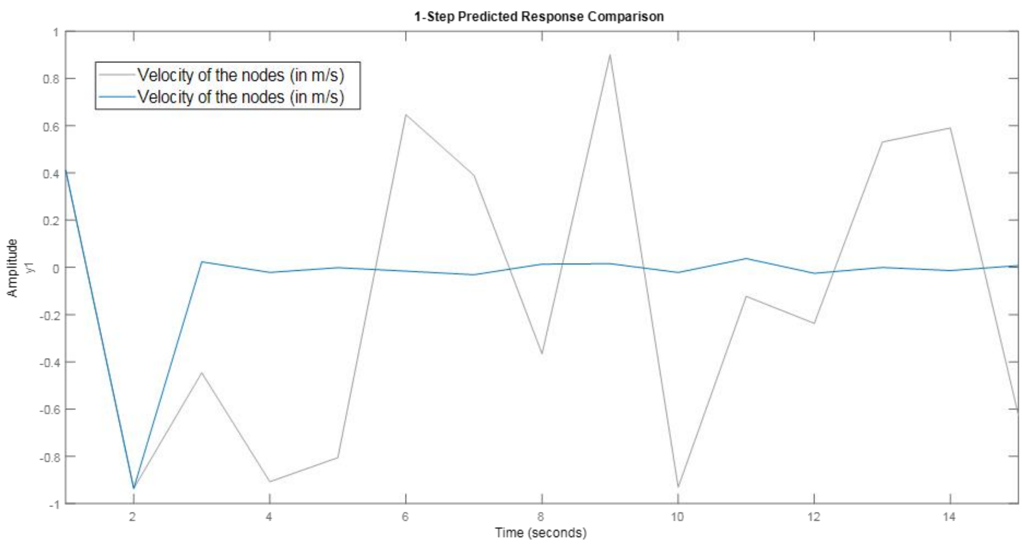


Figure 13. Velocity of the nodes (in m/s).

Nodes might be mobile, as in many real-world situations, like in a vehicular network or a mobile ad hoc network. As a result, it's critical to model node motion in order to assess network performance and create effective communication protocols that can adjust to node mobility.

6.3 *From Scenario 1 and 2: Static and Mobile Nodes analyzer*

The nodes' positions in the static to static network are fixed and do not vary over time. As a result, the network topology is static and the node velocities do not need to be calculated. Each node's communication range is likewise fixed.

The nodes in the mobile scenario have randomly generated positions that vary over time according to their velocities. The nodes' velocities are also produced at random. Due to nodes moving into and out of range of one another, the network topology is dynamic and changes over time. Both the x and y directions have randomly assigned velocities between -1 and 1 m/s.

6.4 *Scenario 3: Number of Connections Vs the Communication Range*

Plotting the number of connections against the communication range in scenario 3 illustrates how the number of connections rises as the communication range does. It determines which nodes are within range of one another by iterating through the various communication ranges that have been specified. Two nodes are added to each other's neighbor lists if they are in range of one another. Once every pair of nodes has been looped through, the number of connections in the network is counted and stored for the current communication range.

The power consumption of a network can be influenced by the number of connections, as data transmission to several neighbors can use more energy than data transmission to a single neighbor (Figures 14 and 15). The network's lifespan can be increased by making it more energy-efficient by maximizing the number of connections and communication range.

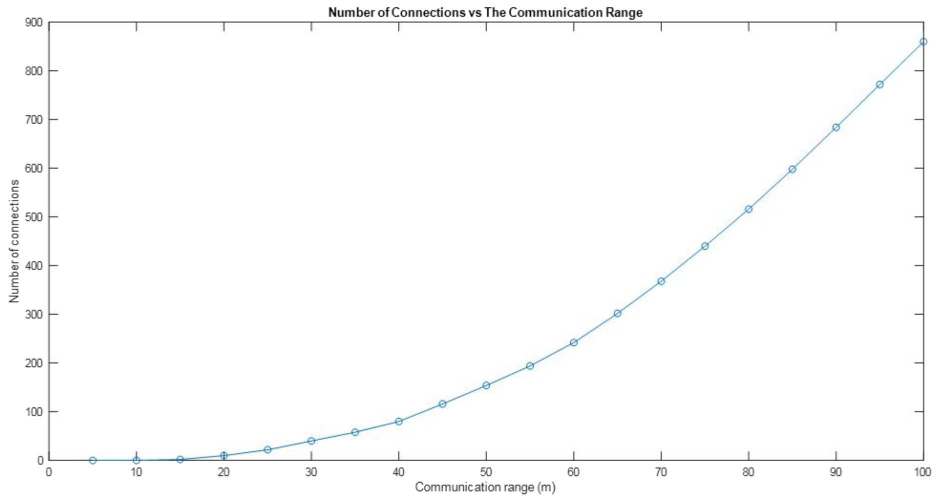
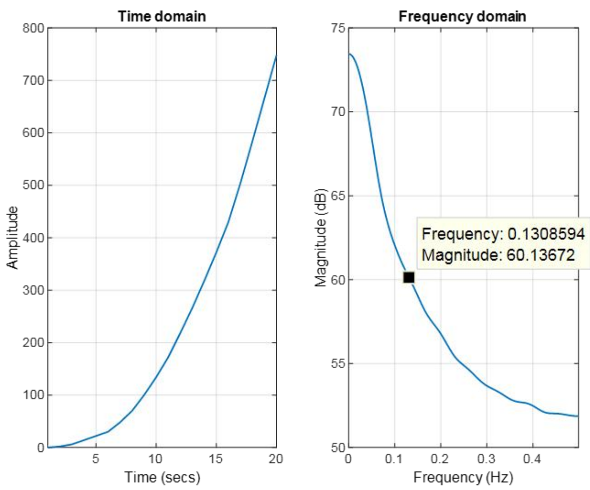


Figure 14. Number of Connections vs The Communication Range.



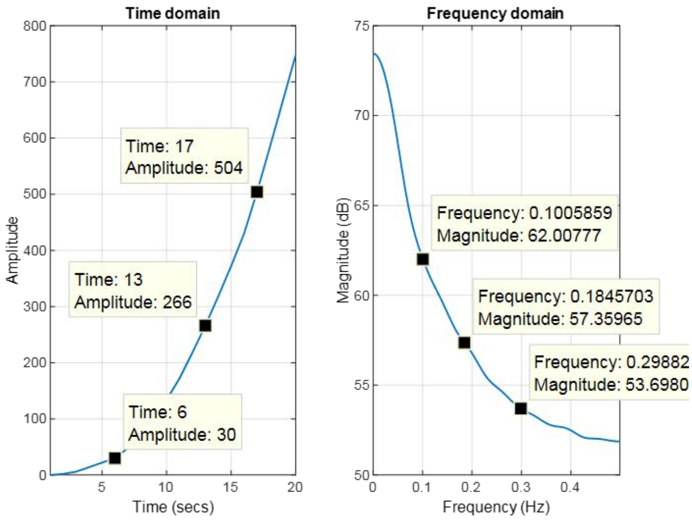


Figure 15. Time domain and frequency domain for Mobile to Mobile Nodes.

6.5 *Scenario 4: Random Zigbee Static to Mobile Sensors*

In scenario 4, a network made up of both static and mobile nodes is created to mimic communication between nodes that are close to one another. Twenty nodes are added to the network at startup, each with a randomly generated x and y coordinate that are all within a 100-meter radius. The nodes are divided into two halves: the stationary nodes and the mobile nodes. The next step is to identify every node's neighbor within a 30-meter communication range in order to create the network topology.

Subsequently, the simulation demonstrates how to locate each node's neighbors based on how far apart they are from one another and how to store this data in a data structure. For many wireless sensor network applications, this is crucial because nodes usually need to communicate with one another in order to share information or plan actions. Lastly, Figure 16 shows how to plot the topology of the network and see each node's communication range. Understanding the network's coverage and connectivity requires knowledge of this.

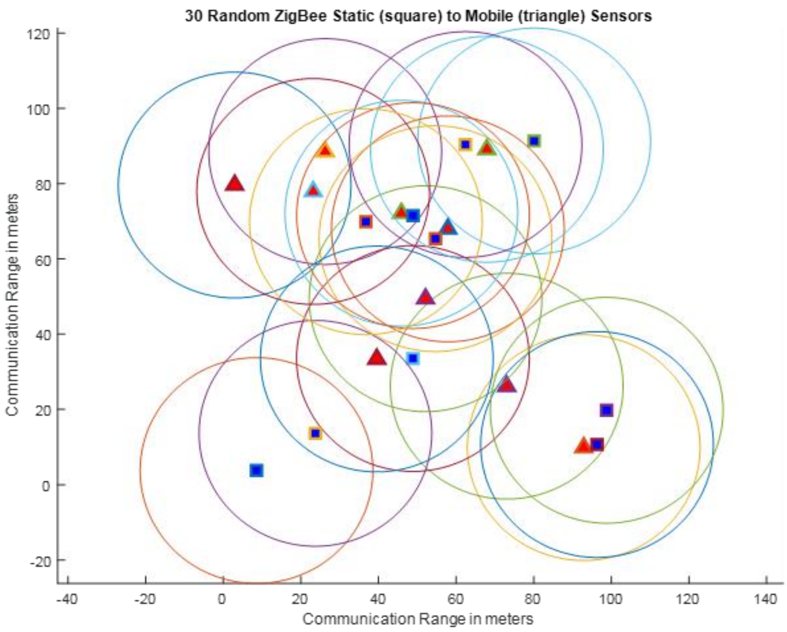


Figure 16. 30 Random Zigbee Static to Mobile Sensors.

7. Conclusions

The four simulations explore particular Wireless Sensor Network scenarios, highlighting their various objectives and features. When taken as a whole, these simulations not only highlight the enormous potential and constraints of these networks with regard to message exchange, mobility, and communication range, but they also highlight important discoveries that are essential to the advancement of WSNs. The transformation of sensor network data for use in surveillance, environmental monitoring, and disaster relief is demonstrated in Scenario 1. Car tracking and mobile ad hoc networks are two examples of how the second simulation clarifies the dynamics of sensor networks in adaptive environments. The third scenario, on the other hand, simulates delays that are proportionate to the distances between nodes, reflecting problems with signal attenuation over longer distances. The fourth scenario, on the other hand, emphasizes the likelihood of message loss in relation to node distance by replicating interference and signal degradation effects. Together, these simulations demonstrate how resilient wireless sensor networks are to interference and noise when transmitting data. This study minimizes the significance of additional research in crucial fields. Future research should concentrate on developing advanced error correction techniques and adaptive transmission strategies to reduce the effects of noise and interference in order to increase the reliability of WSNs. In order to maximize the networks' flexibility and efficacy in a variety of scenarios, more research should focus on energy efficiency optimization, real-time application consideration, and sensor network adaptation to shifting environmental conditions. These prospective studies aim to enhance the reliability, flexibility, and real-time application of WSNs to optimize energy consumption, minimize interference, and enable adaptive operations in dynamically changing situations.

Acknowledgments

The authors would like to thank Thai Nguyen University, Ministry of Education and Training (Project B2023-TNA-16), Viet Nam for the support.

Conflict of Interest

There is no conflict of interest for this study.

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