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IMPROVED POWER OPTIMIZATION TECHNIQUES IN MOBILE AD HOC NETWORK

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ABSTRACT

Mobile Ad hoc Networks (MANETs) are dynamic, self-organizing networks vital for communication in scenarios without established infrastructure, such as disaster recovery and military operations. However, MANETs face critical challenges, including power management, collision issues, and routing inefficiencies caused by hidden and exposed terminal problems. This study proposes an integrated solution combining Beam Sector Directional Antennas with a Mutual Exclusion Medium Access Control (ME-MAC) protocol. The proposed system optimizes power consumption and improves network performance through precise beam-based packet transmission and collision avoidance mechanisms. Simulations conducted using NS2.32 reveal significant improvements over traditional Omni-Directional Antennas. Specifically, signal power consumption is reduced by 50%, collision rates by 25%, energy consumption by 30%, and end-to-end delay by 45-50%. Furthermore, the PMBS-Antenna achieves 15% higher transmission speed, 10% better efficiency, and a 40-50% increase in packet delivery ratio. These findings demonstrate the potential of the proposed approach to address longstanding MANET challenges, paving the way for more efficient and reliable communication systems.
Keywords: *MANET,Antenna, Physical Layer, MAC layer, Hidden and Exposed Terminal (HET) problem, ME-MAC, protocol*

1. INTRODUCTION

Mobile Ad hoc Networks (MANETs) represent a revolutionary approach to wireless communication, offering flexibility and rapid deployment in dynamic and emergency scenarios such as disaster management, military operations, and remote sensing. By forming a self-organizing, decentralized network, MANETs eliminate the need for fixed infrastructure, making them invaluable in situations where traditional communication setups are infeasible. Despite their advantages, MANETs face several critical challenges that hinder their widespread application.
One of the wireless communication devices is Mobile Ad hoc Network (MANET) [1], which can make the instance network forming to make communication in any emergency scenario like earthquake, cyclone, disaster management, etc. Due to the nature of the MANET nodes, they are subject to many kinds of challenges like antenna usage, hidden and exposed nodes, collision, power management, congestion, and security [2]. Traditionally, Omni-directional antennas were used within the Medium Access Control (MAC) protocol

through distribution Coordination Function in IEEE 802.11 named as CSMA/CA along with a handshaking technique. Smart antennas [3] are a kind of antenna that supports more functionality with additional features. Recently, Omni antennas have been overcome by smart antennas to provide more node connectivity and gain power. Another category of antenna supports interference [4] to avoid the collision in the nodes' transmission. A few antennas support more transmission range with long transmission range features by adding high-volume transceivers [5], and some antennas have unique features of more transmission capacity [6], which could support transmitting more packets to the receivers to achieve a better packet delivery ratio.

Much research related to Medium Access Control protocol-based antennas provides solutions to Omni-directional antenna limitations. Mahmud et al. [7] proposed GPS-based MAC-designed directional antennas to defend against hidden and exposed terminal problems. Wang et al. [8] invented CMD-MAC protocol to resolve the MANET Hidden and Exposed node problem with the cooperative directional antenna. Kulcu et al. [3] proposed the smart antenna using the IETF 6TiSCH protocol for MAC layer scheduling mechanisms to overcome hidden and exposed node issues. Vigneshwaran et al. [9] invented the sector-based directional antenna by dividing geographical locations into sectors and proposed the sector-based Antenna. Periyakaruppan [10] uses MIMO link to propose the COASC strategy to overcome the MAC layer problem with the support of scheduling in Physical layer network capacity. A set of research work has evolved in node location-based direction with the support of neighbor node discovery [ND] Yang et al. [11] to minimize the convergence time. Sorribes et al. [10] invented collision detection techniques with the support of Neighbor nodes' location. Wei et al. [12] detect the ND with Gossip technique in VANET by setting sensors on the road vehicle.

A sender node wants to send a packet to another receiver node, while the third node wants to send a packet to the same receiver node. Both nodes detect a free channel and begin transmitting packets to the receiver node; however, there is a collision at the receiving node [13]. Both nodes could not be aware of each other when transmitting the packet. This is referred to as Hidden nodes. Both the senders are hidden from each other. Next, about the exposed nodes, the sender node wants to send a packet to the receiver node, while another sender node wants to send a packet to another receiver node. When both the receiver channels are free, and both sender nodes transmit packets to different receivers respectively, there is a collision. Node sender and receiver nodes are exposed in this case. This problem is called the Hidden and Exposed nodes terminal (HET) problem [14], which is a major challenging task of the MANET power management.

Another set of research was conducted for changing RTS/CTS signals Liu Kai & Xing Xiaoqin [15]) in cooperative and distributed ways, but this research failed when the nodes were mobile. A few studies have been conducted on internal parameters such as clock synchronization, receiver sensitivity, and SINR value. Adaptive antenna array by Mahendrakumar Subramaniam et al. [16] was the most recent strategy in antenna-centric research, replacing the Omni-based antenna with directional antenna techniques to try to solve the Hidden and Exposed node dilemma. For providing the MAC layer issues solution, recent algorithms by Hussien & Mostafa [17] of machine learning, deep learning, artificial intelligence, and cluster algorithms were employed. The ultimate solution for the Hidden and Exposed node concerns could not be addressed by any of the methods. Several methods are still being investigated to find a solution to the Hidden and Exposed node concerns.

Among the several proposals of smart antennas discussed in this chapter, with the MAC layer routing protocol, ND prediction for convergence time and ML algorithms are not assisting to provide solutions for MAC layer and Physical layer which are not solved permanently, still the existence of Hidden and Exposed node problem and power management in MAC and Physical layers predominant issues in MANET. This article addresses the smart antenna with the support of ND and beam defining to float the packet to the next node also uses ME-MAC protocol for finding the hidden and exposed nodes in the network. Through this, it could achieve better power optimization and performance in MANET Physical and MAC layers.

To address these challenges, researchers have proposed various strategies, including the adoption of smart antennas and advanced Medium Access Control (MAC) protocols. However, existing solutions often lack the synergy between physical and MAC layer functionalities, limiting their effectiveness in tackling hidden and exposed terminal issues comprehensively.

This study proposes a novel approach that combines beam sector directional antennas with a

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Mutual Exclusion - Medium Access Control (ME-MAC) protocol to enhance power optimization and network efficiency in MANETs. The beam sector directional antenna divides its transmission range into multiple sectors, enabling precise communication with reduced interference and energy consumption. Simultaneously, the ME-MAC protocol addresses hidden and exposed terminal problems by predicting node locations and optimizing routing decisions.

To further refine MANET performance, this research integrates additional improvements:

- **Advanced Antenna Technologies:** Incorporating dynamic beamforming and hybrid antenna designs to adapt to varying network densities and mobility patterns.
- **Machine Learning and Adaptive Protocols:** Leveraging artificial intelligence for traffic prediction, routing optimization, and real-time decision-making.
- **Energy Harvesting Solutions:** Introducing renewable energy sources and wireless energy transfer to enhance node longevity.
- **Mobility Management:** Implementing predictive algorithms to anticipate node movements and maintain stable communication links.
- **Emerging Technology Integration:** Aligning MANET innovations with advancements in IoT, 5G, and quantum computing to future-proof the network.

The organization of this article begins with an overview of the proposed methods in Chapter 2, followed by a detailed explanation of the research methodology and simulation setup in Chapter 3. Chapter 4 discusses the results and evaluates the performance of the proposed system compared to traditional approaches. Finally, Chapter 5 concludes with insights and directions for future work.

By addressing both longstanding challenges and emerging opportunities, this study aims to establish a robust framework for optimizing MANETs in power-critical and dynamic environments.

2. LITERATURE REVIEW

.The integration of advanced antenna designs and Medium Access Control (MAC) protocols has been a focus of research to improve MANET efficiency. Smart antennas, with features like directional transmission and enhanced connectivity, have emerged as a promising alternative. However, existing solutions often lack a cohesive approach that combines antenna technology and MAC functionalities, leaving issues like hidden and exposed node problems unresolved. This study aims to fill this gap by proposing a novel system that leverages beam sector directional antennas and the Mutual Exclusion-Medium Access Control (ME-MAC) protocol to optimize power consumption and enhance network performance.

The inventors and colleagues by Linn et al. [18] suggested a technique to reduce heterogeneous collisions using the distributed contention-free cooperative medium access control (CFC-MAC) protocol and the corporative communication system and corporative forwarding mechanism. The simulation determines the corresponding position to study the collision; the findings of the simulation comparison reveal that there is less delay and the collision is minimized. Authors Zhou et al. [19] suggested an Intelligent Multi-hop Low Duty Cycle (IMLDC) Media Access Control (MAC) protocol based on long short-term memory (LSTM) to address the short life cycle issue in UAVS. For an optimal mode environment, an LSTM neural network was applied. Real-time simulation only the network life cycle is improved by the LSTM-based IMLDC MAC protocol over existing MAC protocols.

The Researchers of R. Gudodagi and P. K. [20] this study devised CAD-CW, a strategy for avoiding collisions utilizing contention windows. To avoid collisions, this strategy maintains a contention window in which the highest priority node packets are transmitted first. This technique achieves faster throughput, reduced delay, and lower overhead while consuming the least amount of energy. The authors Kalfas et al. [21] presented WiMARK, a hybrid technique for eliminating hidden and exposed nodes. All nodes kept a local matrix for gathering other surrounding nodes' current location and making the transmitter transmit or receive with the use of RTs and Status messages. This work has been improved by including a sleep and awake protocol to reduce node energy consumption. The writers of this survey study, Hussien and Mostafa [22], provide a comprehensive survey connected to building a MAC protocol using modern techniques such as machine learning, deep learning, and artificial intelligence. Finally, three features show that machine learning techniques are ideally suited to MAC protocol design

Finally, research is working on gearbox range in physical later supports to lower internal battery power consumption. Some of the writers use transmission range-based research work to optimize MANET node energy. The uses Dynamic and Adjustable methods to build low-cost MANETs, with each node having an ideal number of three (3) neighbors. Ansari [23] saves a large amount of energy by using ATP-AODV, which minimizes ATP latency. Balanced According to Z. S. J. and Y. Guo [24], the network's energy consumption adopts Metric Norm during the Routing Process, but the results demonstrate that the network's life is extended. Nagpal et al. [26] reduced control by using MTPR and MHR approaches. Park's [26] advised usage of Hello Messages by Neighbor Nodes resulted in maximum network throughput but significant delays. Energy Efficiency via Transmission Power Optimization, as proposed by Porto and Stojanovic [27] for Throughput Maximization. The Optimal Transmission Radius for Flooding in Large Scale Networks by Wang et al [28]. Liu, Yao, Y. Pan, Z. Chi, and T. Zhu achieves Average Setting Time.

Research conducted a study in VANET management to monitor the functionality of packet fragmentation, density, and disruption, as well as to analyze the benefits and drawbacks, and to identify issues for future VANET improvement. Finally, the necessity of communication routes and network node placement is discussed. Liu et al [29] proposed fast neighbor node finding in VANET for data transfer and driving safety. To anticipate the ND, the proposed algorithm employs Kalman filtering theory and spatial movement information for each VANET node. When compared to other proposed algorithms such as HP-AODV, ARH, and ROMSG, simulation results show a higher performance improvement. This strategy employs multiple techniques to address all concerns; nonetheless, the ND fining may take some time. Zeng et al. [30] proposed a hybrid design of an Omni Directional Antenna and a Multi Beam Directional Antenna to address design problems in MANET and FANET. This study investigates the stable data communication from target tracking to location prediction. The end result is a 35.8% improvement in data link strength.

Survey Summary

The literature highlights various strategies to tackle MANET challenges:

- Collision and Interference Management

Linn et al. [18] proposed the CFC-MAC protocol, demonstrating reduced delay and collision through cooperative communication systems.

Zhou et al. [19] developed the IMLDC MAC protocol using LSTM networks to enhance network life cycles in UAV-based scenarios.

- Power Optimization Techniques

Gudodagi and P.K. [20] introduced CAD-CW, a contention-based approach to minimize collisions and energy usage.

Kalfas et al. [21] presented WiMARK, integrating local matrices and sleep protocols for energy-efficient transmission.

- Machine Learning in MAC Design

Hussien and Mostafa [22] explored AI-driven MAC protocols, emphasizing the adaptability and efficiency of modern algorithms in routing and energy management.

- Enhanced Antenna Technologies

Zeng et al. [30] designed a hybrid antenna system combining Omni-directional and multi-beam directional designs, improving link strength and data stability.

- Energy-efficient Routing

Ansari [23] and Guo [24] employed dynamic transmission ranges and metric-based routing norms to conserve node energy while extending network life.

Proposed Work

Building on the existing research, this study introduces a cross-layer approach that integrates: Beam Sector Directional Antennas: Divides the antenna's operational range into multiple sectors, enabling precise, energy-efficient communication while minimizing interference. ME-MAC Protocol: Aims to address hidden and exposed terminal problems by predicting node locations, improving collision management, and ensuring stable routing decisions. This novel framework seeks to enhance MANET performance by optimizing power usage and addressing unresolved challenges in existing methods. The work's results will be validated through simulations, comparing its performance to traditional Omni-directional antennas and other state-of-the-art solutions.

Despite these advances, a gap remains in synergizing antenna designs with MAC layer protocols to tackle hidden and exposed node challenges comprehensively. This article addresses this limitation through a cross-layer approach, combining beam sector directional antennas with the ME-MAC protocol to optimize MANET performance. From the Literature survey, the research finding that the many varieties of antenna and MAC layer functionalities are proposed to improve the performance of the MANET nodes, but the none of the research work has finds the cross layer functionality with combination of the antenna and MAC layer functionality could address the

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power management among the node. This research article proposes the combination of the physical layer and MAC layer functionality could address the MAENT power management

3. PROPOSED METHOD

The objective of the proposed article is to prove that the combination of antenna and MAC layers could be used to improve the power optimization in the MANET nodes. The system model to overcome the Physical layer and MAC layer issues are like antenna usage and Hidden and exposed node problem. Then the proposed model contains the antenna design and Hidden and exposed table creation.

3.1 Antenna Design model

This proposed work uses the directional smart antenna because of its advantages, Antenna has transmitter and receiver .By making the smart alteration on the directional antenna transmission and receiving signal could support MAC layers issues of hidden and exposed node problem. Omni directional antenna transmission range is 360 degree, based on that the proposed beam sector antenna direction is divided in to eight sector as shown in the Figure 1, each sector has 45 degree of the transmission direction and each beam having individual transmitter and a receiver as shown in the Figure 2, the operation of the beam either transmit or receive the packets which is based the next hop neighbour location the respective transmitter forward the packet same for the receiving packet. For selection of the beam for the purpose of the transmit or receive is defined in the algorithm .This support the energy usage of transmission range will be optimized .

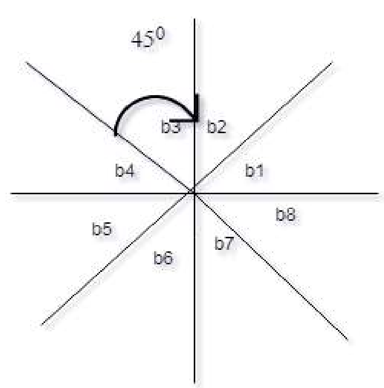

Figure 1. Antenna Model

Algorithm I

MANET SET N = {N1, N2, N3....Nn} where n is the maximum nodes in the MANET communication.

The algorithm designed as follows

Step 1: Finding the neighbor node of each node, and form the hidden and exposed nodes table
Suppose the node Ni has received the neighbor node of Ni1, Ni2 ...Nin then go to stage 2
Step 2: Select the antenna beam sector for each node transmission and receiving based on the hidden and exposed nodes direction [31] .
Step 3 Start Transmit and receiving packet based on the transmission with the respective antenna sector.

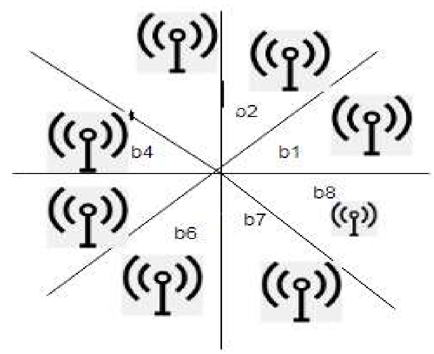

Figure 2. Node Antenna Setting

Let S (t) is a power signal send from an antenna and Transmission signal weight for each antenna sector wRi
Where $1 \leq i \leq 8$. The received signal of the i^{th} antenna is computed using the Eq (1) and Received signal output is computed using the Eq (2).

$$xi(t) = s(t) \sum_{j=1}^{N} wTj\ hji \quad (1)$$

$$\text{Received signal output of } r(t) = \sum_{i=1}^{N} WriXi(t) \quad (2)$$

For an illustration of the Algorithm I working, assume the MANET node has four nodes A, B, C and D as shown in Figure 3. Every node sends a request for live location, upon receiving the location and predicting the neighbor node list and hidden and exposed nodes direction .Finally applies the beam sector selection for transmit and receive the packets.

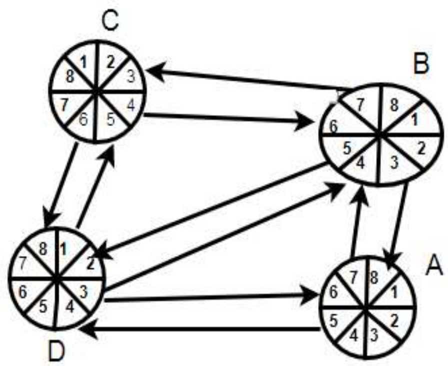

Figure 3. Node Antenna Beam Sector Selections

3.2. Research Method

Initially the proposed work is established, the physical layers use the CSMA/CA techniques over the hidden and exposed node prediction ME-MAC protocol relays [31] to predict the Hidden and Exposed nodes tables, RTS , CTS , Data Packets supports for making the connection establishment. Later Antenna determines based on the available location which beams to act for transmitting and receiving of the packet, finally the packet will be sent from the sender node to reach the receiving node. Antenna sets Zero gain value in another direction so that the other nodes interference will be avoided to overcome collision among the nodes.

Based on the Figure 3 , node D wants to send packet B nodes, RTS signal from D nodes send to other nodes A, C and B says that D need to communicate with B, as per the ME-MAC hidden and Exposed nodes of D is A and C and the directional antenna set for transmitting of the packet from D to B is sector 3 and receiving antenna beam sector is 2 , other beam sector gain are become null so that to avoid the interference .After all the packets transmitted CTS received from other nodes as well from D which make other node can communicate with B. RTS,CTS and Packet frame is modified as shown in the TABLE I. The proposed Physical and MAC layer-based antenna design was simulated with the support of Omni directional antenna set up with beam sector directional antenna. Several metrics are taken for comparing the Omni directional antenna [22] with the proposed antenna 1) Collection rate, 2) Efficiency, 3) speed, 4.) Signal strength. Simulation parameters [23] are defined as in Table II. The total numbers of nodes are ranging from 50 to 100 for making the comparison between the proposed works with existing Omni directional antenna. Starting the simulation with 50 numbers of nodes and slowly increasing the nodes count by 5 in every time duration of 20 ms and computed the evolution metric.

TABLE I RTS, CTS, Packet frame

RTS Frame					
Packet	**Time**	**Receiver**	**Transmitter**	**Receiver Antenna**	FCS
3 bytes	**4ms**	**B**	**D**	**4**	4
CTS Frame					
1 bytes	**2ms**	**A, C, B**	**D**	**4**	4
Data Frame					
4 Bytes	**4ms**	**B**	**D**	**2**	4

Table II Network Simulator Parameter Setup

S. No	***Parameter***	***Value set***
1	*PHY*	*DSSS*
2	*CWmin*	*32 bits*
3	*CWmax*	*1024 bit*
4	*Channel Data Rate*	*11Mbps*
5	*Basic Data Rate*	*1Mbps*
6	*SIFS*	*15 µs*
7	*DIFS*	*45 µs*
8	*Slot time*	*15 µs*
9	*Propagation delay*	*1 µs*
10	*Packet Payload*	*10000bits*
11	*MAC Header*	*200 bits*
12	*PHY Header*	*150bits*
13	*ACK*	*250 bits*
14	*RTS*	*250 bits*
15	*CTS*	*250 bits*
16	*Hidden signal*	*250 bits*
17	*Exposed Signal*	*250 bits*

4. RESULTS AND DISCUSSION

In this section the proposed work has been implemented using the Network Simulator NS2.32, where the simulation parameters are defined in the TABLE II. Two different antennas

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are considered for the results work comparison. Proposed work of Physical and MAC layer-based antennas are named as Physical-MAC layer Beam Sector Antenna (PMBS-Antenna) which is compared with traditional Omni directional Antenna. Power related parameters like signal power and energy consumption are taken for comparison, Antenna related parameters like collision and transmission speed, efficiency are considered for the comparison and finally packet related parameters End to End delay, packet delivery ratio are considered for the comparison. Initially 50 nodes are defined for taking the comparison and every 10 ms the node count is increased by 5 counts to reach the maximum 95 nodes.

A. Signal Power

The Omni directional antenna Signal power value is compared with the proposed PMBS-Antenna, which is depicted in Figure 4. The Omni directional antenna uses more signal power compared with the proposed PMBS-Antenna, even the nodes get increased in the simulation, the usages of Omni directional antenna power is proportional increasing, whereas the proposed PMBS-Antenna the signal power maximum stable in all the scenario of nodes. Hence the Omni directional antenna signal power is double than the proposed antenna, finally the proposed antenna consumed the 50 % less signal power to transmit the packet.

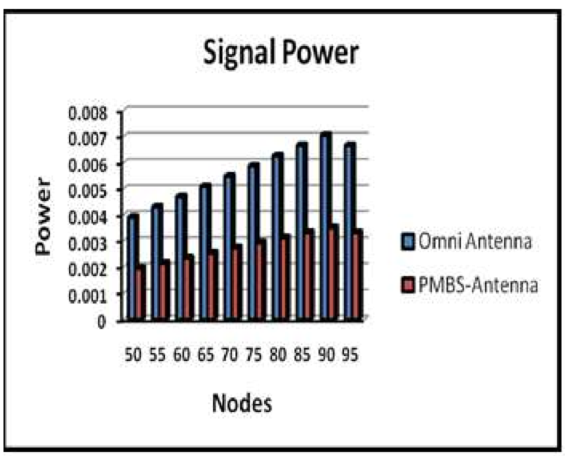

Figure 4 Signal Power

B. Collision Rate

The Hidden and Exposed nodes issues lead to collision, the combined physical and MAC layer functionality supports the collision avoidance. The Omni directional antenna Collision Rate is compared with the proposed PMBS-Antenna, which is depicted in Figure 5. The Omni directional antenna produced more Collision compared with the proposed PMBS-Antenna, even the nodes get increased in the simulation, the usages of Omni directional antenna collision is promotional increasing, whereas the proposed PMBS-Antenna the collision is controlled in all the scenario of nodes. Hence the Omni directional antenna collision rate is higher than the proposed antenna; finally, the proposed antenna reduced the collision 25 % less.

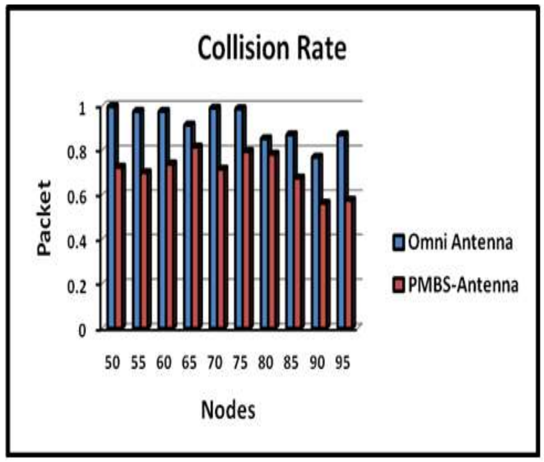

Figure 5 Collision Rate

C. Transmission Speed

Since the use of the Beam sector antenna, any one of the beams from the eight sector is selected for the transmission and receiving of the packets. So, the speed for the packet transmission from the antenna transmitter is compared with the proposed antenna speed. The Omni directional antenna speed is compared with the proposed PMBS-Antenna, which is depicted in Figure 6. The Omni directional antenna produced more transmission of packets compared with the proposed PMBS-Antenna since the all the beam are transmitting the packets, even the nodes get increased in the simulation, where the proposed PMBS-Antenna covers the Omni directional antenna speed, whereas the proposed PMBS-Antenna the speed is high even in all the stages of nodes. Hence the Omni directional antenna transmission speed is 70% but the proposed antenna speed is 85%, finally the proposed antenna increases the transmission speed 15% higher than the Omni antenna.

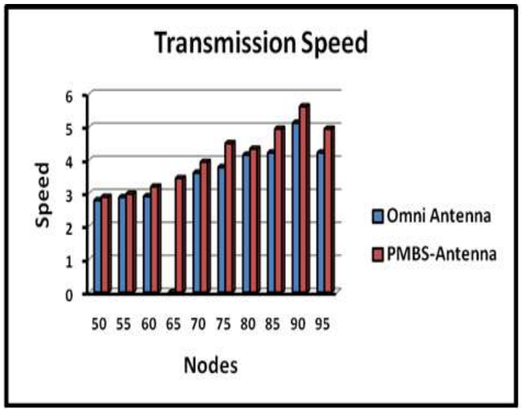

Figure 6 Transmission Speed

D. Efficiency

The Omni directional antenna Efficiency is compared with the proposed PMBS-Antenna, which is depicted in Figure 7. The Omni directional antenna produced less efficiency compared with the proposed PMBS-Antenna, even though the nodes get increased in the simulation, the Omni antenna could not produce the better efficiency, where the proposed PMBS-Antenna efficiency is 10 %.

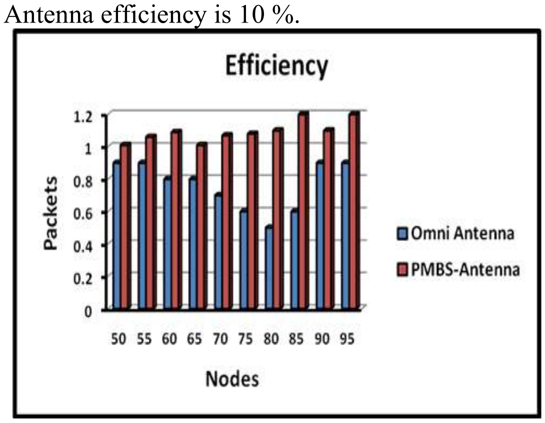

Figure 7 Efficiency

E. Energy consumption

The motivation of this research work focuses on antenna design to attain maximum energy during the packet delivery with respect to the synchronization packet and data packet. This is computed as in Joules with varying the time from 50 ms to 1000 Ms. the Omni directional antenna Energy consumption is compared with the proposed PMBS-Antenna, which is depicted in Figure 8. The Omni directional antenna consumes more Energy compared with the proposed PMBS-Antenna, even the nodes get increased in the simulation, the Omni antenna could not control the energy usages, where the proposed PMBS-Antenna efficiency consumes less energy in 30 % less.

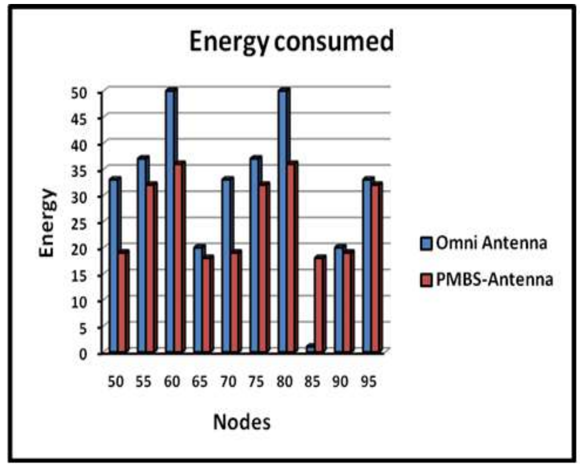

Figure 8 Energy Consumption

F. Packet Delivery Ratio

The other motivation of this research work focuses on antenna design to attain maximum packet transmission during the packet delivery. The Omni directional antenna Packet Delivery Ratio is compared with the proposed PMBS-Antenna, which is depicted in Figure 9. The Omni directional antenna delivers less packet due to the collision among the nodes and compared with the proposed PMBS-Antenna, even if the nodes get increased in the simulation, the proposed antenna delivers more packets because of collision free transmission. The proposed PMBS-Antenna Packet Delivery Ratio is 40 to 50 % higher than the Omni directional antenna.

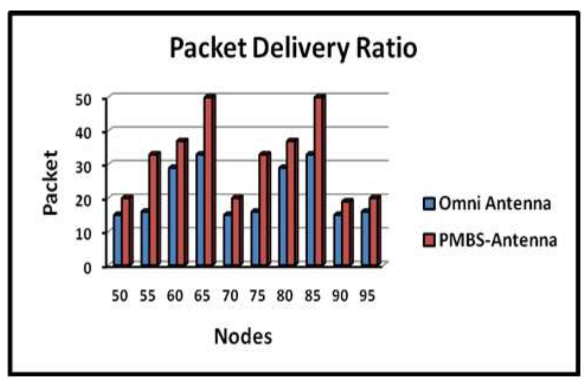

Figure 9 Packet Delivery Ratio

G. End to End Delay

End to End Delay occurs when the more time taken for transmitting of packet from sender to the receiver. Beam sector-based antenna the transmission beam and receiving beam is determined and hidden and exposed nodes collision avoided which aids in improvement of reducing the delay. The Omni directional antenna End to End Delay is compared with the proposed PMBS-Antenna, which is depicted in Figure 10. The Omni directional antenna delay is more due to the collision among the nodes and compared with the proposed PMBS-Antenna, even the nodes get increased in the simulation, the proposed antenna delivers is less delay with a greater number of packets because of collision free transmission. The proposed PMBS-Antenna End to End Delay is 45 to 50 % lesser than the Omni directional antenna.

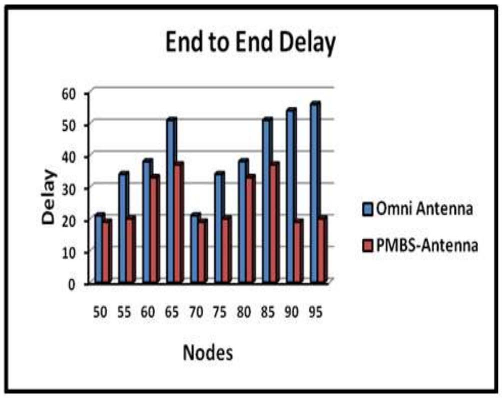

Figure 10 End To End Delay

Summary of Results

The PMBS-Antenna demonstrated significant improvements across multiple performance metrics compared to the traditional Omni-Directional Antenna given in the TABLE III. Signal power consumption was reduced by 50%, reflecting a more energy-efficient operation. The collision rate was 25% lower with the PMBS-Antenna, ensuring fewer packet retransmissions and more stable communication. Transmission speed improved by 15%, thanks to the targeted beam sector approach, while overall system efficiency increased by 10%, showcasing better resource utilization. The PMBS-Antenna consumed 30% less energy than its Omni counterpart, further extending node lifespan. In terms of reliability, the Packet Delivery Ratio (PDR) for the PMBS-Antenna was 40-50% higher, indicating a significant reduction in data loss. End-to-end delay was reduced by 45-50%, resulting in faster and more responsive communication. These results collectively highlight the superior performance of the PMBS-Antenna in optimizing MANET operations.

TABLE III Summary Of Results

Metric	PMBS-Antenna	Omni Antenna	Improvement (%)
Signal Power	50% reduction	Higher	50%
Collision Rate	Lower	Higher	25%
Transmission Speed	Higher	Lower	15%
Efficiency	Higher	Lower	10%
Energy Consumption	Lower	Higher	30%
Packet Delivery Ratio	Higher	Lower	40-50%
End-to-End Delay	Lower	Higher	45-50%

These results demonstrate the effectiveness of the PMBS-Antenna and ME-MAC protocol in optimizing MANET performance, offering significant improvements over traditional Omni-Directional Antennas.

5. CONCLUSION

This study introduces a novel cross-layer framework combining Beam Sector Directional Antennas and the Mutual Exclusion Medium Access Control (ME-MAC) protocol to address key challenges in MANETs, including power inefficiency, collisions, and routing inefficiencies. The proposed system optimizes antenna usage by dynamically selecting transmission sectors based on node location, significantly reducing energy consumption and enhancing collision avoidance.

The performance evaluation demonstrates that the proposed system achieves substantial improvements compared to traditional Omni-Directional Antennas. Key findings include:

- A 50% reduction in signal power usage, enhancing energy efficiency.
- A 25% reduction in collision rates, ensuring smoother communication.
- A 15% increase in transmission speed due to targeted beam operation.
- A 40-50% improvement in packet delivery ratio, boosting network reliability.
- A 45-50% decrease in end-to-end delay, minimizing communication latency.

These results underscore the effectiveness of integrating directional antenna technology with advanced MAC protocols in overcoming longstanding MANET challenges. Future research will explore further enhancements, including

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machine learning-based beam optimization and energy harvesting techniques, to extend the applicability of the proposed system to diverse and large-scale MANET deployments.

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