

LATENCY AND RESIDUAL ENERGY ANALYSIS OF MIMO HETEROGENEOUS WIRELESS SENSOR NETWORKS

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ABSTRACT

Energy-constrained Wireless Sensor Networks (WSNs) have garnered significant research interest in recent years. Multiple-Input Multiple-Output (MIMO), or Cooperative MIMO, represents a specialized application of MIMO technology within WSNs. This approach operates effectively, especially in challenging and resource-constrained environments. By facilitating collaboration among sensor nodes, Cooperative MIMO enhances reliability, coverage, and energy efficiency in WSN deployments. Consequently, MIMO finds application in diverse WSN scenarios, spanning environmental monitoring, industrial automation, and healthcare applications.

This research paper presents a comparative performance analysis of MIMO wireless sensor networks and traditional wireless sensor networks without MIMO using Network Simulator NS2.35 for analysis of End to End Delay for packet transmission and Residual energy of nodes. The research work shows application of MIMO in Wireless Sensor Networks with considerable improvements in Quality of Service parameters 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 which helps in mitigating 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.

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. Hence, MIMO can help to extend the network's lifetime by conserving energy in resource-constrained sensor nodes by preservation of Residual Energy.

KEYWORDS

Wireless Sensor Networks; Heterogeneous Networks; End to End delay; Residual energy; MIMO.

1. INTRODUCTION

Multiple-input-multiple-output (MIMO), or multiple antenna communication, has become increasingly significant in wireless systems in recent years. MIMO technology enhances the

performance of Wireless Sensor Networks (WSNs) by leveraging multiple antennas at both the transmitter and receiver ends, thereby improving data throughput, enhancing reliability, and expanding the coverage of wireless communication in WSNs [1].

The various benefits of MIMO in Wireless Sensor Networks are as follows [2]:

- Improved Spatial Diversity: MIMO exploits multiple spatial paths, resulting in better signal reception, reduced signal fading, and improved link reliability.
- Increased Data Rate: MIMO facilitates higher data rates by simultaneously transmitting multiple data streams over the same channel.
- Enhanced Coverage: MIMO can broaden the coverage area of WSNs, rendering them suitable for larger deployment areas.

However, the application of MIMO in WSNs presents significant challenges that require careful consideration during WSN design. These are

- i) Channel Estimation: Accurate channel estimation is critical in dynamic WSN environments, particularly in MIMO systems.
- ii) Hardware Constraints: Implementing MIMO in resource-constrained sensor nodes poses challenges due to limitations in power and size.

This research work focusses on the implementation of the MIMO in the sensors as a hardware unit to provide energy efficient transmission with reduced delay.

2. MIMO IN WIRELESS SENSOR NETWORKS

A heterogeneous wireless sensor network consists of nodes with diverse capabilities, including sensing, various computational abilities, power-efficient communication, and different sensing ranges. When employing Multiple Input Multiple Output (MIMO) wireless channels, such networks become particularly valuable for energy-efficient multi-channel communication. Integrating MIMO technology into Wireless Sensor Networks (WSNs) has the potential to enhance throughput, reduce end-to-end delay, improve packet delivery ratio, and conserve energy. However, its implementation requires careful consideration, taking into account the specific deployment conditions and resource constraints of the network. This entails attention to proper antenna design, synchronization mechanisms, and the development of energy-efficient algorithms.

In MIMO wireless sensor networks, similar to traditional wireless sensor networks, each node typically possesses only one antenna, with nodes distributed across the network. To achieve higher spatial diversity gain, also referred to as cooperative diversity gain, these dispersed nodes collaborate to form a virtual antenna array [1, 3]. The advantages of MIMO stem from its ability to boost throughput, extend coverage, and enhance capacity in a cost-effective manner. Given the significant benefits offered by MIMO wireless sensor networks, this technology is actively under research, and numerous MIMO techniques have already been integrated into prominent wireless standards [2, 3].

The generic block diagram of a sensor node utilized in MIMO Wireless Sensor Networks is depicted in Figure 1. The essential components of MIMO WSN nodes comprise the power unit, sensor array, A/D Converter unit, signal processing and data computing unit, and the MIMO-based space-time transceiver [4]. The power unit includes a power bank and memory unit, designed to sustain operation over extended periods, ranging from months to years. The sensor array unit detects physical data and converts it into electrical signals, which are then processed by

the Analog to Digital Converter block to digitize the data. Subsequently, the signal processing and data computing block facilitate the adaptation of data to communication standards, preparing it for transmission. Finally, the MIMO-based transceiver is responsible for enabling two-way communication of data.

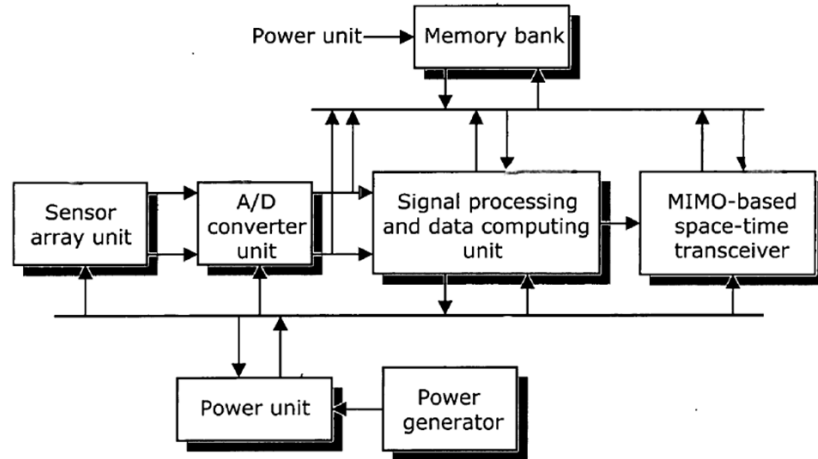


Fig.1 Block diagram of Sensor node in MIMO Wireless Sensor Network

A cluster of sensors collaborates to establish a multiple input multiple output (MIMO) structure, wirelessly connecting to multiple antennas of a Data Gathering Node (DGN). This configuration demonstrates superior energy efficiency compared to the existing Single Input Single Output (SISO) structure [4]. The research at hand investigates the applicability of MIMO techniques to wireless sensor networks, focusing on the total energy consumption aspect. Within heterogeneous wireless sensor networks, nodes are tasked with sensing physical data, performing computations to validate the data for transmission, and transmitting the data using power-efficient communication methods. In this proposed simulation, network parameters such as end-to-end delay and residual energy are analyzed. This analysis incorporates the concept of Multi Input Multi Output (MIMO), which serves to reduce energy consumption, increase residual energy, and extend network lifetime.

3. SIMULATION MODEL PARAMETERS

Considering a hospital scenario and $(1200 \times 1200 \text{ m}^2)$ of 17 bedded patients equipped with 6 sensors at each bed for monitoring different health parameters, which can be presented as 103 nodes comprising of 17×6 (transceivers) + 1(cluster head) in a wireless sensor network communicated and controlled with a remote station through wireless communication with MIMO channel.

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 sensorNodes	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

3.1. Network Initialization

For accurately analyzing the performance of the wireless sensor network, it is crucial to establish ecological settings for various parameters. These include the radio transmission model, the type of antennas employed for communication, the design of the link-layer, the channel type, routing protocol information, and the type of interface utilized in the simulator. In the current scenario layout, 103 nodes are deployed. Fig. 2 shows the distributive nodes placement in a uniform network topology in the animation window.

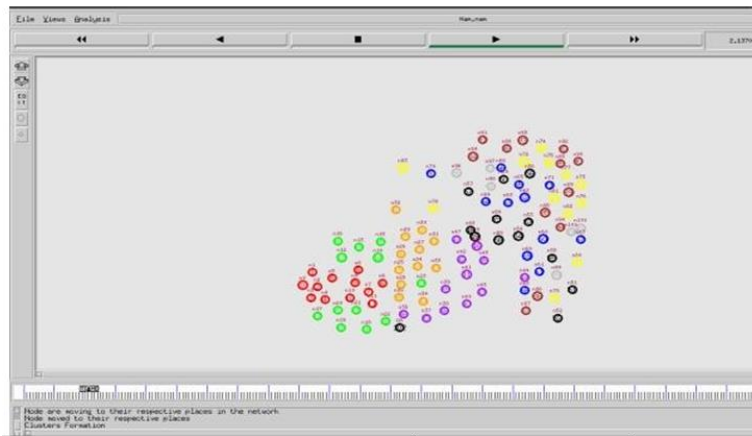


Fig. 2. Node Placement Window

3.2. Cluster Formation

In this simulation, every randomly placed node broadcasts a beacon (Hello) signal within its broadcast range to update the transmission topology by communicating with surrounding nodes. Figure 3 illustrates the formation of clusters in the network simulator. In this setup, a total of 103 nodes are deployed, with 102 nodes acting as cluster authorities. These 102 nodes are organized into 17 clusters, each containing 6 nodes. The Euclidean distance between every pair of nodes is calculated using a two-point distance formula given by Eq. (1).

$$D = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \quad (1)$$



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 [5].

Cluster Head is chosen on the basis of highest initial energy of the nodes [6]. 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 (E_c) and primary energy (E_p) is equal to the amount of residual energy [7]. 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 (E_r) can be defined as in Eq. 2[7].

$$E_r = E_p - E_c \quad (2)$$

3.3. Routing Protocol

In the proposed simulation, the routing of nodes relies on the cluster authority node, and it changes after detecting any disruptive nodes. The cluster authority node adjusts the routing table based on the removal list and reconstructs the best-suited path for packet transmission. The process of discovering suitable routes and selecting the most appropriate one is termed as dynamic routing. However, dynamic routing consumes more bandwidth as routing nodes periodically share updates about malicious nodes [8, 12].

The proposed work employs the Ad-hoc On-demand Distance Vector (AODV) routing protocol in this simulation. AODV is chosen due to its superior characteristics in transmission parameters such as End-to-End Delay and Packet Drop Ratio compared to the Dynamic Source Routing (DSR) protocol, particularly in scenarios with high mobility [9].

4. 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.

4.1. 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 [2,9]. Fig.4 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 2 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.

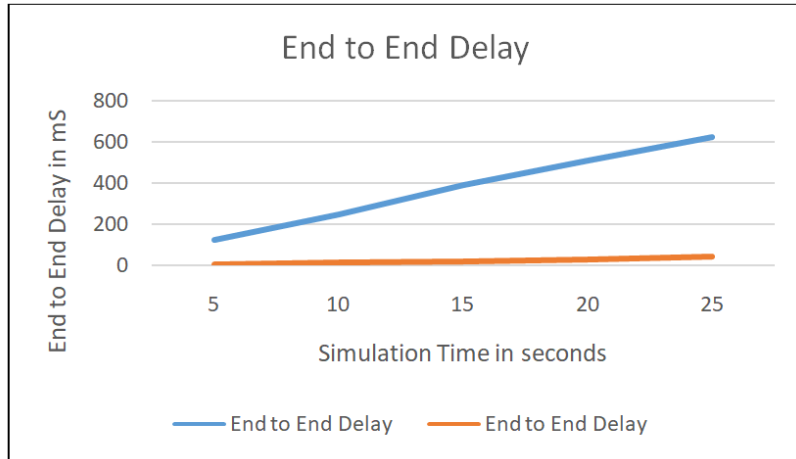


Fig. 4 Comparison of End to End Delay

Table2 below presents the comparison of end to end time delay of existing and proposed model.

Table 2. 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

4.2. 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 [10, 11] and this variation is shown in Fig.5.

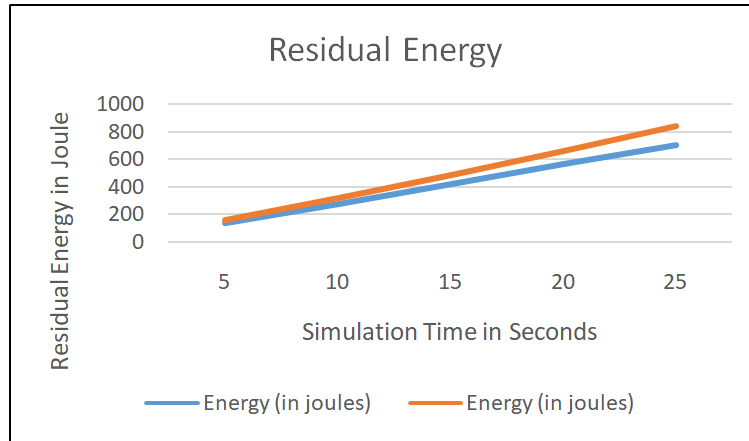


Fig. 5 Comparison of Residual Energy

Table 3 below presents the comparison of values of energy in joules of existing-without MIMO and with MIMO model.

Table 3 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

4.3. Summary of Results

The results for End to End delay and Residual Energy for the above scenario show considerable improvements in battery lifetime which is essentially required for monitoring patients in hospital emergencies. The End to End delay for network simulation time of 25 seconds has been reduced from 624.8 ms to 46.6 ms showing a reduction of 92.5% in End to End delay while residual energy of nodes has increased from 704 joules to 840 joules resulting in preservation of 19% residual energy for the same network using MIMO technique. The results shows that Cooperative MIMO can help extend the network's lifetime by conserving energy in resource-constrained sensor nodes by preservation of Residual Energy.

5. 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 performance metrics including End-to-End delay and residual energy.

MIMO shows considerable improvements in various Quality of Service parameters (QoS) 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.

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. 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 as the network lifetime is dependent on the battery life of the node.

This paper conducts simulations on heterogeneous wireless sensor networks using NS2.35, comparing networks with and without MIMO technology. Multiple Input Multiple Output (MIMO) is a technology applicable to wireless sensor networks (WSNs) aimed at improving performance metrics such as End-to-End delay and residual energy.

MIMO exhibits significant enhancements across various Quality of Service parameters (QoS) through Spatial Multiplexing and Diversity Gain. Spatial multiplexing enables the transmission of multiple data streams simultaneously on the same channel, boosting overall throughput. With MIMO, multiple copies of the same data are transmitted over different antennas, providing diversity gain. This effectively mitigates fading and interference, resulting in a more reliable and higher-throughput communication link compared to Single Input Single Output (SISO) channels.

Moreover, MIMO configuration can optimize the power consumption of individual sensors. By adjusting the number of antennas and transmission power levels based on channel conditions, MIMO conserves energy in resource-constrained sensor nodes, thereby extending the network's lifetime by preserving residual energy. Faster communication from source node to sink node due to multiple inputs and outputs contributes to improved energy efficiency. As energy consumption decreases, the network's lifetime increases, as it directly depends on the battery life of the nodes.

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