# PERFORMANCE ANALYSIS OF GREEN HOUSE MONITORING SYSTEM USING ZIGBEE TECHNOLOGY

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**Abstract:** This study investigates the effectiveness of a greenhouse monitoring system that employs Wireless Sensor Network (WSN) technology, specifically Zigbee-based devices. The system is simulated using the OPNET Network Simulator, with a focus on enhancing transmission power and evaluating the impact of additional sensor nodes on network performance. Four distinct network configurations were created, each with varying numbers of sensor nodes, and performance was evaluated by assessing network load, throughput, packets sent and received, and packet loss. The simulation results indicate that the optimal performance in terms of transmitted/received packets and packet loss is achieved when the transmission power is in the range of 0.05mW to 0.8mW, while the poorest performance is observed when the transmission power is less than 0.05mW or greater than 0.01mW. The increase in the number of sensor nodes leads to improved network performance, with the best results being seen in the configuration with 63 sensor nodes. However, packet loss remains relatively consistent at around 12%.

**Keywords:** ------------------……………………………………………………………………………..

## 1. Introduction

The use of sensor nodes in greenhouses and other devices to monitor indoor climate and power consumption has increased significantly in recent years. In the past, traditional greenhouses relied on wired devices and measurement methods, but now the trend has shifted towards using wireless sensor networks (WSN) for more efficient, cheaper and more productive monitoring. However, energy consumption is still a major concern when implementing a seamless greenhouse monitoring system using WSN technology. Using sensor nodes, it is possible to dynamically track performance metrics related to the indoor greenhouse network and in turn take proactive actions based on established thresholds, which can ultimately lead to increases in greenhouse efficiency, cost effectiveness and productivity [1]. Wireless Sensor Networks (WSN) can greatly enhance the automation system architecture of modern greenhouses by allowing for the use of a centralized control unit and actuators in various parts of the greenhouse to communicate and gather data. These systems are more cost-effective, quicker to set up, and simpler to install than wired systems. Additionally, WSNs allow for flexibility in the placement of measurement points by allowing sensor nodes to be moved within the range of the coordinating unit. The main maintenance cost of a WSN would be replacing or recharging the batteries, but this can be minimized through the implementation of energy-efficient algorithms [2]. The proposed greenhouse monitoring system that we have designed and simulated makes use of the OPNET Modeler network simulator. The goal of the investigation is twofold: first, to determine the optimal transmit power (Tx) to be set on sensor nodes, and second, to understand how an increase in the number of sensor nodes in the same greenhouse network affects the overall network performance. By analyzing monitoring data and managing environmental conditions, in conjunction with cultivation methods, better plant growth can be achieved, even under suboptimal conditions. Traditional methods for controlling and monitoring environmental conditions in greenhouses, such as distributed control systems, can be complicated and costly to maintain due to the need for many electrical wires and complex infrastructure. In contrast, wireless sensor networks (WSNs) have gained attention as an alternative solution due to their portability, low power consumption and ability to provide high-density, high-frequency monitoring. The key benefits of using WSNs for environmental monitoring include the ability to continuously collect data and minimize disruptions. This kind of monitoring system can provide better plant growth by helping to achieve high season during off season under insufficient conditions. By using WSNs, it is possible to avoid the issues that arise from using traditional methods such as complex installations, high maintenance costs and mobility issues [4].

To ensure the smooth operation of a wireless sensor network (WSN) made up of many small nodes, it is important to create a detailed model of the network. This model can be used to evaluate the performance of the network under different conditions and set-ups, and identify any potential issues that may arise. By taking the time to carefully model the network, it is possible to prevent problems with transient activation, which can occur when the network is not properly configured. The use of WSN technology has become more widespread in recent years, thanks to its cost-effectiveness and ease of installation and maintenance [5]. There is now a greater demand for WSN-based greenhouses, which can be equipped with various pieces of equipment such as heaters, coolers, lights, and various sensor nodes. This allows for the automation and monitoring of the greenhouse by a single user. Greenhouses offer farmers the ability to grow crops outside of their typical growing season and provide protection from adverse weather and soil conditions [6]. The ability to achieve high density and frequent monitoring in a wireless sensor network (WSN) is dependent on reducing power consumption and increasing the range and coverage of sensor nodes. One practical solution to these challenges is the use of an environmental monitoring system based on ZigBee technology for greenhouses. This approach offers fewer complications and is more cost-effective, especially when considering the potential for increased production [7]. By combining the use of wireless sensor network (WSN) technology with a geographic information system (GIS), it is possible to create a detailed map of moisture distribution within a greenhouse. This is done by strategically placing wireless nodes equipped with moisture sensors at specific locations within the greenhouse. The geographic coordinates of these points are then determined using GPS technology, and the data collected is analyzed and visualized using GIS software [8].

This approach provides a comprehensive understanding of moisture levels and distribution, allowing for informed decisions to be made about crop management and irrigation [9]. A wireless system has been developed using ZigBee and Wi-Fi technology to monitor the flow of sediment in real-time during low tide periods. The sensor signals are transmitted by a gateway device to an internet server using GPRS. Additionally, a laboratory prototype has been created that utilizes RFID technology to measure soil temperature wirelessly. The measurement results obtained from this system have shown a high level of correlation with those obtained from thermocouple measurements (over 99%) [10]. The system is engineered to use an ARM7 processor, a range of sensors and ZigBee communication module. These sensors are used to gather real-time data on different physical parameters, and this data is transmitted to the processor and final user through ZigBee communication. The ultimate goal is to minimize or eliminate the need for human involvement, by implementing measures to reduce or eliminate human labor, hence increasing the overall system efficiency [11].

A new algorithm called the Dynamic Converge Cast Tree Algorithm (DCTA) has been developed to improve the accuracy of data collection in tracking the growth of orchids. This algorithm has been integrated into a wireless sensor network (WSN) based tracking system [12]. The DCTA algorithm utilizes a tree topology, and it adjusts the routing path of each sensor node by using information on the received signal strength indication and hop count. This algorithm is designed to be adaptable and uses a medium access control protocol to enhance the dependability of sensor data transmission [13].

The use of both IEEE 802.15.4 and ZigBee protocol stack creates an efficient solution for wireless sensor networks (WSN) with low cost, low data usage, and low power consumption. This combination offers the potential for remote functionality in a wide range of applications through the Zigbee protocol's flexibility and versatility [14]. When it comes to surveillance systems that utilize a large number of sensor nodes, factors such as power consumption, latency, and reliability are of paramount importance. Among the options available, Zigbee stands out as the most suitable choice for wireless sensor networks due to its low power consumption and cost-efficiency [15]. Zigbee is a widely accepted open standard for wireless radio networks, but simulating a Zigbee wireless sensor network (WSN) can be challenging due to hardware complexities, performance limitations, and the need to deploy a large number of nodes. Zigbee is based on the IEEE 802.15.4 standard, which defines the media access control (MAC) and physical (PHY) layers [16].

## 2. Research Objectives

*(A)* Examining the difficulties in monitoring and managing greenhouse networks using Zigbee wireless sensor networks to improve performance.

*(B)* Examining the relationship between power consumption and transmit power (Tx) in the context of greenhouse monitoring network performance.

*(C)* Analyzing the impact of node quantity on the overall performance of the network.

## 3. Research Methodology

Examine the effectiveness of the IEEE 802.15.4/Zigbee protocol utilizing the Open-ZB open-source implementation and simulation tools in OPNET and TinyOS. Utilize the version 1.0 of the IEEE 802.15.4 slot in OPNET for an accurate simulation model.

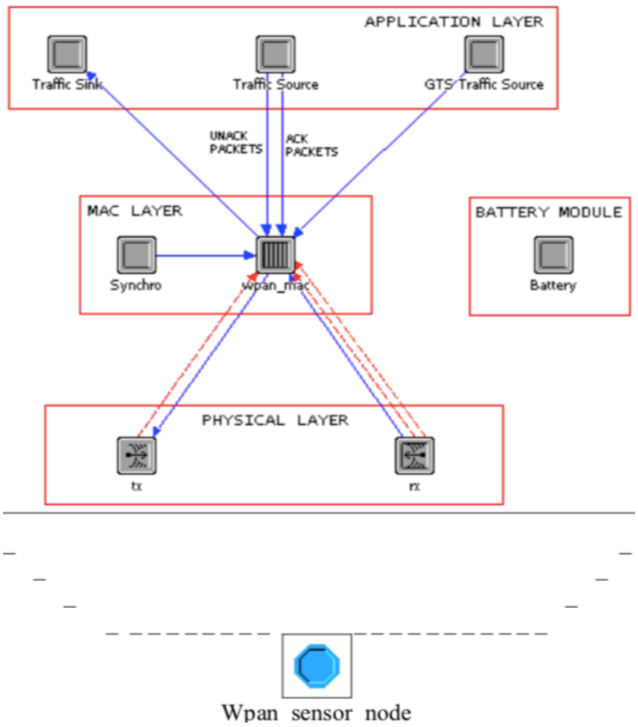


Figure 1. IEEE 802.15.4 Simulation Model Structure

This model is an in-depth simulation of a wireless network that adheres to the IEEE 802.15.4 standard. The simulation includes multiple layers, including the Physical (PHY) layer and the Medium Access Control (MAC) layer. The PHY layer comprises of a transmitter and a receiver that operate at a frequency of 2.4 GHz, a bandwidth of 2 MHz and uses Quadrature Phase-Shift Keying (QPSK) modulation for communication. The MAC layer has various features such as Clear-Channel Assessment/Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) slots, beacon frames, and coordination with a PAN coordinator. Additionally, the model has a battery module that calculates the power consumption and excess power of the network.

The application layer comprises of a sensor data generator and a MAC control image generator, which allows the simulation to generate realistic sensor data and MAC control images. The reception module performs statistics on the received frames to provide insights into the performance of the network. The radio model uses standard OPNET wireless modules to simulate the radio channel, including parameters such as encryption, noise, Bit Error Rate (BER), delay, etc. This allows the model to accurately simulate the radio channel's behavior and its impact on the network's performance. Overall, this model provides a comprehensive and realistic simulation of a wireless network that conforms to the IEEE 802.15.4 standard.

## 4. Results

The greenhouse monitoring system being proposed three different network set-ups were created. The first set-up (Set-up 1) examines how changes in transmit power affect the network's performance, while the other two set-ups (Set-up 2 and Set-up 3) focus on the impact of an increasing number of sensor nodes. Set-up 1 involves simulating 22 different transmission power levels for all components of a greenhouse monitoring network, including sensor nodes, actuators, and routers. Set-up 2 and 3 simulate wireless networks with an increased number of terminals, with Set-up 2 simulating a network with 1x63 endpoints and Set-up 3 simulating a network with 2x63 and 3x63 endpoints, respectively, including more sensor nodes, routers, actuators, and a coordinator.

**(Set-up 1)**
To evaluate the network performance in relation to transmit power, the basic network set-up was replicated and modeled according to the diagram in Figure 2. In addition to the basic set-up parameters, additional set-ups were also considered in this set-up. The performance metrics analyzed include the number of received/transmitted packets and packet loss rate. The simulation included 22 cases with varying transmit power levels, and a series of simulations were run to determine how changes in transmit power affect performance. The transmit power levels simulated in the greenhouse network ranged from 0.0 to 1 mWatt.

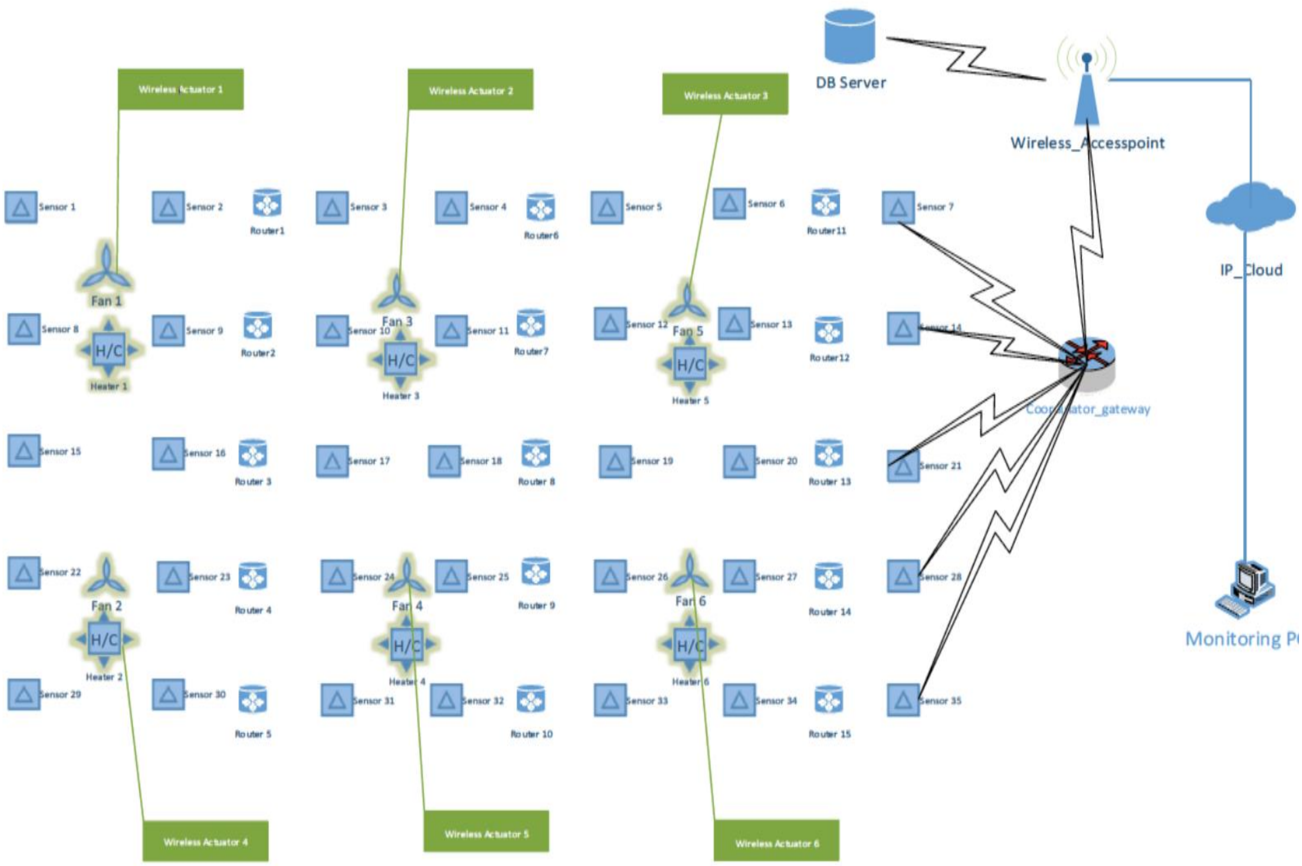


Figure 2. Zigbee-based Greenhouse Monitoring Network Topology

**(Set-up 2)**
This simulation depicts a wireless network for a greenhouse setting, which includes 35 sensor nodes, 8 actuators and 20 routers. The parameters of this simulation are consistent with those of set-up 1, with the exception of a specific transmission power of 0.06 mW.

**(Set-up 3)**
This simulation represents a wireless network topology for a greenhouse environment in set-up 3, which comprises of 70 sensors, 16 actuators, 40 routers and a single coordinator. The simulation also includes a greenhouse monitoring subnet that is connected to the outside world through a wireless access point gateway, and it is connected to an IP-based cloud and intranet. The monitoring subnet has been designed with a comprehensive infrastructure that includes several key components to ensure efficient and effective monitoring. At the core of this infrastructure is a configured database server that is responsible for storing and managing the data collected from the various sensors and actuators. Additionally, there is a dedicated computer that is used specifically for monitoring the Wi-Fi network, which allows for real-time monitoring of the connectivity and performance of the wireless network. To support remote monitoring, there is also a host that is configured for this

purpose, which enables monitoring to be done remotely from a central location. The topology of the monitoring subnet is structured in a three-level architecture, comprising of a large number of sensors, actuators, and rotors. Specifically, there are 70 sensors that are used to collect data and 16 actuators that are used to control the various devices. Additionally, there are 40 rotors that are used to power the various systems and devices. All of these components are coordinated by a single central coordinator, which is responsible for managing the flow of data and ensuring that the monitoring subnet is operating as expected. A sub-network was also established for monitoring, including a wireless access point to connect to the outside world, an intranet-configured database server, and a computer for monitoring the Wi-Fi network. The system also featured a remote monitoring host computer that could be accessed through an IP cloud via the internet.

This network set-up is different from the previous one, as it includes twice as many sensors, actuators, and routers. The previous system was composed of 35 sensors, 20 routers, and 8 actuators that were responsible for controlling 8 fans and heaters. All the devices in the network had similar set-ups, with the exception of the coordinator's position, which was relocated 2 meters downward. This change in location for the coordinator device would have an impact on the overall network, as the device is responsible for maintaining communication and coordination between all other devices in the network. This change in location may have an impact on the performance and overall functioning of the network. The devices in the greenhouse network are evenly distributed and positioned 2 meters apart, with the rail devices also positioned 2 meters apart. The maximum number of routers that can be connected to the coordinator has been increased to 10, and the maximum depth has been set to 10.

## 5. Network Performance &Transmit Power

This study aimed to investigate how changes in transmit power affect the performance of a greenhouse network. The researchers specifically looked at how transmit power impacts metrics such as packet sending and receiving, as well as packet loss. To conduct the study, they used 22 different transmit power levels and analyzed the results to understand the relationship between transmit power and network performance.

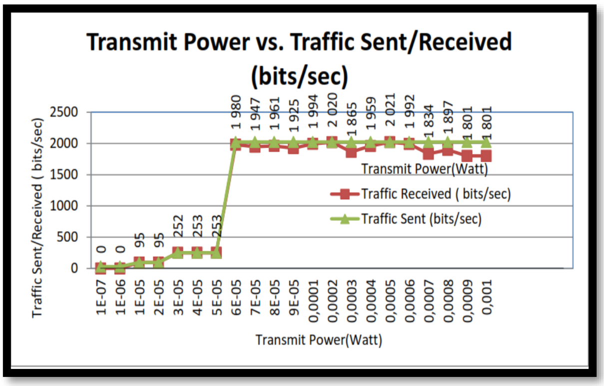


Figure 2. The amount of power transmitted relate to the amount of data sent or received (Measured in bits per second)

The results of the study revealed that as the transmission power increases, the received traffic also increases and stabilizes at a transmission power of 0.06 mW for PAN 1. Within the range of 0.06 to 0.8 mWatt, the received traffic was unstable, with a maximum of 2.01 Kbps and a minimum of 2.02 Kbps at a transmit power of 0.5 mWatt. The optimal transmit power was found to be 0.9mWatt, at which point the received traffic stabilized and reached around 1.8Kbps.

The simulation results for 22 different transmission power values are displayed in Figure 2. The figure illustrates the amount of data that is being transmitted in bits per second, where the "application traffic sent" refers to the quantity of packets that have been received by an application, measured in bits per second.

The results of the study indicate that for the first two transmission power cases, (0.0001 and 0.001 MW), the average application traffic transmission rate is 31 bits per second, which is relatively low. This is because each of the 63 sensor nodes in the network is sending out a 32-bit packet every second. In other words, the graph shows the amount of data sent and received by the application in bits per second, and the results of the experiment suggest that when the transmission power is set to 0.0001 and 0.001 MW, the average rate of data sent and received by the application is 31 bits per second. This low rate is likely due to the fact that each of the 63 sensor nodes in the network is only sending one 32-bit packet every second.

This low rate could be caused by various factors such as low transmission power, network congestion, or low data rate of the sensor nodes. When the transmission power is increased to 0.01 and 0.02 MW, the average of 94 bits of transmitted application traffic is achieved. This indicates that the nodes closest to the sink (coordinator) are able to transmit data, but it is still not enough. It is clear that increasing the transmission power results in an increase in the transmitted application traffic, but it reaches stability at a certain point. In conclusion, the study shows that the transmission power has a significant impact on the performance of a greenhouse network. As the transmission power increases, the transmitted application traffic also increases and reaches stability at a certain point. As the transmit power increases to 0.03, 0.04 and 0.05 mWatt, the transmitted application traffic increases to 252bps.

Figure 3 illustrates the correlation between the transmission power and the number of packets discarded due to connection failure. As the transmission power decreases, the number of packets discarded increases. At the lowest transmission power value of 0.0001 mW, a total of 384 packets are lost. However, as the transmission power increases, there is a steady decline in the packet loss rate. The least amount of packet loss is reported when the transmission power is at 0.05 MW, with 336 packets discarded. This indicates that as the transmission power of the sensor nodes is increased, the packet loss rate decreases.

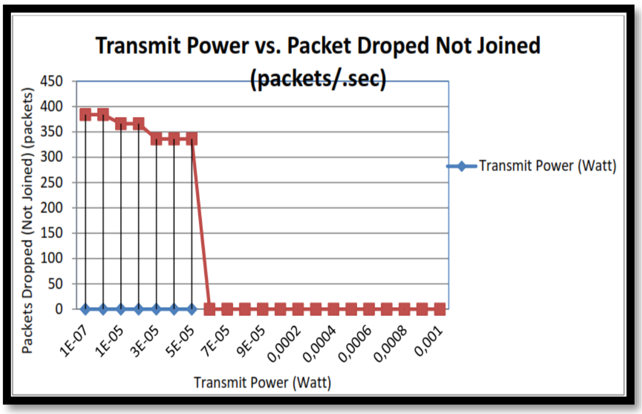


Figure 3. Transmit Power VS Packet Dropped (Not Joined)

The graph in figure 4 displays the impact of the number of sensor nodes on the MAC load in two greenhouse surveillance network models, se-tup 2 and set-up 3. Set-up 2 includes 63 sensor nodes while set-up 3 includes 126 sensor nodes. It is shown that in set-up 2, the MAC load reaches around 35 Kbps, while in set-up 3 it reaches around 48.48 Kbps.

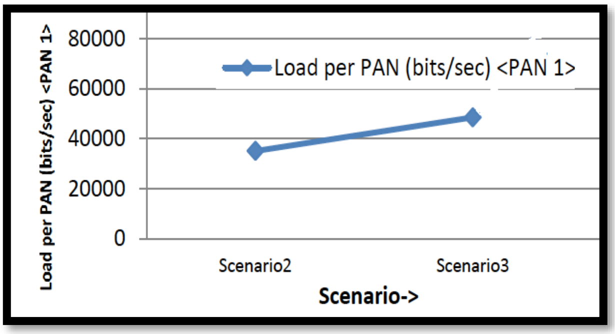


Figure 4. The relationship between the number of nodes in a PAN (personal area network) and the load per node (measured in bits per second)

The data illustrated in Figure 4 demonstrates that as the quantity of sensor nodes in the network increases, the physical layer performance throughput also increases. Set-up 1, with 63 sensor nodes in the greenhouse network, has a throughput of around 35 Kbps. When the number of sensor nodes is doubled in set-up 3, the throughput rises to 48 Kbps. These results indicate that the performance of the network in set-up 3 is superior to that of set-up 2.

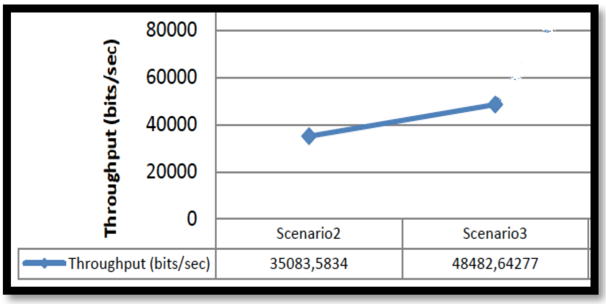


Figure 5. The number of nodes in a network affect the throughput (bits/sec)

Network throughput is a way to evaluate the efficiency and capability of a wireless network. It refers to the amount of data that can be sent and received over the network within a specific time frame. This metric is typically measured in bits per second (bps), which indicates the number of bits of data that can be transmitted in one second. Understanding the throughput of a network is important because it can help to identify bottlenecks or other issues that may be limiting its performance, and allow for adjustments to be made to optimize the network's capacity. This metric is important because it directly impacts the overall performance and user experience of a wireless network. In wireless networks, throughput is typically measured at layers above the MAC (Media Access Control) layer, which is responsible for managing access to the shared medium. The MAC layer is responsible for controlling how devices access the wireless channel, and it enforces rules for when devices can transmit and receive data. By measuring throughput at layers above the MAC layer, we can get an accurate picture of the network's overall performance. A high throughput is generally considered to be desirable, as it means that more data can be transmitted across the network in a given period of time. However, when the network's throughput becomes too high, it can put a lot of pressure on the network infrastructure and can lead to several negative effects. An increase in throughput can cause more collisions, retransmissions, and packet loss, which can ultimately lead to a decrease in overall network performance. Furthermore, high throughput can also increase the power consumption of the network, which can lead to shorter battery life for the network devices. To conclude, network throughput is an important metric that is used to measure the capacity and efficiency of a wireless network. It is the amount of data that can be transmitted across the network in a given period of time. While a high throughput is generally desirable, an excess of it can lead to negative effects such as increased collisions, retransmissions, packet loss and power consumption.

The simulation aimed to study the impact of different transmission power levels on performance measurements such as packets sent, packets received and packet loss in a greenhouse network. The simulation was carried out using 63 sensor nodes, 8 actors and 20 routers, with 22 different transmission power values being tested. The results were analyzed and compared among different set-ups. In particular, the received traffic was measured at the coordinator level for set-up 2 and 3. set-up 2 consisted of a single coordinator and 63 sensor nodes, while Set-up 3 had twice the number of sensor nodes. Notably, a common transmission power of 0.06 mW was used for all nodes in both set-ups. In simple terms, the simulation was trying to understand how the strength of the signal, or transmission power, affected the performance of a greenhouse monitoring network.

They used a variety of different transmission powers and looked at how it affected the number of packets sent, received, and lost. They also looked at how the number of sensor nodes and coordinators affected the results. In set-up 2, the coordinator acts as a sink and all other devices act as sources. Traffic received at the coordinator under PAN 1 is defined as application traffic received from the application layer. By comparing the received traffic performance in the two set-ups, it can be seen that the traffic received in set-up 2 averages 1806 bps, while the traffic received in set-up 3 averages 3518 bps, which is significantly higher. This indicates that as the number of sensor nodes in the network increases, the overall performance of the network also improves.

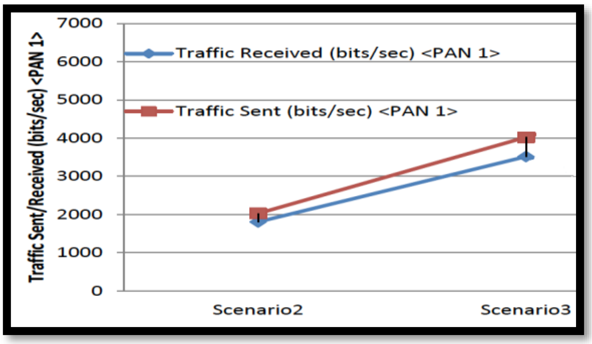


Figure 6. The number of nodes in a network relate to the traffic sent and received (bits/sec)

The results of the simulation show that as the number of sensor nodes in the network increases, the received traffic at the coordinator level also increases. This is demonstrated by comparing the received traffic performance in set-up 2 and set-up 3, where set-up 3 has double the number of sensor nodes as set-up 2. The data shows that the traffic received in set-up 3 averages 3518 bps, which is significantly higher than the 1806 bps received in set-up 2. Additionally, it is observed that the average sent traffic in set-up 3 is also higher than that in set-up 2. These results indicate that increasing the number of sensor nodes in the network leads to an improvement in the overall performance of the network in terms of received and sent traffic.

## 6. CONCLUSION

The study found that using a transmission power of 0.06mWatt resulted in better performance in terms of transmitted and received packets and packet loss compared to the transmission power in Set-up 1. As the number of nodes increased, packet loss also increased. It was found that a certain number of nodes, such as 63, had lower packet loss compared to larger numbers of nodes like 126 and 189. The research also compared the effects of different number of nodes on a greenhouse network. Parameters such as transmission performance and network performance were analyzed, revealing that packet loss was evident as transmission performance impacted throughput performance. The cost of the three network set-ups, which had 63, 126, and 189 nodes respectively, was also considered.

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