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# Performance Analysis of MIMO Heterogeneous Wireless Sensor Networks

**Saurabh Mishra, Rakesh Ranjan, Sonika Singh, Gagan Singh**

***Abstract: Wireless Sensor Networks (WSN) are widely used in remote applications related to defence and healthcare. A network with nodes having different capabilities like sensing, various computational capabilities, power-efficient communication, and a varied sensing range is called a heterogeneous wireless sensor network. Heterogeneous wireless sensor networks using MIMO wireless channels are more useful for energy-efficient multi-channel communication. MIMO applications in wireless sensor networks have the potential to enhance throughput, reduce End-to-End Delay, improve packet delivery ratios, and conserve energy in wireless sensor networks. Its implementation needs to be carefully considered in light of the specific deployment conditions and resource constraints of the network, considering proper antenna design, synchronisation mechanisms, and energy-efficient algorithms. This paper presents a comparative performance analysis of MIMO wireless sensor networks and traditional wireless sensor networks without MIMO for various Quality of Service parameters like Packet Delivery Ratio, End to End Delay, Throughput and Residual energy. The research work shows that the application of MIMO in Wireless Sensor Networks enables sensor nodes to collaborate effectively, leading to improved reliability and coverage, and also increases the network's lifetime by conserving energy in resource-constrained sensor nodes through the preservation of Residual Energy.***

***Keywords: Wireless Sensor Networks; Heterogeneous Networks; Throughput, End to End delay; packet delivery ratio; residual energy, MIMO***

## I. INTRODUCTION

Energy-constrained Wireless Sensor Networks have gained considerable research attention in recent years. In such sensor networks, battery-operated sensors are expected to work for months or even years without replacing or renewing their energy, rendering energy optimisation a critical issue in system design. Multiple-input-multiple-output (MIMO), or multiple antenna communication, is one of the techniques that has gained considerable importance in wireless systems in recent years.

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MIMO technology enhances the performance of WSNs by exploiting multiple antennas on both the transmitter and receiver sides, thus improving data throughput, increasing reliability, and enhancing the coverage of wireless communication in WSNs [2]. Hence, MIMO can be applied in various WSN scenarios, including environmental monitoring, industrial automation, and healthcare applications [2], [13]. The various benefits of MIMO in WSNs are as follows: Improved Spatial Diversity: MIMO enables better reception of signals by exploiting multiple spatial paths, reducing signal fading, and improving link reliability. Increased Data Rate: MIMO allows for higher data rates by transmitting multiple data streams simultaneously over the same channel. Enhanced Coverage: MIMO can extend the coverage area of WSNs, making them suitable for larger deployment areas. At the same time, the application of MIMO in WSN faces huge challenges that need to be considered while designing a WSN with MIMO [2], [8].

1. Channel Estimation: Accurate channel estimation is crucial in MIMO systems, especially in dynamic WSN environments.
2. Hardware Constraints: Implementing MIMO in resource-constrained sensor nodes can be challenging due to power and size limitations.

The work presented in the paper has been emphasized on the implementation of the MIMO in the sensors as a hardware unit to provide energy efficient transmission.

## II. MIMO IN WIRELESS SENSOR NETWORKS

MIMO is a valuable technique for enhancing the performance of wireless sensor networks. Multiple-Input Multiple-Output or sometimes referred as Cooperative MIMO is a specialized application of MIMO technology in wireless sensor networks (WSNs) which works efficiently, particularly in challenging and resource-constrained environments [4]. It enables sensor nodes to collaborate effectively, leading to improved reliability, coverage, and energy efficiency in WSN deployments [6]. It is an effective approach to increase throughput and energy efficiency through the collaboration of individual antennas working together as a virtual multi-antenna system. Multiple-input multiple-output (MIMO) has been proved as a key technology to reduce the energy consumption in communication systems [12][16][17][18]. Similar to wireless sensor networks, MIMO wireless sensor networks only have one antenna per node, and nodes are dispersed throughout the network. In order to obtain higher spatial diversity gain, also known as cooperative diversity gain, these scattered nodes create a virtual antenna array [2].

The benefits of MIMO come from its potential to increase throughput, coverage, and capacity in an economical way. Due to the enormous advantages that MIMO wireless sensor networks provide, this technology is actively being researched, and numerous MIMO techniques have already been incorporated into important wireless standards [9].

A generic block diagram of a sensor node used in a MIMO Wireless Sensor Networks is shown in Fig. 1. The building blocks of a MIMO WSN nodes are power unit, Sensor array, A/D Convertor unit, Signal Processing and data computing unit and IMO based space-time trans receiver [10][14]. Power unit consists of a power bank and memory unit which must work longer for months or years. Sensor array unit will sense the physical data and convert the data in to electrical quantity, processes by Analog to Digital convertor block for digitization of data. Signal processing and Data computing block allow the data to be moulded in the standards as per communication link and finally MIMO based trans receiver are responsible for two-way communication of data.

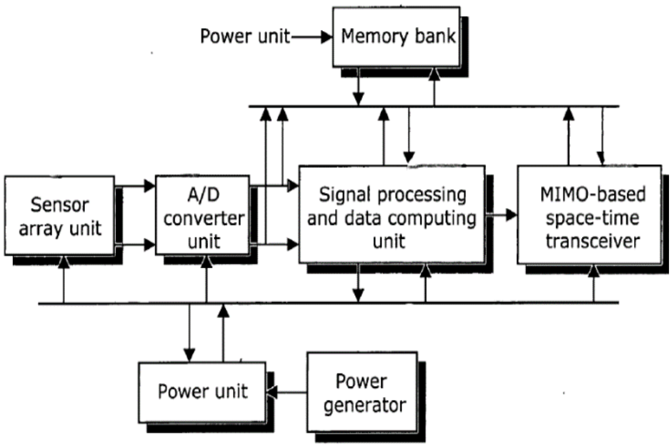


**Fig. 1: Block Diagram of Sensor Node in MIMO Wireless Sensor Network**

A numbers of sensors in a cluster are used to form a multiple input multiple output (MIMO) structure wirelessly connected with multiple antennas of a Data Gathering Node (DGN) which show energy efficient performance over existing one when they are compared with SISO structure [4]. The following research work considers the applicability of MIMO techniques to wireless sensor networks based on total energy consumption. In heterogeneous wireless sensor networks, nodes are used to sense the physical data, make a computation to validate the data for transmission, and transmit the data in a power-efficient communication mode. In this proposed simulation, network parameters like throughput, packet delivery ratio, end-to-end delay, and energy are analysed by incorporating the concept of Multi Input Multi Output (MIMO) which reduces energy consumption and increases residual energy and network lifetime.

## III. SIMULATION MODEL PARAMETERS

The simulation tool used for the simulation in this work is Network Simulator NS 2.35. Table 1 lists the simulation parameters used in this simulation. The objective of the proposed work is to evaluate the performance of MIMO Wireless Sensor Network in with respect to SISO Wireless Sensor Networks for same simulation environment.

**Table - 1. Simulation Parameters for Proposed Simulation**

| Description | Values |
|---|---|
| Network Simulator | NS 2.35 |
| Number of Nodes | 103 |
| Simulation area | 1200*1200 ($m^2$) |
| Propagation model | Two Ray ground |
| Energy Model | Radio |
| Initial energy of sensor Nodes | 90 J |
| Packet size | 4000 bits |
| Traffic source | CBR |
| Transmission power | 0.15 W |
| Channel type | Wireless |
| Transmission range | 200m |
| Mac type | IEEE 802.15.4 |

### A. Network Initialization:

For performance analysis of the wireless sensor network it is essential to establish ecological settings for radio transmission model, type of antennas used for communication, link-layer design, channel type, routing protocol information, type of interface in the simulator. There are 103 nodes deployed in the present scenario layout. Fig. 2 shows the distributive nodes placement in a uniform network topology in the animation window.

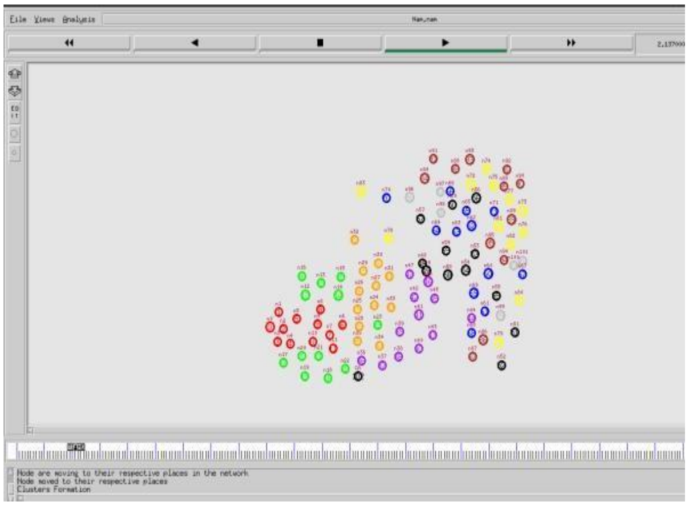

**Fig. 2: Node Placement Window**

### B. Cluster Formation

Every node placed randomly send a beacon (Hello) signal in the network to all surrounding nodes with in its broadcast range for updating the topology used for transmission. Fig. 3 shows the formation of cluster in network simulator. In this simulation total 103 nodes are placed out of which 102 nodes acts as cluster authority. Total 102 nodes are clustered in to 17 clusters with 6 nodes in each cluster. Euclidian distance between each and every pair is calculated with a two-point distance formula given as in Eq. (1)

$$D = \sqrt{(x1 - x2)^2 + (y1 - y2)^2} \quad (1)$$

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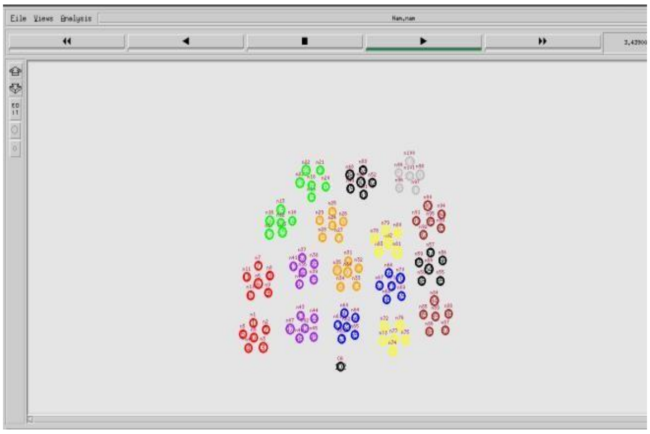

**Fig. 3: Cluster Formation**

Node 103 is cluster authority CA which is placed in the cluster based scheme to inform all the nodes about the attacker node at the time of black hole attack in the network. Cluster authority node stores the information of the malicious node after detection of attack in the remove list [7].

Cluster Head is chosen on the basis of highest initial energy of the nodes [12]. Since it is a rotational process to select the cluster head, so in-spite of the initial energy residual energy is also measured to select cluster head for the next round. The difference of the consumed energy (Ec) and primary energy (Ep) is equal to the amount of residual energy [1]. Initial energy provided to all the nodes in sensor network is termed as Primary energy. The amount of consumed energy is dependent on the rate of packet transmission and the size of packet of transmission. The residual energy (Er) can be defined as in Eq. 2 [1].

$$Er = Ep - Ec \qquad (2)$$

### 3.3 Routing Protocol

In the proposed simulation, routing of the nodes is dependent on the cluster authority node and it is changed after every detection of destructive node. The cluster authority node changes the routing table as per the remove list and reconstruct the best suitable path for packet transmission. Any discovery of the suitable route and choosing most suitable route is termed as Dynamic routing. However dynamic routing consumes more bandwidth as the routing nodes share updates of malicious nodes periodically [3].

The proposed work is using Ad-hoc On-demand Distance Vector (AODV) routing protocol in this simulation, as it has better characteristics for transmission parameters like End to End Delay and Packet Drop Ratio as compared to Dynamic Source Routing (DSR) protocol for high mobility [6].

## IV. SIMULATION RESULTS AND ANALYSIS

Analysis of simulation results using NS2.35 for MIMO Wireless Sensor Networks and WSN without MIMO are described below and compared which show improvement in Throughput, End to End Delay, Packet Delivery Ratio, and Residual Energy as shown in the following figures[11].

### A. Packet Delivery Ratio (PDR)

PDR is the ratio of the packets obtained by the sink node to the total number of packets transmitted by source node including the packets which are dropped during transmission [3].

In Fig. 3 the packet delivery ratio for the proposed work is shown for the time slots of simulation time in 5, 10, 15, 20 and 25 sec. Thus, it can be observed from the Fig. 4 that packet delivery ratio increases linearly with increase in time slot of equal interval. In the existing research, the networks are not prevented with the black hole attack and the packet delivery ratio are measured with the presence of malicious nodes.

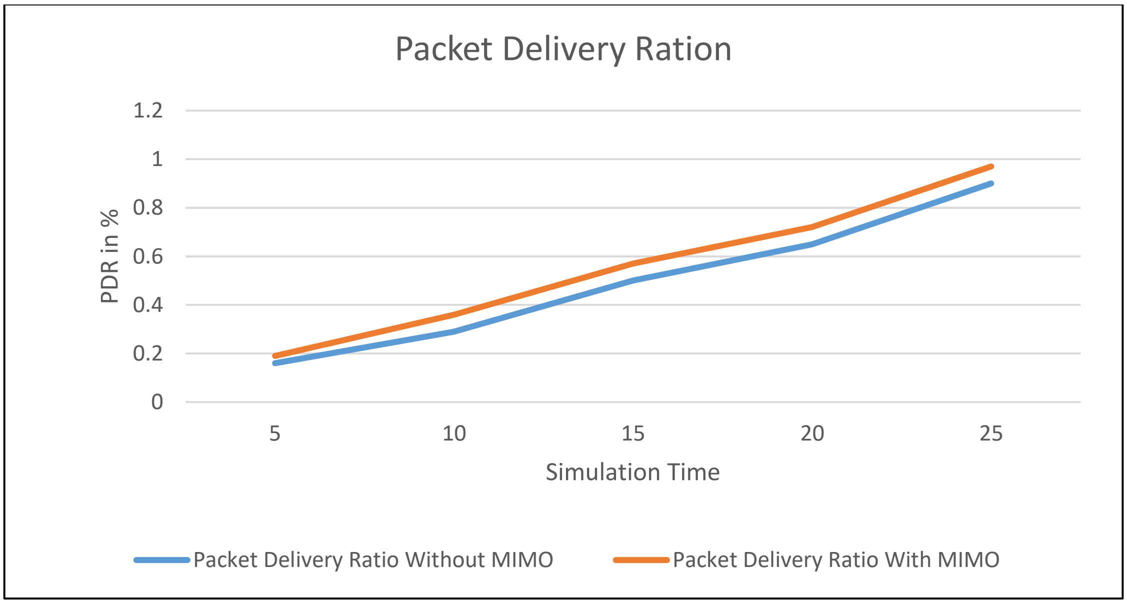


**Fig. 4: Comparison of PDR**

Table 2 presents the comparison PDR for without MIMO and MIMO WSN model.

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**Table - 2: PDR of Proposed and Existing System**

| Simulation time (MAC Protocol) | Packet Delivery Ratio | |
|---|---|---|
| | Without MIMO | With MIMO |
| 5 | 0.16 | 0.19 |
| 10 | 0.29 | 0.36 |
| 15 | 0.50 | 0.57 |
| 20 | 0.65 | 0.72 |
| 25 | 0.90 | 0.97 |

### B. End to End Delay

The amount of time taken between the delivery of data packets from source and obtaining data packets at the sink or the destination node is called End to End Delay [5][15]. Fig. 5 shows the analysis of end to end time delay with respect to the time slots 5, 10, 15, 20 and 25 on the X-axis. Table 3 shows the comparison of Delay values of existing and proposed models. The value of the end to end time delay in transmission is dependent on the time slots and protocol used in the wireless sensor networks.

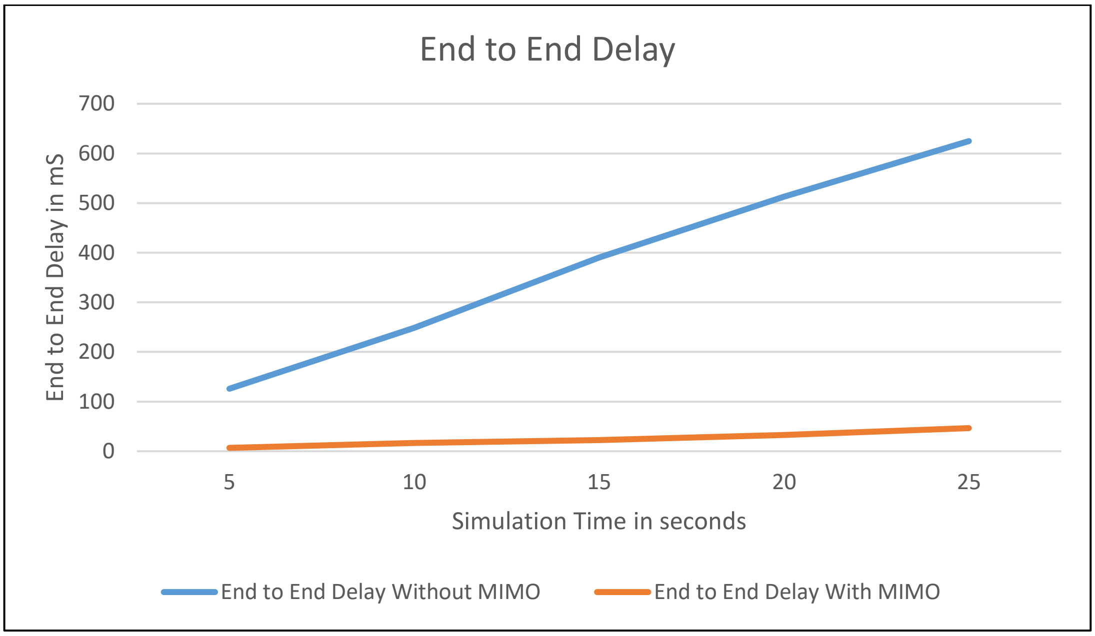


**Fig. 5: Comparison of End to End Delay**

Table 3 below presents the comparison of end to end time delay of existing and proposed model.

**Table - 3: End to End Delay of Proposed and Existing System**

| Simulation Time MAC Protocol (sec) | End to End Delay | |
|---|---|---|
| | Without MIMO (msec) | With MIMO (msec) |
| 5 | 125.96 | 6.80 |
| 10 | 248.9 | 16.5 |
| 15 | 390.25 | 22.48 |
| 20 | 512.65 | 32.68 |
| 25 | 624.8 | 46.6 |

### C. Throughput

As the proposed model is designed for transmitting and receiving multiple inputs multiple outputs, while increasing the data rate and bandwidth simultaneously, so the throughput is improved in case of proposed simulation compared to the existing system. The distinction of the throughput with time in each of the proposed simulation is shown in Fig. 6.

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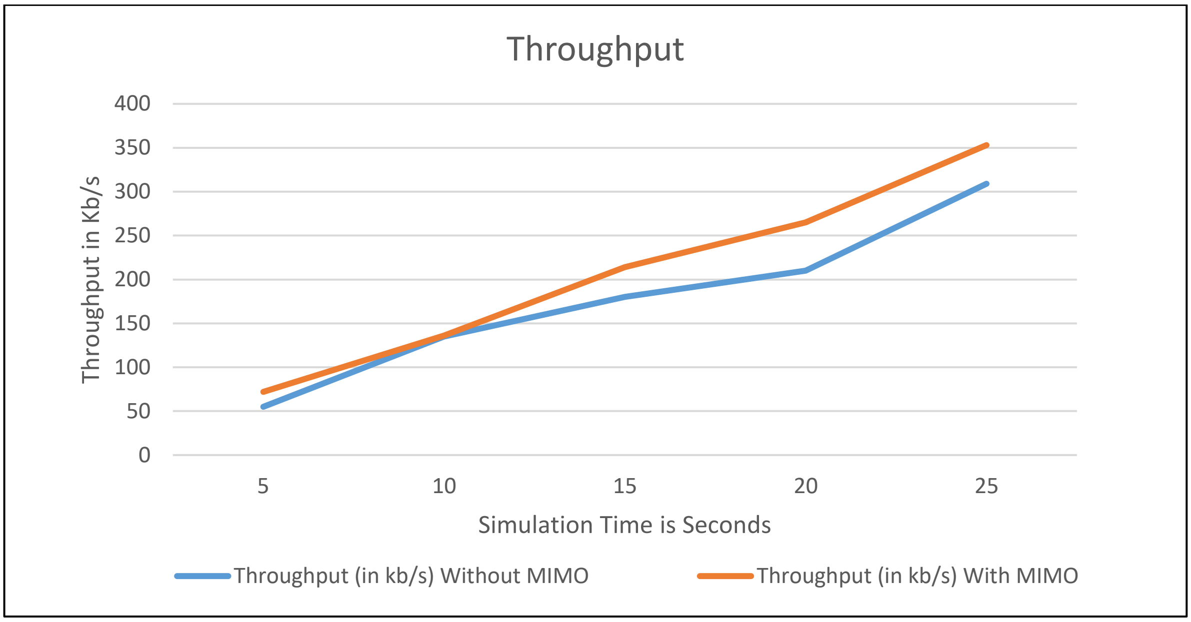


**Fig. 6: Comparison of Throughput**

In the proposed model, MIMO topology used in the data transmission has more number of antenna which increases data throughput within the cluster. The values of the throughput in the proposed model are compared with the existing for the same packets as shown in Table 4.

**Table - 4: Throughput of Proposed with MIMO and Existing System-Without MIMO**

| Simulation Time MAC protocol | Throughput (in kb/s) | |
|---|---|---|
| | Without MIMO | With MIMO |
| 5 | 55 | 72 |
| 10 | 135 | 136 |
| 15 | 180 | 214 |
| 20 | 210 | 265 |
| 25 | 309 | 353 |

## D. Residual Energy

The network size of Wireless sensor network does not affect the energy loss in the sensor network. Residual energy is calculated on the basis of initial energy and consumed energy by the node in the simulation time and this variation is shown in Fig. 7. Energy efficiency is improved as the information from source node to the sink node is communicated faster due to multiple inputs and multiple outputs. With the decrease in the energy consumption the network lifetime also increases.

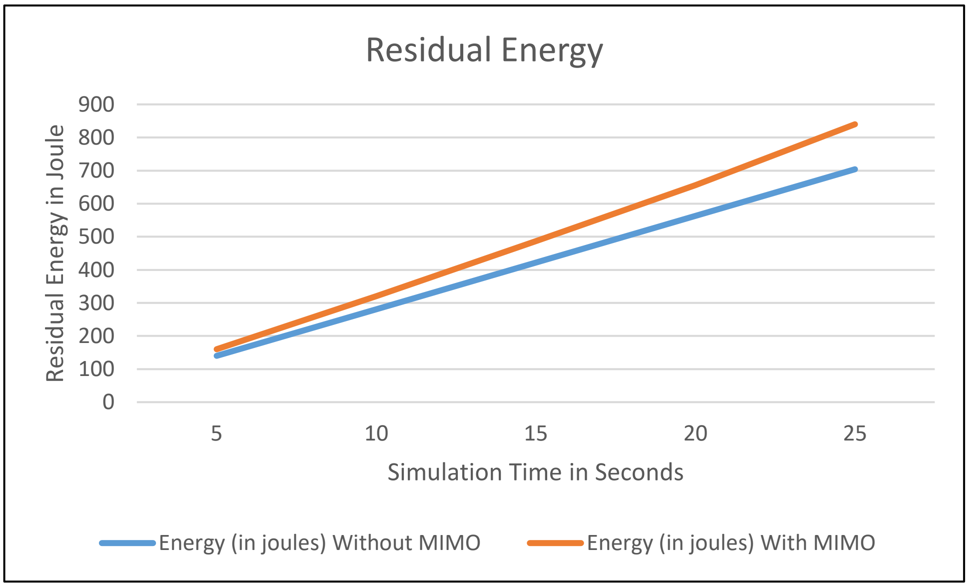


**Fig. 7: Comparison of Residual Energy**

Table 5 below presents the comparison of values of energy in joules of existing- Without MIMO and proposed – With MIMO model.

**Table - 5: Residual Energy Graph of Proposed – With MIMO and Existing – Without MIMO System**

| Simulation time MAC protocol | Energy (in joules) | |
|---|---|---|
| | Without MIMO | With MIMO |
| 5 | 140 | 160 |
| 10 | 281 | 320 |
| 15 | 422 | 487 |
| 20 | 563 | 656 |
| 25 | 704 | 840 |

## V. CONCLUSION

In this paper heterogeneous wireless sensor networks are simulated using NS2.35 simulators for MIMO and without MIMO networks. Multiple Input Multiple Output (MIMO) is a technology that can be applied to wireless sensor networks (WSNs) to enhance various performance metrics, including throughput, end-to-end delay, packet delivery ratio, and residual energy. MIMO shows considerable improvements in Throughput which is achieved through Spatial Multiplexing and Diversity Gain. MIMO enables multiple spatial streams, allowing several data streams to be transmitted simultaneously on the same channel. This increases the overall throughput as multiple sensors can transmit their data concurrently without interference. MIMO systems also provide diversity gain by transmitting multiple copies of the same data over different antennas. This helps mitigate the effects of fading and interference, resulting in a more reliable and higher-throughput communication link as compared to a SISO channel. Another advantage of employing MIMO in WSN is reduction in end-to-end delays in data transmission . MIMO's spatial diversity and multiplexing capabilities can significantly reduce packet loss due to fading and interference resulting in enhancement of Packet Delivery Ratio. Last but not the least, MIMO can be configured to optimize the power consumption of individual sensors. By adjusting the number of antennas used and transmission power levels based on channel conditions, MIMO can help extend the network's lifetime by conserving energy in resource-constrained sensor nodes by preservation of Residual Energy.

## DECLARATION STATEMENT

| | |
|---|---|
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| Ethical Approval and Consent to Participate | The article does not require ethical approval and consent to participate. |
| Availability of Data and Material | Not relevant. |
| Authors Contributions | All authors have equal contributions. |

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