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Original Article

Enhancing Satellite Communication through MANETs: A Comprehensive Analysis of Optimization Approaches and their Impact on Network Performance

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Abstract *- Satellite communication is critical in modern telecommunications, whereas Mobile Ad hoc Networks (MANETs) are a dynamic and decentralized wireless communication infrastructure used in both civilian and military settings. This article investigates the integration of MANETs with satellite communication systems to address the inherent issues that satellite networks provide. The goal is to identify the synergies between various technologies, categorize optimization techniques, and analyze their influence on network performance. The study emphasizes the development of a comprehensive approach that includes numerous optimization strategies in a hybrid manner. It delves into the continuous emphasis on interoperability among various systems, assessing how they complement one another and the potential performance trade-offs. The findings provide insights that promise to advance the field by giving innovative techniques for improvement. The study focuses on the creation of a complete methodology that incorporates several optimization techniques. It dives into the ongoing emphasis on the interoperability of different systems, evaluating how they complement one another and the potential performance trade-offs. The findings give insights that have the potential to progress the discipline by proposing novel ideas to improve the efficiency and reliability of satellite networks. Furthermore, the paper provides optimization issues for various performance characteristics, which are presented as a series of nonlinear optimization problems. These challenges seek to improve resource use and overall satellite network performance. The study recommends that future research prioritize compatibility, the lack of conflicts across techniques, and improvements over the present system.*

Keywords *- Mobile Ad-hoc Network, Performance parameters, Routing protocols, Security, Wireless communication.*

1. Introduction
1.1. Satellite Communication
A vital component of contemporary technology, satellite communication offers global connectivity and supports a wide range of uses, including emergency communications, weather monitoring, television transmission, internet services, and navigation systems [1]. Because of its scalability and dependability, its long-distance connectivity makes it a preferred solution for both military and civilian applications.

Even though satellite communication is essential to modern telecommunications, several challenges limit its effectiveness. These challenges require investigation and creative solutions. Propagation delay, scarce bandwidth, signal interference, high deployment costs, security flaws, dynamic topology, scalability issues, and power management are some of the difficulties that satellite communication must overcome [2]. These elements emphasize how difficult it is to optimize satellite networks for dependable and effective operation.

1.2. Mobile Ad-hoc Networks
MANETs are a type of decentralized wireless communication infrastructure that is perfect for scenarios where permanent infrastructure is impractical or expensive. Nodes can establish and break connections independently with the help of MANETs. They are adaptable and enable direct connections between nodes without requiring pre-existing network infrastructure. Because of their versatility, MANETs are especially helpful in military operations, disaster relief efforts, and remote locations where it is challenging to establish a reliable communication infrastructure [3]. For both military and civilian applications, MANETs provide cost-effectiveness, flexibility, and mobility that allow for quick deployment in case of emergencies or transient events. They automatically realign themselves to sustain connectivity, thereby offering redundancy and enhanced reliability through self-healing. By complementing the characteristics of satellite communication, MANETs can enhance performance and efficiency in satellite communication.

1.3. Rationale for Integration

Because MANETs provide resource efficiency, dynamic topology management, and flexibility, they can enhance satellite communication systems [4]. These self-organizing networks are perfect in scenarios where terrestrial infrastructure is unstable or non-existent. By facilitating effective data routing and dissemination and guaranteeing efficient satellite bandwidth usage, MANETs also enhance resource utilization.

By decreasing vulnerabilities and boosting network resilience, integrating MANETs with satellite communication adds layer of security. By addressing resource optimization, security, and flexibility, the integration gives satellite networks a dynamic and flexible element and enhances performance in a range of communication scenarios [5]. Additional analysis of optimization techniques will yield more insights into the benefits and effects of this integration on the performance of satellite communication networks.

1.4. Research Gap and Objectives

Though there is a large research gap in integrating MANETs to improve performance, satellite communication is essential for global connectivity. A thorough analysis of optimization techniques and how they affect network performance when coupled with MANETs is lacking in the literature. This disparity emphasizes the necessity of conducting a thorough study to comprehend the benefits of satellite communication and MANETs working together. With an emphasis on network performance, scalability, and adaptation issues, the study attempts to assess the limitations of satellite communication systems. It assesses how well MANETs integrate with satellite systems and examines how this affects flexibility, scalability, and performance.

The study also examines optimization techniques, such as resource management, routing, and security, to improve satellite communication performance through MANET integration. Through MANET integration, the study offers creative ways to increase the effectiveness and dependability of satellite systems while concentrating on resource allocation, power consumption, and bandwidth usage. To evaluate the efficacy of optimization strategies, the study also establishes performance metrics.

1.5. Significance of the Study

The research aims to increase satellite communication capabilities, which will improve connectivity in underserved and remote areas. Through an analysis of optimization methodologies leveraging MANETs, the study also highlights the significance of promoting resilience in communication networks, especially those susceptible to intentional interference or disturbances from the environment.

The study investigates optimization techniques to enhance satellite communication and offers practitioners, academics, and business experts a road map. By outlining the advantages and drawbacks of integrating MANETs, it also supports strategic decision-making by empowering stakeholders to create reliable, high-performing satellite networks. The research holds importance in mitigating obstacles, augmenting network efficiency, and establishing the foundation for enhanced communication systems, thereby bolstering worldwide connectivity and propelling technological progress.

2. Literature Review

2.1. Satellite Communication

Due to issues with spectrum misuse, security flaws, design specifications, and convergence with terrestrial networks, satellite communication systems confront challenges related to efficiency, security, and reliability. They are susceptible to spectrum misuse because of their openness [1]. The high bit error rates and latency of satellite communications render traditional security methods inadequate. Convergence of terrestrial and satellite networks could resolve current problems with mobile communication systems [2]. Due to several difficulties, the security and dependability of satellite communication systems, in particular Physical Layer Security (PLS), have been major concerns [3].

Complex problems arise from the heterogeneous nature of satellite networks and their lack of unified planning, dividing resources into categories such as processor, orbit, and communication [4]. There are security risks in data communication between satellites and within their internal structures due to the growing use of space-based wireless networks [5]. Service continuity, ubiquity, and scalability are provided by satellite communication; however, issues with resource management, network control, security, spectrum management, and energy consumption need to be resolved. It offers a thorough analysis of the risks, remedies, and difficulties associated with link-layer security when implementing and running SATCOM systems, especially concerning the physical layer [6].

To reduce latency and maximize application performance over satellite IP networks, investigate methods like User Datagram Protocol, Performance Enhancement Proxies, and Delay-Tolerant Network Architecture [7]. The study [8] explains the history of satellite mobile communications, examines the difficulties in integrating satellite networks into 5G cellular networks, and evaluates the current state of satellite networks and related technologies. Due to spectrum misuse, vulnerabilities, and design requirements, satellite communication systems confront challenges with reliability, security, and efficiency. One possible solution is convergence with terrestrial networks, but security at the physical layer is paramount. Strategies such as Delay-Tolerant Network Architecture and Performance Enhancement Proxies can be beneficial.

2.2. Mobile Ad-hoc Networks

In the context of satellite communication, Mobile Ad Hoc Networks (MANETs) offer several key characteristics that enhance network performance, particularly in dynamic and resource-constrained environments [9]. One of the key characteristics of MANETs is their decentralized and self-configuring architecture, which enables them to create communication links on their own without the assistance of pre-existing infrastructure. This feature is especially helpful for satellite networks, as fixed infrastructure is frequently impractical in remote locations or for disaster recovery plans. Furthermore, MANETs use multi-hop routing, which improves coverage and connectivity over wide geographic regions by allowing data transmission over multiple intermediary nodes in situations where direct communication with a satellite is impractical [10, 11].

MANETs' dynamic topology, in which nodes can join and exit the network regularly, is like satellite communication's sporadic link availability, which can be disrupted by outside influences or user mobility. Because of their built-in adaptive routing protocols, MANETs are well-suited to the erratic conditions of satellite links, effectively adapting to these topological changes [12]. Energy efficiency is also very important because a lot of satellite communication nodes, especially mobile terminals that are based on the ground, run on limited power. In satellite systems with limited energy resources, MANETs' capacity to implement energy-aware routing guarantees longer operational times, which is pivotal [13].

Finally, the scalability and low infrastructure dependency of MANETs match the requirements of communication networks that cater to sizable, dispersed, and frequently mobile user bases. Because of these qualities, MANETs are a perfect match for communication systems, offering scalable, resilient, and adaptable solutions that can meet the ever-changing demands of space-ground network integration [14, 15].

2.3. Rationale for Integration with MANET

Integrated Satellite-Terrestrial Networks (ISTNs) lessen dependency on terrestrial infrastructure while expanding network coverage. For architectural development and protocol upgrades, they have four stages. Tests indicate that ISTN can use low-Earth orbit satellite communication to enable industrial Internet applications. Programmable satellites and AI-powered networking are examples of future developments that will be compatible with MANETs [16]. Research on integrating MANETs with satellite systems found that ad-hoc routing protocols can be effectively used in a hybrid MANET-satellite network to meet Quality of Service (QoS) criteria.

Simulation results with NS3 show that the hybrid network can achieve QoS performance. The study highlights the importance of routing protocols in designing and implementing hybrid MANET-satellite networks for efficient and reliable communication [17]. According to the study, adding MANET technology to satellite networks can improve polar satellite missions, which will improve the flexibility, self-organization, and self-configuration of satellite systems [9].

The study highlights SatSim's benefits as a user-friendly, modular tool for improving satellite network protocols, with potential applications in intelligent agents, terrestrial vehicles, and new protocols [18]. The article [19] addresses the use of MANETs in conjunction with satellite networks for military operations and disaster relief. It talks about the difficulties with QoS, energy management, routing, and gateway selection. The article also covers the functions of gateways, including security, multi-homing, handoffs, and load balancing. It looks at ongoing projects such as DUMBONET, MONET, SAVION, and P2PNET. Benefits of the integration include robust communication, global communication, quick response times, and spontaneous communication that can happen anywhere at any time.

The articles [20-22] highlight the characteristics of MANETs that are compatible with satellite communication requirements. By reducing dependency on terrestrial infrastructure, integrated satellite-terrestrial networks can improve network coverage. They are appropriate for programmable satellites and artificial intelligence-based networking, and they can support industrial Internet applications. While maintaining Quality of Service standards, hybrid MANET-satellite networks can effectively employ ad-hoc routing techniques. Protocols for routing are essential to effective communication. For emergency and disaster relief services, integrating MANET with satellite networks offers advantages like worldwide communication, robust communication, quick response, and spontaneous communication.

2.4. Challenges and Proposed Solutions for Integration

Long propagation delays, interference, and complex network dynamics are just a few of the difficulties that come with integrating satellite and terrestrial networks [23]. It is imperative to tackle these concerns to guarantee seamless communication and enduring relationships for individuals globally. The study [24] examines research projects on SDN satellite networks and talks about the difficulties in incorporating satellite communication networks into the 5G ecosystem, such as network virtualization, hardware compatibility, and satellite mobility.

This paper [25] investigates a range of machine-learning methods for satellite networks. It also highlights the challenges faced, including limited and poor-quality data, a dynamic and complex environment, and communication and computational constraints in satellite communication. The hybrid MANET-cellular network [26] is intended for data offloading, focusing on system architecture, data delivery techniques, privacy protection, and resource management. It highlights shared concerns and obstacles, such as network heterogeneity, mobility, scalability, dependability, and differing service needs and performance indicators.

The article [27] examines the advantages and disadvantages of combining terrestrial and satellite components into a single telecom network, emphasizing gains in QoS, resilience, faster deployment, and enhanced service coverage. It also looks at how software-defined networking and network function virtualization can improve upon current satellite communication systems' drawbacks. The article [28] covers a variety of optimization methods for MANET routing protocols, such as artificial neural networks, bacterial foraging optimization, genetic algorithms, ant colony optimization, particle swarm optimization, and more. It summarizes the literature on these techniques, emphasizing both their advantages and disadvantages. Using measures like energy consumption, latency, overhead, and throughput, the article assesses these algorithms.

The paper [29] examines how terrestrial networks can use satellites to provide redundant connections and data offloading, as well as to improve performance and overcome congestion. It suggests a framework for network simulation that makes use of ns3 to assess the need for load balancing and routing in dynamic hybrid networks. By extracting temporal and spatial variations from low-resolution images, a less parameterized MANET methodology outperforms traditional machine learning and deep learning fusion techniques, leading to more accurate prediction accuracy and precise fusion results [30].

Integrating satellite and terrestrial networks is challenging due to propagation delays, interference, and complex architecture. Solutions include virtualization, hardware compatibility, and satellite mobility. Machine learning can address data shortages and quality concerns. Hybrid MANET-cellular networks address network heterogeneity, mobility, scalability, and dependability, increasing service coverage, deployment, resilience, and QoS.

2.5. Recent Evaluation Metrics' Optimization Strategies in ISTNs

The study [31] looks at how much energy routing protocols use and how that affects the longevity and performance of MANETs. It shows that OLSR uses less energy than DSDV and that reactive procedures use less energy than proactive protocols. Additionally, the study looks at how routing protocols affect routing overhead, throughput, and end-to-end latency. It models and assesses routing strategies with the help of the network simulator ns2. The study [32] surveys, categorises and analyses current route optimization algorithms based on strategy, overhead, and performance.

The study [33] looks at how five different routing protocols operate in a MANET system with node number. Utilizing NS2, the study has between 50 and 150 nodes. The simulation tool is used, and the results are shown in tables and graphs. According to the study, OLSR is the optimal routing protocol for end-to-end latency, while AODV is the best for throughput and packet delivery ratio. The report makes recommendations for future directions in research to enhance the performance of routing protocols in MANET systems.

The study [34] emphasizes the significance of putting forward novel metrics to measure route performance in MANETs using the Path Change Factor (PCF) and Route Repair Effect (RRI) to assess connection failure, which is frequently brought on by high mobility. The paper [35] offers a hybrid routing method that keeps data transport inside the MANET while outsourcing routing to a MANET-Controller (MC). Based on QoS requirements and network conditions, the MC can schedule flows.

In comparison to conventional MANET techniques, Omnet++ simulations demonstrate that the method can identify congested segments, improve packet delivery, and reduce end-to-end latency. But the report also covers constraints and roadblocks. Federated Satellite Systems can make use of the Optimized Link State Routing (OLSR) protocol, a viable option for enhancing polar mission monitoring [36].

Future networks can benefit greatly from Federated Learning (FL) over wireless communication networks, especially for low-Earth orbit-based satellite communication. On the MNIST dataset, combining FL with LEO satellite systems results in realistic accuracy and reduced communication overheads. FL-based SatCom lowers communication overheads and traffic costs by supporting massively networked devices and improving communication efficiency [37].

To enhance inter-satellite optical wireless communication performance, research has looked into optimizing satellite communication overhead [38]. Rebroadcasting and route maintenance are two tactics for lowering traffic and overhead [39]. A proposed technique aims to optimize the frequency plan and bandwidth allocation in the return links of broadband satellite networks.

[40], to reduce bandwidth usage in networks that use continuous coding and modulation schemes. The evaluation of two heuristic- and integer-based linear programming-based solutions revealed only slight reductions in total bandwidth consumption. A hybrid metaheuristic combining Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) was proposed [41], significantly reducing power consumption and service rate.

The study [39] identifies three strategies to increase MANET performance in military environments: concentrating on critical nodes with high connectedness and centrality in the network, utilizing twin cluster heads to divide the workload and conserve energy. Moreover, it provides a traffic categorization routing algorithm that considers energy when meeting the quality of service standards in a microsatellite network with limited energy [42].

Numerous research projects, including multibeam satellite systems, have been undertaken to increase the energy efficiency of satellite communication systems [43] and Low Earth Orbit (LEO) satellite communication systems [44]. These works concentrate on improving a Ka-Band Multi-Beam LEO Satellite Communication System and Secure Energy Efficient (SEE) beamforming in multibeam satellite systems. They also created a technique that makes use of enhanced Cooperative Spectrum Sensing (CSS) techniques to improve energy economy in cognitive communication scenarios.

[45] and investigated collecting data from IoT gateways via LEO satellites in an energy-efficient manner via Lyapunov optimization [46]. The studies [47, 48] emphasize the value of satellite communication in relieving traffic on terrestrial wireless networks and the potential of Reconfigurable Intelligent Surfaces (RISs) to improve communication efficiency and service quality for small satellites that require less power [49].

The methodologies introduced in the study [50] optimize overall energy efficiency under two distinct scenarios: Ideal Environment (IE) and Non-Ideal Environment (NIE), thereby helping to improve energy efficiency in satellite-to-ground communication systems. In the IE scenario, the research aims to maximize power reception by precisely regulating each RIS element's phase shift and utilizing Selective Diversity to identify the RIS element that is producing the greatest amount of power. To achieve energy efficiency, these studies conclude by emphasizing the need for energy optimization in satellite communication systems and by proposing several methods, including beamforming, spectrum sensing, power allocation, and intelligent surface technologies.

The study [51] examines performance metrics, QoS-influencing factors, and the architecture of satellite networks for internet access with support for Quality of Service (QoS). It identifies factors to consider when creating a quality-of-service policy as well as performance indicators for customer satisfaction. The study [52] discusses QoS features in satellite networks, including jitter, packet loss, and delay, and how they impact the Quality of Experience (QoE) of multimedia services. The study [53] presents the QoS-aware Routing Algorithm (QoSRA), which uses a variety of satellite network types to distinguish between services. It provides Software-Defined Satellite Networking (SDSN) with an intelligent Quality of Service routing strategy [54], which provides fine-grained QoS guarantees. This strategy improves network integration and reduces costs in satellite networks.

The study [55] explains why different QoS standards are necessary for satellite networks and provides an adaptive routing technique to meet those standards. It [56] suggests a multi-QoS routing approach to meet complex and different QoS needs. The study [57] provides fybrrLink, a novel QoS-aware routing algorithm for satellite networks made to satisfy different QoS requirements for a range of uses. The study [58] draws attention to problems with high-throughput satellite communications, in particular the need for efficient signal processing to reduce interference.

A hybrid protocol is proposed [39] that integrates proactive and reactive routing techniques, modifying settings according to the direction and speed of node mobility. Compared to traditional protocols, this one can carry 1.41 per cent more packets. The study [59] offers BO-CL-DBA, a dynamic bandwidth allocation technique based on bee colony optimization, which is intended to allocate bandwidth resources in broadband satellite communication systems in the most efficient way possible.

The simulation model assessed the proposed algorithm's performance in terms of utility value, user happiness, and throughput and found that the allocation is highly efficient and meets numerous QoS criteria. The articles examine performance metrics, factors that impact the quality of service, and satellite network architecture. They cover adaptive algorithms, multi-QoS strategies, QoS-aware routing algorithms, intelligent QoS routing schemes, high-throughput satellite communications, signal processing, and adaptive design. Additionally, they suggest a mechanism for dynamic bandwidth allocation based on the optimization of bee colonies.

In satellite communications, Physical-Layer Security (PLS), which depends on randomness to maintain confidentiality and authentication, is a potential substitute security paradigm. However, there are special security challenges associated with the integration of satellite and terrestrial networks in next-generation communication systems, especially for critical infrastructures like space stations, autonomous ships, and aeroplanes.

A survey [60] highlights several research challenges in PLS for satellite communications and makes recommendations for possible directions for further study. This paper discusses how to implement PLS in an integrated satellite-terrestrial network, looks at how these challenges affect an ISTN's security performance, and offers suitable solutions. A study [61] offers challenges to maximize the sum secrecy rate of satellite users, a framework for symbiotic secure transmission between satellites and terrestrial devices, and a method for secure key agreement that is both efficient and verifiable for satellite communication networks. The proposed scheme [62] provides anonymity by substituting the user's genuine identity with a temporary identity updated throughout each session. The study [63] focuses on utilizing artificial noise at the transmitter and creating optimization problems to reduce the Signal-to-Noise Ratio (SNR) received at radar targets while maintaining the signal-to-noise ratio requirement at legitimate users to provide transmission secrecy in a MIMO dual-functional radar-communication system. For satellite communications, Physical-Layer Security (PLS) is a workable solution. However, the limitations of merging satellite and terrestrial networks create unique security risks, particularly for critical infrastructure such as space stations and autonomous ships.

2.6. Gaps in the Literature and Research Questions

- Scarcity of studies on the resilience and reliability of MANET-satellite communication systems: The literature does not provide a thorough study of how MANET integration might improve the resilience and dependability of satellite communication systems, particularly in demanding conditions or during catastrophe recovery operations [64, 65]. What effect do MANETs have on the resilience and dependability of satellite communication systems, particularly in demanding situations or during disaster recovery efforts?
- Resource allocation and management: Efficient resource allocation and management are critical in MANET-satellite communication, as resources are restricted and shared by several users. Dynamic resource allocation, resource sharing, and traffic management are some of the optimization methodologies proposed in the study [66]. How can MANETs be integrated with satellite communication systems to handle networking, data transmission, and connection concerns in remote or inaccessible locations?
- Network performance metrics: There is a limited understanding of how different optimization methodologies affect certain network performance indicators in MANETs and satellite communication [67]. What performance indicators are most important for assessing the efficacy of optimization techniques in this context, and how do various approaches influence these metrics?
- Limitations of existing approaches: While numerous optimization approaches have been developed to improve the performance of satellite communication-MANET networks, it is critical to recognise their limits and devise tactics to overcome them [6]. This research might shed light on the most successful optimization approaches for this sort of network.
- Understanding the trade-off among approaches: There is still a lack of research on the trade-offs between different optimization strategies for improving satellite communication via MANETs. While some techniques concentrate on energy efficiency, others enhance throughput or lower latency [68]. The challenge is to know how to strike a balance between these conflicting goals because pursuing one at the expense of another often prompts additional research.

3. Key Performance Parameters and Optimization Approaches

MANET performance optimization is inherently challenging because of MANETs' characteristics. Research aims to improve design and implementation by evaluating routing protocol performance to tackle these problems. Routing protocols are assessed based on performance metrics, which include energy consumption, overhead, QoS metrics (e.g., packet delivery ratio, end-to-end delay), network dynamics, mobility, bandwidth restrictions, and energy constraints.

3.1. Overhead Optimization Approaches

A crucial factor that impacts network performance in MANETs is overhead, which raises data transmission and contributes to congestion, packet loss, delay, and congestion. Routing protocols, control messages, and neighbour discovery mechanisms are some of the factors that affect it. Researchers can improve network performance by managing overhead. Given that overhead optimization has a major impact on network efficiency and performance, it is an essential component of MANET design. The requirements of the application and the properties of the network determine which optimization technique is most suited. Consequently, when designing and implementing MANET protocols, careful consideration of these overhead factors is crucial. The following are a few typical MANET overhead optimization techniques:

3.1.1. Broadcasting Optimization

In MANETs, broadcasting is essential for distributing information to numerous nodes. On the other hand, excessive broadcasting can result in high overhead and energy consumption, which lowers network lifetime and performance. Reducing overhead and increasing energy efficiency require optimizing broadcasting. Location-based broadcasting, multi-hop broadcasting, probabilistic broadcasting, and selective broadcasting are methods for optimizing broadcasting in MANETs.

By only broadcasting a message to nodes within a particular geographic region, location-based broadcasting lowers overhead. To ascertain whether nodes are in the broadcast region and can receive the message, this method makes use of their location data. By limiting the number of hops in the broadcasting process, multi-hop broadcasting lowers the total number of broadcasts while increasing energy efficiency. Using probabilistic models, probabilistic broadcasting chooses a subset of nodes at random based on factors like energy consumption and network topology to determine which nodes receive the message. Selective broadcasting chooses a subset of nodes to receive the message based on heuristics such as connectivity or distance.

To sum up, optimizing broadcasting is crucial for lowering overhead and raising MANET energy efficiency. The network topology, node, and other factors determine which broadcasting optimization technique is most suitable.

3.1.2. Cluster-Based Routing

In MANETs, cluster-based routing is one method for optimizing overhead. It entails partitioning the network into clusters, each headed by a cluster head who handles communication inside the cluster. Lowering the number of transmissions lowers overhead. Cluster-Based Forwarding (CBF), Hybrid Energy-Efficient Distributed (HEED) clustering, Low Energy Adaptive Clustering Hierarchy (LEACH), and Power-Efficient Gathering in Sensor Information Systems (PEGASIS) are a few cluster-based routing techniques.

By sending packets to their cluster heads, who subsequently forward them to the destination node, CBF employs a cluster-based technique. By lowering the number of transmissions and increasing the energy efficiency of the network, this lowers overhead. HEED uses a hybrid approach, selecting cluster heads based on node density and residual energy. Designed for energy-efficient communication in MANETs, LEACH is a well-liked cluster-based routing protocol that forms clusters around a cluster head in charge of gathering and aggregating data. PEGASIS is a chain-based clustering algorithm that forms a chain of nodes from sensor nodes to the base station, reducing overhead by minimizing transmissions and improving network energy efficiency.

In conclusion, cluster-based routing is an effective technique for overhead optimization in MANETs, but the choice depends on network topology, node mobility, and energy constraints.

3.1.3. Location-Based Routing

By making use of nodes' location data, location-based routing reduces overhead in MANET architectures. This method extends the lifetime of the network, increases network efficiency, and decreases the number of transmissions. Geographic routing, grid-based routing, position-based routing, and zone-based routing are a few location-based routing methods.

Geographic routing ensures that every node keeps a routing table with the location data of its neighbours by using node location information to make routing decisions. This increases MANET energy efficiency and lowers the overhead of flooding. Grid-based routing creates grids within the network and gives each one a special number. This increases the efficiency of MANETs and lowers the overhead associated with maintaining routing tables. Position-Based Routing routes the packet to the closest neighbour after calculating the distance to the destination node. Zone-Based Routing creates distinct identifiers for each zone while dividing the network into them.

To sum up, location-based routing is a useful technique for cutting overhead and boosting MANET performance. The topology of the network, node mobility, and node energy constraints all influence the selection of an appropriate location-based routing technique.

3.1.4. Multicasting

With multicasting, a single transmission can simultaneously reach several receivers in a MANET, thereby reducing overhead. Through fewer transmissions and more effective use of available bandwidth, this technique increases the energy efficiency of MANETs.

Because of the broadcast storm issue, flooding-based multicasting results in high overhead and decreased network efficiency. Flooding is a technique that uses flooding to multicast packets to all nodes in the network. By building a mesh network among nodes, mesh-based multicasting sends packets to every node in the mesh. This method increases the efficiency of MANETs while lowering the overhead of flooding. By building a tree structure among nodes, tree-based multicasting distributes packets to every node in the network. A node's forwarding of a multicast packet to its parent and all its offspring lowers the overhead of flooding and boosts the effectiveness of MANETs. Zone-based multicasting creates distinct identifiers for each zone within the network. To lower the overhead of flooding and increase the efficiency of MANETs, a node forwards a multicast packet to all other nodes in its zone as well as to nodes in nearby zones.

In summary, multicasting is a useful method for cutting overhead and raising the effectiveness of MANETs. The network topology, node mobility, and node energy constraints all play a role in choosing the best multicasting technique.

3.1.5. Neighbour Coverage-Based Optimization

One method for lowering MANET overhead is neighbour coverage-based optimization. To minimize control overhead, it entails grouping nodes according to the coverage of their neighbours and optimizing the routing protocol. Within a given transmission range, neighbour coverage is the number of neighbouring nodes that a given node can reach.

Adaptive control packet transmission, which modifies the frequency of control packet transmission based on the node's neighbour coverage, and grouping nodes according to their neighbour coverage are two methods to carry out this optimization. By doing this, you can preserve the routing table and maximize the overhead. Another method for distributing control packets in MANETs is optimized broadcast. This method minimizes the number of nodes that must receive the broadcast and lowers overhead by optimizing the broadcast to target nodes with poor neighbour coverage.

Another method for spreading control packets in MANETs is reduced flooding. However, this can result in excessive overhead and congestion. By limiting flooding to nodes with poor neighbour coverage, this technique lowers overhead while guaranteeing that all nodes receive the required control packets. In conclusion, neighbour coverage-based optimization is a useful method for cutting down on MANET overhead.

3.2. Energy Optimization Approaches

Energy consumption is an important performance parameter in MANETs because it affects the network's longevity and performance. Overconsumption of energy can lead to node fatigue and network partitioning, which reduces QoS and dependability. The factors that affect energy consumption are node mobility, traffic load, transmission power, and node distance. To improve network stability, each node in a MANET should be energy aware, regularly calculating and reporting how much energy it still has left. As a result of the limited battery life of mobile nodes, energy optimization is an important issue in MANETs. Typical techniques for energy optimization in MANETs include the following:

3.2.1. Cross-Layer Optimization

Cross-layer optimization is a technique for maximizing energy consumption in MANETs. Multiple network protocol stack tiers work together to optimize energy consumption. Through improved coordination and communication between layers, this approach increases energy efficiency and optimizes network resources.

Adaptive Modulation and Coding (AMC) increases energy efficiency by adapting modulation and coding schemes according to channel quality in response to changing channel conditions. Cross-layer power control enhances MAC and physical layer coordination by reducing transmission power when not needed. Cross-layer scheduling synchronizes data transmission scheduling with network layer routing decisions to minimize idle nodes and packet delays.

Further optimization of multiple layers (physical, MAC, and routing layers) is also possible by considering the properties of each layer. This allows for increased energy efficiency. Cross-layer optimization that considers quality-of-service considers the requirements of different network applications when allocating resources, prioritizing traffic, and optimizing energy consumption. All things considered, cross-layer optimization is a practical technique for MANET energy optimization. Enhancing coordination and communication among the different layers of the protocol stack prolongs the network's life and boosts its efficiency.

3.2.2. Energy-Aware Data Aggregation

Energy-aware data aggregation is one technique for MANET energy optimization. It entails gathering data at intermediate nodes before forwarding it to the destination node, extending the network lifetime, and reducing energy consumption during data transmission. Applications for this technique include location-based data aggregation, load-balancing data aggregation, hybrid data aggregation, energy-aware routing with data aggregation, and threshold-based data aggregation.

Data aggregation-based energy-conscious routing minimizes the number of hops and avoids nodes that consume a lot of energy. Hybrid data aggregation optimizes energy consumption by merging these techniques, allowing nodes to tailor their data aggregation to the characteristics of the network. Load-balancing data aggregation reduces energy consumption during data transmission and avoids network congestion by distributing the load uniformly throughout the network. Location-based data aggregation minimizes unnecessary data aggregation over long distances by only aggregating data when nodes are physically close to one another.

Threshold-based data aggregation aggregates data only if the quantity received exceeds a predefined threshold, preventing unnecessary data aggregation and consuming less energy during data transmission. All things considered, energy-aware data aggregation is a helpful technique for optimizing MANET energy, leading to increased network performance and lifetime.

3.2.3. Energy-Efficient Data Dissemination

Because MANETs self-organize and their network topology changes quickly, efficient data dissemination is essential for energy optimization. Cluster-based routing, cross-layer design, geographic routing, and power-aware routing are some methods for disseminating data in an energy-efficient manner.

By dividing the network into clusters and choosing a cluster head for each cluster, cluster-based routing optimizes network traffic and reduces redundant packet transmission, hence saving energy. By considering physical layer parameters, MAC layer protocols, and network-layer routing protocols, cross-layer design maximizes communication between various network layers. By using node coordinates to forward packets, geographic routing prevents flooding and uses less energy. To prevent premature node failure and lower energy consumption, power-aware routing takes node residual energy levels into account when choosing a data transmission path.

Finally, the choice of protocol relies on network topology, node mobility, and energy constraints. Energy-efficient data dissemination is crucial for energy optimization in MANETs.

3.2.4. Energy-Efficient Localization

A key component of MANETs is localization, which allows nodes to pinpoint their location without the aid of outside infrastructure. Applications in MANETs that require routing, tracking, and monitoring depend on it. However, localization can require a large amount of energy and resources. Thus, energy optimization requires the use of energy-efficient localization techniques.

By minimizing the use of GPS or other location-based services, cooperative localization minimizes energy consumption by allowing multiple nodes to work together to estimate each other's locations. By utilizing data shared among nearby nodes, distributed localization reduces the need for GPS and other location-based services to determine the location. By allocating more tasks to nodes with higher energy levels, energy-aware localization minimizes workload and hence cuts down on energy consumption. By doing away with the need for pricey range measurement equipment, range-free localization minimizes energy consumption by estimating node locations without measuring distance.

To sum up, energy-efficient localization is crucial for energy optimization in MANETs, and the network topology, node mobility, and node energy constraints all influence which technique is best.

3.2.5. Power-Aware Routing

By choosing the optimal path based on factors like node residual energy, transmission power needed to forward packets, and destination distance, power-aware routing helps MANETs use less energy. This method increases the lifetime of the network and balances node energy consumption.

Adaptive Power-aware Routing Protocol (APRP), Energy-Aware Routing Protocol (EARP), Location-based Energy-aware Routing Protocol (LEAP), and Minimum Energy Routing (MER) are a few methods for power-aware routing in MANETs. To balance energy consumption among nodes, APRP modifies the transmission power of nodes based on residual energy and distance to the destination. Intending to save energy for nodes with lower energy levels, EARP chooses the path that uses the least amount of energy based on residual energy and the distance to the destination. To minimize energy consumption and enhance network performance, LEAP makes use of node location data to estimate the energy consumption of possible routes to the destination.

In conclusion, network topology, node mobility, and energy constraints all influence the choice of power-aware routing, an efficient method for energy optimization in MANETs. Through the appropriate selection of power-aware routing techniques, MANETs can maximize both their lifetime and energy consumption.

3.3. Packet Delivery Ratio Optimization Approaches

A critical performance factor in MANETs that influences QoS and network dependability is the packet delivery ratio or PDR. Having a high PDR guarantees that data will reach its intended audience. Node mobility, link quality, interference, network congestion, and routing protocol efficiency are some of the factors that affect PDR. Depending on the specifications of the application and the properties of the network, several methods are available for PDR optimization. In MANETs, the following are some typical techniques for optimizing packet delivery ratio:

3.3.1. Fuzzy Logic Approaches

MANETs can maximize the packet delivery ratio by implementing Forward Error Correction (FEC). To recover lost or corrupted packets at the recipient without retransmission, FEC adds redundant data to packets. This can lower the amount of lost or corrupted packets, which will increase the packet delivery ratio.

FEC can be applied in a variety of ways to optimize the packet delivery ratio in MANETs. By adding redundant data to each packet, packet-level FEC lowers the amount of lost or corrupted packets. Block-level FEC helps to improve the ratio by appending redundant data to a block of packets, particularly when there are multiple packet losses. With fountain coding, a limited number of source packets can produce an endless stream of packets, offering an infinite quantity of redundant packets for recovery. Hybrid FEC provides an infinite stream of redundant packets in addition to packet-level redundancy by combining several FEC techniques, such as fountain coding and packet-level FEC.

In conclusion, by appending redundant data to packets, FEC is a useful technique for maximizing the packet delivery ratio in MANETs.

3.3.2. Geographic Routing

In MANETs, geographic routing is a method that maximizes the packet delivery ratio. It entails cutting down on hop counts, decreasing the effect of link failures, and forwarding packets based on node location data.

Energy-efficient routing, GPS-free routing, greedy forwarding, hybrid routing, and perimeter forwarding are some of the methods for maximizing the packet delivery ratio. Enhancing the packet delivery ratio, extending network lifetime, and considering node energy consumption during packet forwarding are all goals of energy-efficient routing. GPS-free routing is useful in situations where GPS signals are erratic or unavailable because it uses connectivity information to determine the next hop. Greedy forwarding lowers the number of hops needed to reach the destination by forwarding packets to the closest neighbour. When geographic routing is insufficient, hybrid routing a combination of geographic routing and other routing techniques can increase the packet delivery ratio. By sending packets around barriers, such as local minima, perimeter forwarding helps to minimize packet loss.

All things considered, geographic routing is an effective technique for maximizing packet delivery in MANETs.

3.3.3. Link Quality-Based Routing

To maximize the packet delivery ratio in MANETs, a variety of link quality-based routing techniques are available. The energy levels of nodes in a network control the selection of paths and, consequently, the link quality metric.

Energy-based routing makes sure the network stays up and running. Link stability-based routing prioritizes link stability, which denotes a decreased probability of failure or disconnect. Mobility-based routing avoids frequent disconnections by choosing routes with reliable nodes. Routing based on packet delivery ratio chooses the paths with the highest ratio, which denotes dependable and steady links. Signal strength-based routing identifies the most dependable links by concentrating on the signal strength between two nodes. These techniques support preserving the stability and dependability of the network.

To further optimize the packet delivery ratio in MANETs, link quality-based routing techniques can be combined with other strategies like geographic routing or fuzzy logic-based routing. Depending on the particulars of the MANET, including its topology, traffic patterns, and resource availability, the chosen approach will vary.

3.3.4. Reliable Transmission

In MANETs, reliable transmission is a technique that helps to maximize the packet delivery ratio by making sure every packet gets sent and received at its intended location. Congestion control, forward error correction, quality of service, error detection and correction, and retransmission are important mechanisms.

To avoid congestion and guarantee effective transmission, congestion control manages the packet flow within the network. Errors in transmitted data are found and fixed by error detection and correction codes, such as CRC. To reconstruct lost or corrupted packets without retransmission, forward error correction adds redundant information to the transmitted data. To reduce latency and packet loss, quality of service gives priority to some types of traffic over others, such as multimedia traffic that occurs in real-time. Replacing lost or corrupted packets during transmission is known as retransmission. Retransmitting lost or corrupted packets is possible with the use of Automatic Repeat Request (ARQ) techniques. To further optimize the packet delivery ratio in MANETs, reliable transmission techniques can be combined with other strategies, such as fuzzy logic-based routing or link quality-based routing.

3.3.5. Trust-Based Routing Protocols

Trust-based routing protocols are a class of routing techniques that choose the most dependable and trustworthy nodes for packet forwarding based on trust metrics. Using these protocols in MANETs can help to maximize the packet delivery ratio.

It is possible to modify nodes' trust values according to their network behaviour by using dynamic trust management techniques. Only the most reliable nodes are chosen for packet forwarding because unreliable nodes are punished, and reliable nodes are rewarded. Malicious nodes cannot disrupt the network by using secure routing techniques like cryptographic authentication and key management. To determine the most dependable paths for packet forwarding, one can employ trust-based multipath routing, which employs multiple paths to forward packets to the destination node. Reputation, history, and recommendation are examples of trust-based routing metrics that assess nodes' reliability and choose the ones with the highest trust values for packet forwarding.

In conclusion, trust-based routing protocols have the potential to greatly increase the network's efficiency and dependability in MANETs.

3.4. End-to-End Delay Optimization Approaches

In MANETs, end-to-end latency is an essential performance metric that affects user experience and quality of service. Reduced throughput, higher packet loss, and worse application performance can all result from excessive delay. The length of the route, congestion, packet size, and efficiency of the routing protocol are the factors that determine the end-to-end delay. Application requirements and network characteristics determine the selected approach. The following are a few typical methods for end-to-end delay optimization in MANETs.

3.4.1. Congestion Control

To optimize MANETs and avoid network congestion, which can result in lower performance, higher packet loss, and higher latency, congestion control is an essential technique. To guarantee the effective and equitable use of the resources at hand, it attempts to control traffic flow.

To control traffic flow and avoid congestion, several network protocol stack layers work together in cross-layer congestion control. It is possible to modify sending rates because the routing layer informs the transport layer about congestion levels and available bandwidth. Using a unique flag to indicate network congestion is another method known as Explicit Congestion Notification (ECN). The sender can lower the sending rate to avoid congestion when it receives a packet with the ECN flag. Queue-based congestion control modifies the sending rate in response to queue size, monitoring the size of the network queue. To avoid overloading and congestion, rate-based congestion control adjusts data transfer rates based on network conditions. To minimize the number of packets that must wait for an acknowledgement, window-based congestion control modifies the sender's window size in response to feedback from the network or receiver. When the sender detects congestion, it can avoid overloading the network and prevent congestion by reducing the window size.

To sum up, congestion control is an essential method for MANET optimization that guarantees equitable and effective use of the available resources.

3.4.2. Load Balancing

To maximize network performance, end-to-end optimization in MANETs focuses on optimizing elements like load distribution, data transfer, and routing. One way to accomplish this is by using load-balancing techniques.

Adapting load distribution choices in response to shifting network circumstances, such as node mobility, availability, and topology changes, is known as adaptive load balancing. A centralized entity controls network traffic and routes it to the right nodes in a centralized load-balancing system. Given that MANETs function in a decentralized manner, this method might not be appropriate. By dividing up load-balancing decisions among several nodes, distributed load balancing enables each node to keep an eye on loads of both its own and its neighbours' nodes and adjust its strategy as necessary. Because it is decentralized and does not rely on a single point of failure, this method is better suited for MANETs. QoS-based load balancing prioritizes traffic according to variables such as latency, jitter, and throughput. It takes QoS requirements into account when making load-balancing decisions.

In conclusion, load balancing is essential for MANETs, and because distributed and adaptive load-balancing techniques are more flexible and decentralized, they work better in changing network environments. Optimizing the network for application requirements is another use for QoS-based load balancing.

3.4.3. Localized Route Repair

In MANETs, localized route repair is a decentralized method for mending broken routes without the need for a centralized organization like a network controller. Through the ability to quickly recover from routing failures and maintain effective data transfer, this technique enhances end-to-end optimization.

It is possible to minimize control overhead and improve route repair delay by using localized flooding to quickly spread information about link or node failures. Notifying impacted nodes of a link failure via neighbour notification can also lower control overhead and increase network scalability. Route caching enables the fast repair of interrupted routes in the event of a link failure by storing previously found routes to a destination node.

In addition to being more scalable and efficient than centralized route repair techniques, localized route repair can adapt to changes in network topology and traffic patterns and reduce packet loss and latency caused by routing failures. These benefits make localized route repair an excellent choice for end-to-end optimization in MANETs. This guarantees that the network is always configured to maximize the available resources.

3.4.4. Multi-Channel and Multi-Interface Approaches

Techniques for maximizing the performance of MANETs include multi-channel and multi-interface approaches. These techniques improve data transfer reliability, decrease interference, and expand network capacity.

Using multiple channels for data transfer, channel hopping entails nodes periodically switching between channels to prevent interference. Using intelligent radios, cognitive radio dynamically detects available channels and chooses the optimal channel for data transfer. This maximizes resource usage by adjusting to shifting network conditions. Hybrid approaches offer a flexible and adaptable solution by combining several techniques to optimize network performance. Using multiple paths for data transfer, multi-path routing chooses them based on reliability, latency, and bandwidth measurements. This lowers the chance of a network failure and improves data transfer reliability. Nodes with multiple radio interfaces can send and receive data simultaneously on various channels thanks to multi-radio interfaces. Through capacity expansion, interference reduction, and interference reduction, these methods can enhance network performance. In conclusion, multi-channel and multi-interface techniques are useful for improving network capacity, decreasing interference, and improving data transfer reliability in MANETs, as well as for end-to-end optimization.

3.4.5. Quality-of-Service Routing

A key technique in MANETs to guarantee the network satisfies the QoS requirements of the applications operating on it is quality-of-service routing. It entails deciding which data transfer path is optimal given the application's QoS requirements and the network resources at hand. There are several applications for QoS routing, including multi-objective optimization, energy-efficient routing, bandwidth-aware routing, delay-sensitive routing, and reliability-aware routing.

By choosing the data transfer path with the maximum available bandwidth, bandwidth-aware routing makes sure the application has enough bandwidth to meet its needs. To guarantee that the application's delay requirements are satisfied, delay-sensitive routing chooses the path with the lowest end-to-end delay. Energy-efficient routing preserves battery life, satisfies QoS requirements, and reduces network energy consumption over time. By simultaneously optimizing several goals, multi-objective optimization improves network performance overall and empowers nodes to choose the best data transfer path. Reliability-aware routing chooses the data transfer path with the best reliability, guaranteeing error-free data delivery to the application.

To sum up, QoS routing ensures that the network satisfies the QoS requirements of the applications that operate on it. It is a useful technique for end-to-end optimization in MANETs.

3.5. Security Optimization Approaches

In MANETs, security is a crucial performance factor that influences the dependability and efficiency of the network. Preventing denial-of-service attacks, illegal access, and data manipulation is crucial. Measures such as Packet Delivery Ratio (PDR), overhead, energy consumption, and end-to-end delay can be used to assess security. Low latency denotes effective data transfer, while high PDR denotes secure operations. Increased overhead may result from the extra data that security measures introduce. High energy usage can lead to node power outages, which lowers network dependability. To determine the efficacy of security mechanisms and implement the necessary changes to enhance network security, it is imperative to evaluate security as a performance parameter. For an evaluation to be impartial and accurate, network security performance must be the primary focus of the evaluation. Here are some of the different security optimization approaches in MANET:

3.5.1. Anomaly Detection

MANETs, which are dynamic networks with frequent node changes and are therefore susceptible to attacks and security threats, use anomaly detection as a technique for security optimization. By spotting unusual or suspicious network behaviour, it aids in the detection and prevention of security breaches.

Machine learning, rule-based, signature-based, and statistical analysis are methods for detecting anomalies in MANETs. While rule-based detection makes use of predefined rules based on known attack scenarios, machine learning uses historical data to train models to identify abnormal behaviour. By comparing node behaviour with known attack signatures, signature-based detection flags suspicious behaviour when it does. Finally, statistical analysis examines network behaviour using metrics like variance, mean, and standard deviation and marks unusual behaviour as suspicious. Overall, anomaly detection optimizes security in MANETs by detecting abnormal or suspicious behaviour, preventing attacks, and reducing the risk of security breaches.

3.5.2. Authentication

Authentication is necessary in MANETs to guarantee security because it confirms nodes' identities and stops illegal access to network resources. There are many ways to implement authentication, such as public-key cryptography, password-based, biometric, and certificate-based methods. Biometric features, which can be stored on safe gadgets like smart cards or mobile phones, are used in biometric authentication to verify nodes. These features include fingerprints, facial recognition, and voice recognition.

Using digital certificates from reputable authorities, nodes can authenticate one another using certificate-based authentication. For nodes to access network resources through password-based authentication, they must input a password or shared secret, which can be shared via physical exchange or secure channels like encryption. Public-key cryptography verifies network nodes using two keys: a public key and a private key. Every node has its pair of public and private keys. To authenticate itself to another node, a node encrypts a message using the public key of that node, which can only be unlocked with the matching private key. All things considered, authentication helps maximize security in MANETs by confirming nodes' identities and thwarting illegal access to network resources.

3.5.3. Cryptography-Based Approaches

Techniques based on cryptography are essential for optimizing security in MANETs. These techniques convert data into a format that is only accessible to authorized parties by using mathematical algorithms. They guarantee the authenticity of messages in MANETs by offering data confidentiality, integrity, and authentication.

Message authenticity is confirmed via digital signatures that are created with the sender's private key. Data integrity is maintained by hash functions, which convert data into a fixed-size output and check that the data hasn't been altered in transit. Key public to encrypt and decrypt data, cryptography uses a pair of keys: a public key and a private key. Every node shares a distinct pair of public and private keys with other nodes. Data is encrypted and decrypted using a shared secret key in symmetric key cryptography. Secure channels, such as physical exchange or encryption, are used to transfer data between communicating nodes. Overall, by ensuring data confidentiality, integrity, and authentication, cryptography-based techniques can maximize security in MANETs.

3.5.4. Intrusion Detection and Prevention Approaches

The use of Intrusion Detection and Prevention (IDP) techniques is essential for improving MANET security. These strategies can be either proactive or reactive, with the former emphasizing the prevention of attacks before their occurrence.

Conversely, reactive IDP uses network traffic analysis and malicious activity identification to find and stop ongoing attacks.

Anomaly-based IDP, which examines network traffic and spots anomalies in node behaviour, is one IDP technique for security optimization in MANETs. It can detect assaults like insider threats, zero-day attacks, and novel iterations of pre-existing attacks. To enhance security performance and lower false positives and false negatives, hybrid IDP combines signature-based and anomaly-based techniques. Reputation-based IDP stops attacks such as black hole and grey hole attacks by giving nodes trust scores based on their prior network behaviour. Using a database of recognized attack signatures, signature-based intrusion detection protects against threats such as viruses, worms, and denial-of-service attacks.

In conclusion, IDP techniques can enhance network security in MANETs by identifying and stopping malicious activity that jeopardizes network resource availability, confidentiality, and integrity. The needs and limitations of the MANET, such as network topology, size, and traffic patterns, determine which IDP technique is best.

3.5.5. Reputation-Based Systems

Reputation-based systems are an essential technique for MANET security optimization. By using historical node behaviour to gauge a node's trustworthiness, these systems improve network security by identifying and isolating malicious nodes and thwarting attacks. Collaborative filtering, which assesses a node's reputation based on the opinions of other nodes, is a feature of some of these systems that can help stop attacks like routing and packet dropping.

As an additional reputation-based system, distributed Bayesian reputation evaluates a node's reputation based on its historical behaviour by utilizing Bayesian statistics. In addition to preventing attacks like black holes and selective forwarding, this can assist in identifying malicious nodes. Eigen Trust is an additional reputation-based system that assesses a node's reputation based on its interactions with other nodes using a global trust metric. This can assist in locating malicious nodes and thwarting assaults such as Sybil attacks. Peer Trust is an additional reputation-based system that assesses a node's reputation using direct feedback from its neighbours. This technique can assist in locating malicious nodes and stop assaults such as routing attacks.

The selection of a reputation-based system is contingent upon the needs of the MANET, including traffic patterns, network topology, and size. One way to maximize security in MANETs and guarantee the network's ongoing security and dependability is to combine reputation-based systems with other security measures like cryptography and intrusion detection.

4. Selection of Optimization Approach

4.1. Neighbour-Based Probabilistic Rebroadcast (NCPR) Approach

The Neighbour-Based Probabilistic Rebroadcast technique was intentionally chosen for its distinct qualities and benefits that coincide with specific network needs. It employs a combination of Neighbour coverage-based and broadcasting optimization methods [61].

One important component of the NCPR strategy is its reliance on information on neighbour coverage. The technique disseminates knowledge throughout the network by using information about surrounding nodes' coverage. This distribution is especially beneficial since it may be used in different ways, establishing a collaborative and synergistic atmosphere inside the network.

The NCPR technique integrates Rebroadcast Delay and Rebroadcast Probability, which adds intricacy to packet transmission management. This strategic use of retransmission delay and computed probability allows the strategy to prevent duplicate retransmission of control packets, maximizing network resource use. The introduction of Rebroadcast Delay allows for a more regulated and efficient retransmission procedure, whilst the computed probability adds a probabilistic aspect to guarantee prudent packet redistribution.

However, the NCPR technique necessitates node-level processing because of its dependence on neighbour coverage information and the use of Rebroadcast Delay and Rebroadcast Probability. This indicates that each node in the network must do processing activities to carry out these characteristics, resulting in a more localized and dispersed decision-making process.

One advantage of the NCPR technique is its appropriateness for bandwidth-sensitive applications. NCPR is especially useful in circumstances where bandwidth saving is crucial, as it reduces unnecessary retransmissions and optimizes control packet dispersal depending on neighbour coverage. This makes these techniques ideal for applications and situations where effective bandwidth usage is critical to reaching peak network performance.

In conclusion, the Neighbour-Based Probabilistic Rebroadcast approach was chosen for its emphasis on leveraging neighbour coverage knowledge, strategic use of Rebroadcast Delay and Rebroadcast Probability to avoid redundancy, node-level processing capabilities, and applicability to bandwidth-sensitive applications. These traits combine to establish NCPR as a beneficial optimization strategy for solving specific network requirements while also adding to the network's overall efficiency and performance.

4.2. Adaptive Hello (AH) Messaging Approach

The Adaptive HELLO message technique stands out as a strategic and well-supported solution for network optimization, particularly in situations where energy conservation is crucial. Unlike standard periodic HELLO message exchange techniques, AH implements a dynamic modification in the periodicity of HELLO messages based on the predicted activity of the node and the network [62]. It is like the duty cycling methods mentioned in energy optimization approaches. This adaptive feature is critical for tailoring communication frequency to the actual needs of the network environment.

By decreasing the frequency of control packet exchanges, AH effectively reduces the routing overhead associated with HELLO messages. This optimization aims to improve the network's overall efficiency by preserving important resources. The reduced requirement for exchanges not only reduces routing costs but also shortens node activity time. This reduction in activity time is an important aspect of the energy optimization of individual nodes in the network.

Energy optimization at the node level is very important since it has a direct influence on the network's total lifespan. By saving energy resources, AH increases the lifetime of individual nodes, hence contributing to the overall network infrastructure's sustainability and resilience. This is especially important in cases when energy-sensitive applications are deployed, and battery power is constrained.

In practice, the Adaptive HELLO technique becomes the favoured option for situations where power conservation is critical. For example, in wireless sensor networks or Internet of Things (IoT) deployments, where devices are frequently battery-powered and might be placed in remote or inaccessible areas, the ability to adaptively regulate HELLO message exchanges ensures that energy is spent wisely. This flexibility is consistent with the unique requirements of energy-sensitive applications, making AH an appropriate and justifiable optimization strategy for scenarios where effective power management and conservation are critical. As a result, the Adaptive HELLO messaging technique tackles not only the immediate need to lower routing overhead but also the larger issues of energy management and network sustainability.

4.3. Trust-Based Secure and QoS Routing Scheme (TSQRS) Approach

The Trust-Based Secure and QoS Routing Scheme was chosen as an optimization strategy because it focuses on improving network security and quality of service. It [63] utilizes trust-based and fuzzy logic methods. The trust-based method used by TSQRS is particularly intriguing since it incorporates a full and multidimensional examination of trust characteristics. Trust is calculated using characteristics such as faithfulness, connection quality, residual energy, and closeness degree. This multifaceted trust calculation allows for a more sophisticated assessment of network node dependability and trustworthiness.

The use of welcome messages to exchange trust information between neighbouring nodes is an important aspect of TSQRS. The network keeps track of the trustworthiness of its nodes in real-time thanks to frequent updates of trust information. This dynamic and adaptive trust management technique enables TSQRS to respond efficiently to changes in the network environment, ensuring that trust evaluations stay reliable over time.

One significant advantage of TSQRS is its ability to avoid untrustworthy nodes, resulting in a more secure communication environment. By selectively routing data through nodes with proven trust, TSQRS reduces the danger of data breach or manipulation by malevolent actors.

This emphasis on security is especially important in situations where data confidentiality and integrity are critical, making TSQRS ideal for applications with bandwidth and data security requirements.

Furthermore, the TSQRS technique goes beyond security by helping to prioritize data lines. This capability is useful for applications that require differentiated services based on parameters like bandwidth or data sensitivity. TSQRS may improve data routing to favor safe and reliable pathways, hence improving the overall quality of service for network users.

In summary, the Trust-Based Secure and QoS Routing Scheme was chosen because of its complete trust-based methodology, dynamic trust management via welcome messages, and subsequent increase in network security and QoS. The ability to avoid untrustworthy nodes, together with the ability to prioritize data lines, distinguishes TSQRS as a strategic choice for applications that require both secure communication and high service quality.

4.4. Cross-Layer (CL) Approach

The Cross-Layer technique stands out as a strategic alternative for network optimization, especially in cases where signal quality is prioritized above the standard minimal hop count criterion for selecting data lines. By emphasizing signal strength, the CL method recognizes that a stronger signal frequently translates into a more dependable and efficient communication channel. This deviation from the usual hop count statistic enables a more nuanced selection of data connections that meet the network's unique quality of service needs. It is a mix of cross-layer, QoS-based traffic engineering techniques [64].

One of the CL approach's distinguishing qualities is its capacity to pick more than one data channel for communication based on signal strength, which encourages the use of multipath routing. This multipath routing approach improves network fault tolerance and dependability by using many pathways for data transfer. While multipath capability adds complexity to the routing process, the potential benefits of higher QoS and data connection priority make it a worthwhile trade-off.

The CL approach's major goal is to increase QoS, highlighting its potential for applications that require real-time performance and are intolerant of delays. In circumstances requiring minimal end-to-end latency, the CL method shines by optimizing data connection selection depending on signal strength. This prioritization not only allows for speedier data transfer but also assures that the network can fulfil the rigorous timing requirements of time-critical applications.

Furthermore, the CL method is useful in situations where priority of data channels is required. By using signal strength as a major criterion, the strategy coincides with optimizing network resources for greater overall performance. This prioritizing is especially important in cases where specific data lines are allocated for vital or high-priority communication, resulting in a more efficient and responsive network.

In conclusion, the Cross-Layer strategy was chosen because it diverged from typical hop count metrics, emphasis on signal strength for data connection selection, and ability to accommodate multipath routing. These qualities address the unique demands of applications that require improved QoS, data link priority, and low end-to-end delay, making the CL method an effective optimization technique in a variety of network situations.

4.5. Security Enhancement Approach (SE) Using a Trust-Based Approach

The Security Enhancement strategy, which employs trust-based methodologies, is an intelligent choice for networks in which security is a crucial qualitative performance criterion. SE's trust-based strategy improves network dependability and security. In this context, trust is formed and maintained by evaluating the Packet Delivery Ratio (PDR), a statistic that measures the success of packet delivery in the network. By allocating weightage to nodes based on their PDR, the SE method assures that nodes with a history of regularly delivering packets are considered more trustworthy [65].

One major element of the SE method is the ability to ban nodes based on repeat offender criteria. This technology improves the network's capacity to detect and isolate rogue nodes, helping to prevent black holes, grey holes, and Denial-of-Service (DoS) assaults. By proactively identifying and eliminating nodes with a compromised PDR, the SE method dramatically increases the network's resistance to possible security attacks. Furthermore, the SE technique is especially useful in data-sensitive applications where the secrecy, integrity, and dependability of sent information are critical. SE's trust-based solutions fit with the necessity for strong security measures in circumstances where sensitive data is transmitted. The method improves not just the network's security posture but also the general trustworthiness of the communication infrastructure.

In conclusion, the Security Enhancement strategy using Packet Delivery Ratio and the option to blacklist nodes based on their previous behaviour is deliberately chosen for its ability to strengthen network security. Its use is well-suited for environments with data-sensitive applications, where preventing various forms of attacks is critical for ensuring the integrity and confidentiality of transmitted data.

5. Results

5.1. Simulation Parameters

The study focuses on assessing protocol performance in terms of energy, end-to-end latency, packet delivery ratio, and overhead. The study does not address security since it is a qualitative criterion that calls for additional research. To take into consideration its impact on other factors, an optimization technique is added.

The number of nodes in the first network scenario ranges from 20 to 100, while all other parameters stay the same. Similar loads and environmental conditions will be used to test the procedures; each run will need scenario files that precisely detail the movements of every node. A direct comparison of performance outcomes is possible because all procedures have a 500-second time interval.

This is followed by comparing the performance of each approach with the AODV routing protocol to assess its relative influence. The LINUX operating system's Network Simulator 2 (NS 2.35), along with the Tool Command Language (TCL) to implement routing protocols, will be used for the simulations. Using the AWK tool, performance indicators will be extracted from trace files and displayed in Microsoft Excel 2019.

The simulation parameters for the study are as follows: There were five different values for the number of nodes: 20, 40, 60, 80, and 100. The simulation lasted 500 seconds, during which time each node travelled at a steady pace of 10 meters per second within a topology measuring 1200 by 1200 meters. There were 25 Source-Destination (S-D) pairs. Constant Bit Rate (CBR), with a bandwidth of 0.4 Mbps and a packet size of 512 bytes, was the applied traffic.

The Random Waypoint mobility model and the TwoRay Ground propagation model were both put into practice. The configuration of the queue files was Queue/Drop Tail/Prique, with a queue length of 50. The channel type was wireless. IEEE 802.11 was the foundation for the MAC layer, and an Omni Antenna was employed for the antenna type.

5.2. Results

5.2.1. Routing Overhead

The Neighbour Coverage-based Probabilistic Rebroadcast (NCPR) optimization technique provides many routing efficiency benefits. First, it significantly reduces routing overhead, resulting in a more streamlined and resource-efficient network. This is especially important in improving the overall performance and responsiveness of the communication infrastructure.

Second, the NCPR technique shows increased bandwidth usage, which leads to higher data rates. The optimization not only reduces the routing burden but also increases the network's data-carrying capacity, resulting in a more stable and fast communication environment.

In contrast, the Adaptable Hello (AH) optimization strategy focuses on reducing routing overhead caused by Hello messages or control packets. By carefully lowering the frequency and effect of these control packets, AH optimization reduces wasteful network signals while increasing overall efficiency. This focused optimization guarantees that network resources are utilised more efficiently, resulting in increased dependability and responsiveness.

The Trust-based Secure and QoS Routing Scheme (TSQRS) optimization technique makes a complex trade-off. While the distribution of trust-based data via welcome messages improves network security and dependability, it also results in a minor increase in routing cost due to the additional control packets required. This technique highlights the relevance of security issues while balancing them against the necessity for fast routing in a dynamic network environment.

In the context of the Cross-Layer (CL) optimization technique, which includes multipath routing, the trade-off is visible in the increased routing overhead. The frequent requirement to pick different pathways adds greatly to the routing overhead. Although multipath routing improves dependability and fault tolerance, it comes at the price of more control packet broadcasts, emphasising the importance of smart network prioritisation.

Finally, the Security Enhancement (SE) optimization strategy prioritises the removal of harmful nodes to improve network security. This systematic elimination of possible threats prevents wasteful rebroadcasting of control messages, lowering routing overhead. SE optimization aims to improve network security and efficiency by removing the disruptive effect of hostile entities.

In summary, each optimization technique offers a distinct set of benefits and trade-offs, stressing the necessity of picking the best strategy based on the network's requirements and goals.

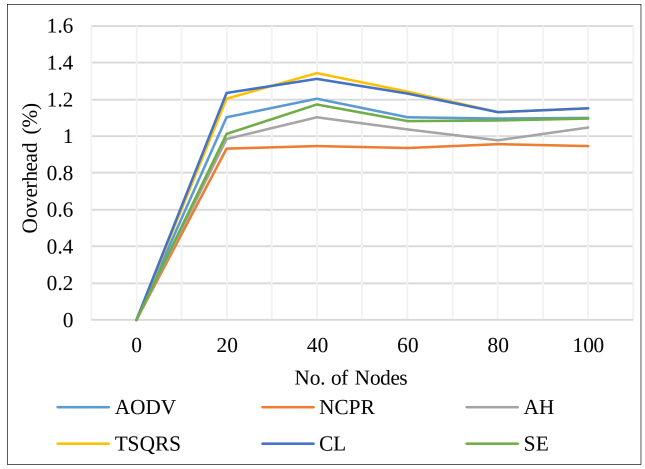

Fig. 1 Routing overhead comparison with varying number of nodes

5.2.2. Energy Consumption

The Neighbour Coverage-based Probabilistic Rebroadcast (NCPR) optimization strategy, although improving routing efficiency, increases node energy consumption. This increased energy demand is due to the increased processing needs associated with the adoption of NCPR. Unfortunately, this increase in energy demand reduces the network's overall lifetime. The NCPR optimization strategy, while beneficial in certain ways, presents issues in sustaining a sustainable and energy-efficient network environment, necessitating rigorous trade-off analysis.

In contrast, the Adaptive Hello (AH) optimization method turns out to be more energy-efficient. The reduced energy usage is a direct outcome of AH's optimised control packet transfers. This strategy not only reduces superfluous signals but also increases the network's total longevity. The AH optimization finds a compromise between energy efficiency and network lifetime, making it an attractive option for contexts where resource preservation is a top priority.

The Trust Based Secure and QoS Routing Scheme (TSQRS) optimization strategy adds functionality to improve security and quality of service but at the expense of slightly increased energy usage. The use of trust-based procedures needs more processing, which contributes to a small increase in energy consumption. Despite this, the TSQRS method provides improved security features while balancing more functionality and energy economy.

In the Cross-Layer (CL) optimization strategy, including more nodes in the data delivery process results in a large increase in energy usage. While CL optimization improves reliability and fault tolerance, it also increases energy demand owing to the involvement of more nodes. This underscores the importance of carefully weighing energy factors when pursuing CL optimization, particularly in circumstances where energy efficiency is crucial.

In contrast, the Security Enhanced (SE) optimization technique does not optimise energy. Despite its emphasis on network security by removing rogue nodes, the SE technique does not reduce energy usage. This emphasises the necessity of considering both security and energy efficiency needs when selecting optimization methodologies since the SE strategy may be better suited for scenarios that prioritise security above energy conservation. Finally, network designers must carefully consider the energy implications of each optimization strategy with their network requirements to achieve an optimal balance of performance and resource sustainability.

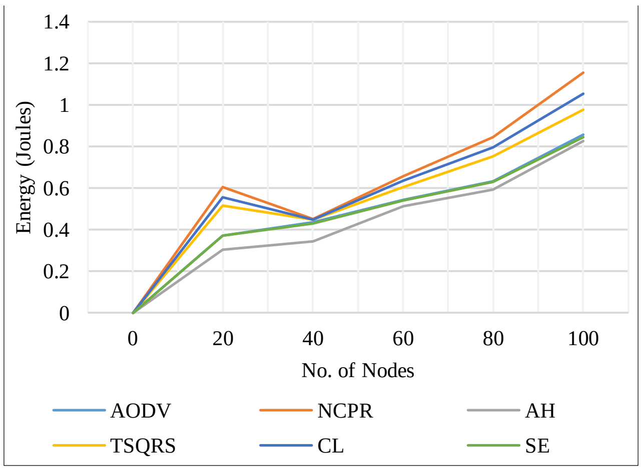

Fig. 2 Energy consumption comparison with varying numbers of nodes

5.2.3. Packet Delivery Ratio

The Neighbour Coverage-based Probabilistic Rebroadcast (NCPR) optimization technique is notable for its favourable effect on packet delivery performance. By enhancing bandwidth usage, NCPR optimises network resources, resulting in a greater Packet Delivery Ratio (PDR). This increased efficiency guarantees that a greater proportion of transmitted packets reach their intended destinations, improving the overall dependability of the communication network.

In contrast, the Adaptive Hello (AH) optimization strategy poses a problem linked to the selective availability of connections. The practice of carefully picking accessible links increases the possibility of data transmission across an unavailable link, thereby impacting the Packet Delivery Ratio (PDR). This demonstrates the tight balance between improving network characteristics and the potential negative repercussions for data delivery when utilising the AH technique.

The Trust-Based Secure and QoS Routing Scheme (TSQRS) optimization strategy uses trust-based routing, resulting in a significant increase in data delivery. By reducing the likelihood of data transmission over an expired route, TSQRS improves network dependability. This trust-based mechanism guarantees that data is continually routed via dependable pathways, resulting in a higher Packet Delivery Ratio (PDR) and better overall network performance.

The Cross-Layer (CL) optimization strategy makes use of the availability of numerous pathways for data transmission, resulting in a significant boost in throughput. With more routes at its disposal, CL optimization significantly increases data delivery capacity, resulting in higher throughput.

This technique highlights the need to use cross-layer knowledge to optimise routing decisions, hence increasing network data transmission efficiency. In conclusion, each optimization technique has its own set of benefits and considerations, underlining the necessity of choosing the best strategy based on the network's individual goals and requirements.

In the Security Enhanced (SE) optimization strategy, the eradication of rogue nodes acts as a crucial aspect in improving the Quality of Service (QoS). By eliminating possible risks, SE optimization dramatically enhances the network's integrity and resilience. This leads to a significant boost in QoS, guaranteeing that supplied data meets or exceeds the required level of service.

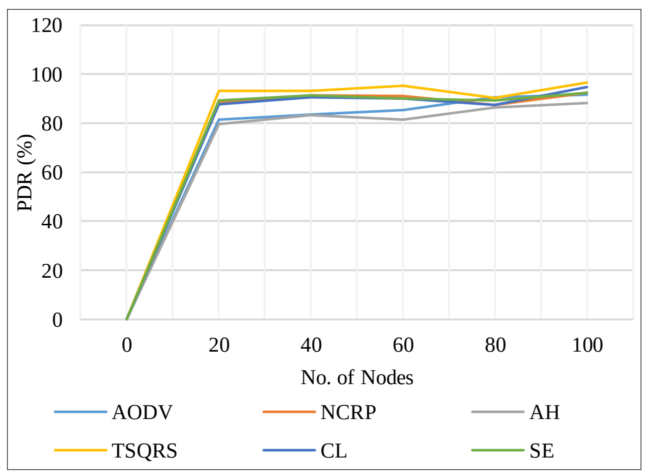

Fig. 3 Packet delivery ratio comparison with varying number of nodes

5.2.4. End-to-End Delay

The Neighbour Coverage-based Probabilistic Rebroadcast (NCPR) optimization strategy has a remarkable property in terms of end-to-end latency, which remains relatively constant. This implies that while the NCPR approach focuses on increasing rebroadcasting efficiency through neighbour coverage and probabilistic processes, it has no substantial influence on the overall time it takes for data to travel throughout the network from source to destination. The constancy in end-to-end latency demonstrates the success of the NCPR strategy in meeting its rebroadcasting goals while maintaining fast data delivery.

The Adaptive Hello (AH) optimization strategy has an undesirable effect on the end-to-end latency, which mirrors the reported impact on the Packet Delivery Ratio (PDR). This means that the AH approach's strategic modifications, which are most likely intended to reduce control packet overhead, come at the expense of increasing data transmission delays. As a result, the trade-off between control packet optimization and end-to-end latency in the AH method emphasises the importance of carefully considering network priorities and trade-offs.

The Trust-Based Safe and QoS Routing Scheme (TSQRS) optimization technique, which focuses on trust-based data dissemination and secure routing, results in no substantial change in end-to-end latency. This implies that while security measures are taken, they are carried out in such a way that data delivery remains efficient. The TSQRS technique finds a balance between network security and timely communication while creating minimal latency.

In contrast, the Cross-Layer (CL) optimization technique, which uses a multipath strategy, greatly lowers the time it takes for data to reach target nodes. The multipath method to CL optimization improves data delivery efficiency by exploiting different channels to reduce latency. This faster data transmission demonstrates the benefits of the CL approach in scenarios where reducing end-to-end delay is an important performance metric despite the complexity of managing multiple paths. The Security Enhanced (SE) optimization strategy is said to have an end-to-end latency comparable to the Ad-hoc On-Demand Distance Vector (AODV) routing protocol. This implies that the security enhancements supplied by the SE technique do not significantly affect the time it takes for data to arrive.

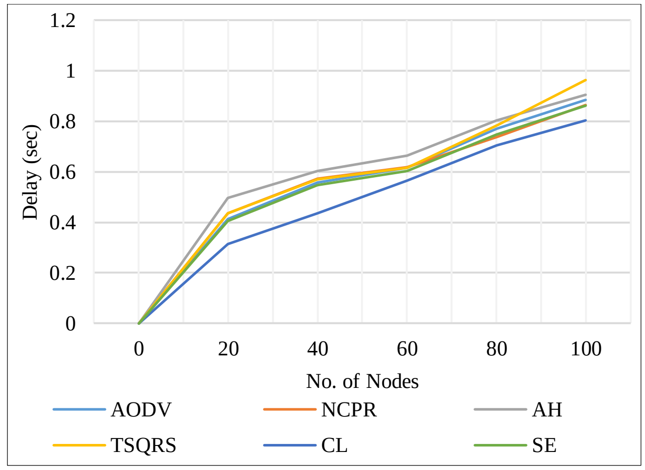

Fig. 4 End-to-end delay comparison with varying number of nodes

6. Result Analysis

Based on the results discussed in the previous section, Table 1 compares five optimization algorithms (NCPR, AH, TSQRS, CL, and SE) with AODV based on four metrics (end-to-end latency, packet delivery ratio, routing overhead, and energy consumption). Additionally, it displays the overall outcome and impact of various methods, with percentages denoting variations from a baseline. While the net impact assesses the overall influence of the techniques on the measures, the net result offers a summary. A net positive impact denotes a favourable influence, whereas a net negative impact denotes an unfavourable outcome.

Table 1. Impact of optimisation approaches on the performance of the network

Optimisation Approach	Routing Overhead	Energy Consumption	Packet Delivery Ratio	End-to-End Delay
NCPR	-15.78%	30.82%	4.20%	-0.44%
AH	-8.03%	-9.06%	-3.19%	7.05%
TSQRS	8.39%	16.10%	8.27%	3.87%
CL	8.16%	22.83%	4.10%	-12.99%
SE	-2.75%	-0.81%	4.61%	-2.41%
Net Result	-10.02%	59.87%	18.00%	-4.91%
Net Impact	Positive (Desired)	Negative (Undesired)	Positive (Desired)	Positive (Desired)

6.1. Observation, Cause and Impact

6.1.1. Routing Overhead

- Observation: NCPR shows a significant reduction in routing overhead (-15.78%).
  Cause: This is expected as the NCPR approach specifically targets to optimize the routing overhead.
  Impact: This suggests an increase in the efficiency of routing procedures.
- Observation: AH also demonstrates a decrease in routing overhead, but to a lesser level (-8.03 per cent).

Cause: The reduction in routing overhead results from the adaptive and controlled dissemination of control packets (Hello messages).
Impact: This indicates a beneficial effect on the network's resource consumption and signalling efficiency.

- Observation: TSQRS and CL show similar and positive percentages (8.39 per cent and 8.16 per cent, respectively), indicating a rise in routing overhead.
Cause: The increase in routing overhead is due to high processing needs.
Impact: This implies that these techniques may impose extra signalling or computational loads on the network.
- Observation: SE optimization decreases routing overhead marginally (-2.75 per cent), which contributes to increased efficiency, but to a smaller extent than NCPR and AH.
Cause: Due to the trust-based strategy in SE and enhanced security, the overall overhead is reduced by eliminating untrustworthy nodes that would otherwise cause issues like denial of service and flooding.
Impact: Slight improvement in routing overhead.

6.1.2. Energy Consumption

- Observation: NCPR causes a large increase in energy consumption (30.82 per cent), suggesting a trade-off between routing efficiency and energy efficiency.
Cause: Higher processing at the node level may contribute to this increase.
Impact: High computational requirements come at the cost of higher energy requirements.
- Observation: AH comes up as an energy-efficient optimization strategy, with a negative percentage (-9.06 per cent), signifying a decrease in energy use.
Cause: This is expected as the AH approach is specifically designed for energy optimization.
Impact: AH is the most effective at reducing needless energy-intensive network processes.
- Observation: TSQRS and CL have positive energy consumption percentages (16.10 per cent and 22.83 per cent, respectively).
Cause: The major cause of energy inefficiencies of these methods is their intensive resource requirements.
Impact: Both techniques are highly energy inefficient.
- Observation: SE optimization results in a minor reduction in energy consumption (-0.81 per cent).
Cause: Due to the inherent architecture of the SE approach, it maintains energy neutrality.
Impact: The SE approach has no substantial energy optimization impact.

6.1.3. Packet Delivery Ratio

- Observation: NCPR and CL have a favourable influence on the packet delivery ratio (4.20 per cent and 4.10 per cent, respectively).
Cause: This is due to robust architecture in terms of throughput by both strategies.
Impact: Better throughput is achieved.
- Observation: AH has an unfavourable impact on the packet delivery ratio (-3.19 %)
Cause: Due to the selective forwarding of control packets, the chances of sending data through an unavailable path increase.
Impact: There is a trade-off between energy efficiency and packet delivery ratio in this approach.
- Observation: TSQRS and SE have the most beneficial influence on the packet delivery ratio (8.27 per cent and 4.61%, respectively).
Cause: These approaches are inherently focused on quality of service, which in turn increases the throughput.
Impact: Increased dependability in packet delivery.

6.1.4. End-to-End Delay

- Observation: AH produces a positive end-to-end delay (7.05 per cent).
Cause: Due to the selective exchange of hello messages, the chances of misdetection of a broken link are higher. This results in increased delays.
Impact: An increase in the time required for data to travel the network.
- Observation: TSQRS had an unfavourable influence on end-to-end delay, and SE had a favourable influence on end-to-end delay (3.87 per cent and -2.41 per cent, respectively).
Cause: Though both approaches prioritise the quality of service, the trust-based approach is more prone to delays as compared to the SE approach.
Impact: TSQRS leads to a longer delay, and SE indicates a decrease, almost negating each other's impact.
- Observation: NCPR and CL have negative percentages of end-to-end latency (-0.44 per cent and -12.99 per cent, respectively).
Cause: NCPR's insignificant impact and CL's significant impact are understandable, as CL is a dedicated approach to improve end-to-end delay.
Impact: NCPR has an insignificant impact on delays, while Cl provides significantly improved data delivery timing.

6.2. Net Result and Net Impact

- A 10.02% decrease in routing overhead indicates increased control message overhead efficiency within the network. This is advantageous because it lessens the additional load on the network, which may result in increased throughput and decreased congestion.
- The notable rise in energy consumption (by 59.87%) suggests that although routing efficiency may have increased, total energy consumption has increased. This might be the result of increased activity or the energy expenditures incurred by applying specific optimization

techniques. Higher energy consumption can result in higher operating costs and shorter battery life for devices with limited energy, so this is an undesirable outcome.

- The network can now successfully deliver packets to their destinations because of the significant improvement in the packet delivery ratio of 18.00%. This enhancement is essential because it directly affects the network's efficacy and dependability, improving user experience and reducing data loss.
- The 4.91% decrease in end-to-end latency indicates that packets are getting to their destination faster. Reduced latency is essential for real-time communication applications like VoIP and streaming. This enhancement suggests that the network is now more responsive, which enhances performance.
- Positive results include a decrease in end-to-end delay, an increase in packet delivery ratio, and a reduction in routing overhead. When taken as a whole, these elements improve user experience, dependability, and network efficiency. On the other hand, the rise in energy usage is a serious worry. Higher energy costs may outweigh some of these benefits, even though other metrics indicate improvement. To achieve a more sustainable network operation, future optimizations should strive to strike a balance between energy efficiency and performance improvements. The results demonstrate the trade-offs and various implications linked to each optimization technique, highlighting the necessity of considering a variety of metrics in a balanced way when deciding which course of action is optimal for a given network scenario.

7. Conclusion

Research has produced a more sophisticated knowledge of network reactions to different routing schemes, shedding light on both strengths and limitations. By investigating trade-offs and inherent flaws, researchers may make more educated judgments regarding their uses. Analysing each approach's effect on routing performance allows researchers to extrapolate its usefulness in improving certain parameters or addressing specific network situations. This complete examination provides insights into the synergies between various techniques, which may lead to the construction of an ideal set of interconnected strategies for an efficient routing protocol while ensuring that no performance criteria are negatively impacted.

Optimization techniques in routing protocols provide adequate performance for specified parameters, matching the demands of critical applications. The integration of various techniques as modules demonstrates a feasible strategy for unique application requirements. For example, in real-time applications that prioritise end-to-end latency, a customised combination of modules can be used, even at the expense of bandwidth. However, depending entirely on a solo strategy fails to provide comprehensive routing performance.

This highlights the rising demand for hybrid routing protocols that smoothly incorporate several components, resulting in an overall improvement in routing performance. The possible trade-offs between these techniques, which reflect the rising complexity of the routing process, necessitate careful selection and integration.While the use of several techniques improves routing performance, it also increases processing demands and energy consumption. As a result, there should be more focus on energy optimization. Furthermore, application flexibility emerges as critical, underlining the importance of flexible techniques in the dynamic world of network routing.

For overall routing performance, various and complete sets of techniques are required, which necessitates the establishment of a central authority to manage these approaches. This central authority is required for system-wide implementation and correlation among approaches. Hello messages, which act as control messages in network nodes, allow a periodic interchange of information while keeping track of the current topology and other relevant parameters. Their periodic nature guarantees stability and flexibility in the network, making them an appropriate correlation factor. This correlation factor allows for the employment of different techniques in a single complete hybrid routing protocol, resulting in application universality.

When it comes to impact analysis, the interoperability of approaches how they complement one another and the level of performance trade-offs is always a priority. Future research should focus on application universality, compatibility, the lack of conflicting techniques, and enhancements over the current system.

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