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PAPER

Analyzing Data Transmission Reliability in Mobile Ad-Hoc Networks under Dynamic Scenarios

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ABSTRACT

Mobile ad hoc networks (MANETs) face inherent challenges in maintaining reliable data transmission because of their dynamic and unpredictable nature. This research conducts a comprehensive reliability analysis of data transmission in MANETs, emphasizing the influence of dynamic conditions such as node mobility, changing network topologies, and fluctuating channel conditions. Through the utilization of mathematical models and simulations, the study assesses the overall reliability of data transmission, considering scenarios with diverse node densities, mobility patterns, and network sizes. Existing routing protocols, error correction mechanisms, and adaptive transmission strategies are examined for their effectiveness in reducing the impact of dynamic conditions on reliability. The research not only examines the current state of protocols but also explores potential enhancements and introduces novel approaches to enhance data transmission reliability under dynamic conditions. The findings offer a nuanced understanding of the challenges and opportunities related to reliable communication in MANETs. This research provides crucial insights for designing resilient communication systems in dynamic and mobile network scenarios, offering valuable guidance to researchers, network designers, and practitioners involved in optimizing the performance of MANETs in real-world applications.

KEYWORDS

mobile ad hoc networks (MANETs), data transmission, network reliability, dynamic conditions, routing protocol, reliable communication

1 INTRODUCTION

Mobile ad-hoc networks (MANETs) represent a dynamic and decentralized form of wireless communication wherein nodes collaborate to form a network without the need for a fixed infrastructure [1]. This distinctive feature makes MANETs well-suited for scenarios where establishing a traditional network infrastructure is impractical or impossible, such as emergency response situations, military operations, and mobile device interactions in dynamic environments.

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The intrinsic nature of MANETs presents numerous challenges to reliable data transmission. The dynamic and unpredictable behaviors, such as node mobility, ever-changing network topologies, and variable channel conditions, contribute to the complexity of ensuring consistent and dependable communication within these networks. In the context of MANETs, data transmission reliability is a critical metric that influences the success of various applications and services relying on seamless communication among mobile devices. This research delves into a comprehensive exploration of data transmission reliability in MANETs under dynamic scenarios. The term "dynamic scenarios" encompasses a range of factors, including node mobility patterns, evolving network topologies, and fluctuations in channel conditions. By delving into the intricate dynamics of MANETs, we aim to scrutinize the challenges associated with data transmission reliability and, in turn, identify effective strategies and solutions to mitigate these challenges. A network segment diagram, complete with communication nodes and the connections that link them, is depicted in Figure 1.

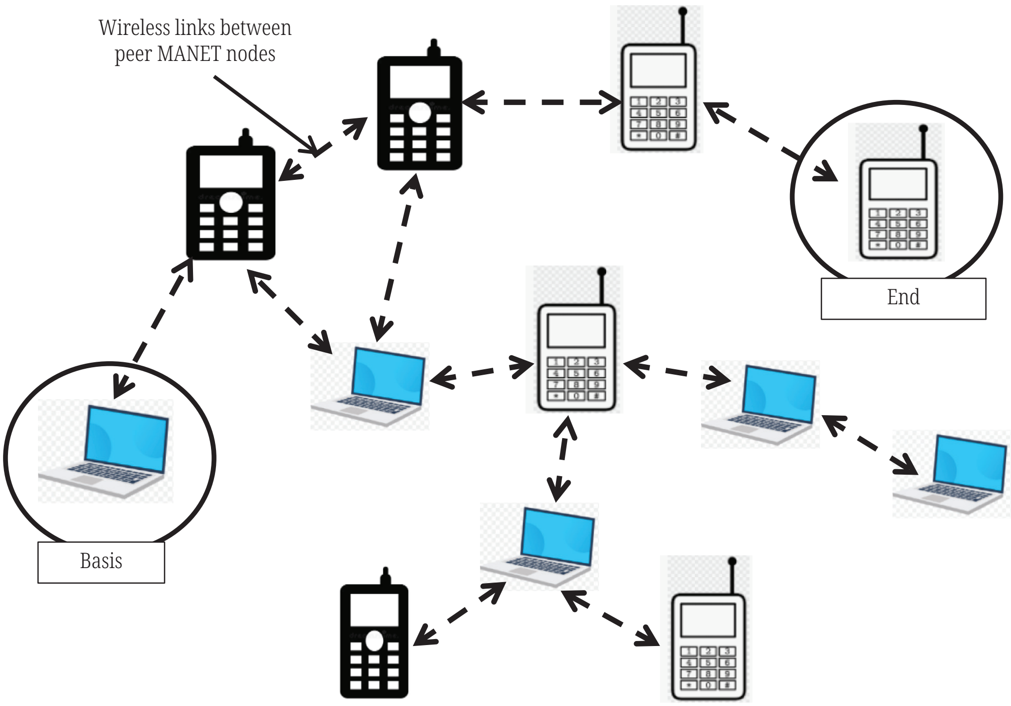

Fig. 1. Diagram of the network section

1.1 Challenges in MANETs

One of the defining characteristics of MANETs is the mobility of nodes. Nodes in the network can move freely, resulting in frequent changes in the network topology. This dynamic nature poses a challenge to reliable data transmission as the paths between nodes are constantly changing. Understanding how various mobility patterns affect data transmission reliability is essential for designing resilient communication protocols.

1.2 Evolving network topologies

Mobile ad hoc networks undergo rapid changes in network topologies because of node mobility and potential join or leave events. The ability to adapt to these changes and maintain efficient routing paths is pivotal for reliable data transmission.

Examining the impact of evolving topologies on transmission reliability provides insights into the resilience of MANETs under dynamic conditions.

Fluctuating channel conditions: The wireless communication channels in MANETs are susceptible to variations in signal strength, interference, and environmental conditions. These fluctuations can lead to packet loss, delays, or reduced transmission quality. Analyzing how different channel conditions affect data transmission reliability is essential for developing strategies to improve communication robustness.

1.3 Research objectives

The primary objective of this study is to conduct a comprehensive reliability analysis of data transmission in MANETs under dynamic scenarios. To achieve this overarching goal, we have established the following specific objectives:

Assessment of overall reliability. We aim to evaluate the overall reliability of data transmission in MANETs using mathematical models and simulations. By considering diverse scenarios with varying node densities, mobility patterns, and network sizes, we seek to provide a comprehensive understanding of how these factors impact the reliability of communication within mobile ad hoc networks.

Evaluation of existing protocols. Scrutinizing the current state of routing protocols, error correction mechanisms, and adaptive transmission strategies is crucial for understanding their effectiveness in mitigating the impact of dynamic conditions on data transmission reliability. This evaluation serves as a foundation for identifying strengths, weaknesses, and areas for improvement in existing protocols.

Exploration of enhancements and novel approaches. Beyond assessing existing protocols, our study explores potential enhancements and introduces novel approaches to bolster data transmission reliability under dynamic conditions. This involves proposing innovative solutions, adapting existing protocols, or combining strategies to address the unique challenges presented by mobile ad hoc networks.

Significance of the study. The findings of this research have significant implications for the design and optimization of communication systems in dynamic and mobile network scenarios. By offering nuanced insights into the challenges and opportunities associated with data transmission reliability in MANETs, this study contributes to the foundational knowledge necessary for constructing resilient communication systems.

The practical applications of our study extend to various domains, including emergency response systems, military communications, and pervasive mobile computing. Designers and practitioners in these fields can utilize the insights gained from this study to improve the performance and reliability of MANETs in real-world applications.

1.4 Structure of the paper

The following sections of this paper delve into a detailed exploration of data transmission reliability in MANETs: Section 2 provides a comprehensive literature review, highlighting relevant studies and existing frameworks in the field. Section 3 presents the methodology employed in our research, outlining the mathematical models and simulation techniques used for reliability analysis. Section 4 details the results obtained from our evaluations and simulations, offering insights into the impact of dynamic scenarios on data transmission reliability. Finally, Section 5 concludes the paper by summarizing key findings and emphasizing the broader significance of the study in advancing the field of mobile ad-hoc networking.

2 LITERATURE REVIEW

Routing protocols for mobile ad hoc networks are the main topic of [4]. To maintain routes to every node, even those to which no packets are transmitted, traditional routing systems are proactive. They respond to changes in network structure even when there is no impact on traffic. Regular control messages are necessary to maintain routes to all network nodes. These messages are based on either distance vector or link-state concepts. To keep valid routes open, the pace at which these signals are sent must match the network's dynamics. Given increased node mobility, the utilization of limited resources—such as power and connection bandwidth—for control traffic would increase.

Performance concerns in MANET routing, specifically the challenge of minimizing communication overhead related to broadcast dispersion in on-demand route identification and maintenance, have garnered significant attention in recent literature on mobile networking [5]. Many strategies have been proposed to address this challenge. These strategies are often grounded in probable routing mechanisms and aim to adjust the forwarding probability based on local topological factors to avoid unnecessary broadcast transmissions whenever feasible.

Batteries are used to power mobile nodes [6]. If their batteries run out, they won't be able to use their mobile ad hoc network. Cluster heads typically consume significantly more energy than cluster members. If a cluster head runs out of battery power, the entire MAHN will collapse. As a result, it is critical to reduce cluster head power consumption while maintaining a sufficiently high energy level to support longer operation. Regular plastering can disrupt scheduling procedures, capacity allocation, and network performance. Therefore, it is practically necessary to reduce the amount of plastering for mobile ad hoc networks.

Because gateways serve as the interface between two systems, they are essential for integrating a MANET with the Internet [7]. In a multiple-gateway MANET, gateway discovery can increase traffic delay and expenses. For instance, a MANET node may use a distant gateway instead of nearby gateways, leading to increased costs and delays. MANET nodes must identify a gateway to forward their traffic to the Internet. Generally speaking, there are three types of gateway discovery mechanisms: proactive, reactive, and hybrid methods. A gateway node engaging in proactive discovery regularly broadcasts advertisement messages containing all the necessary details for MANET nodes to recognize the gateway.

[8] presented a novel concept called identity-based encryption, where any publicly known string that identifies a user—such as their email address, domain name, or physical IP address—is utilized to compute their public key. This identification information can eliminate the need for a CA and PKCs as it inherently connects to a user without relying on digital certificates to associate users with their corresponding public keys. For MANETs, identity-based encryption is a better fit than classical symmetric encryption. Identity-based cryptography offers several benefits MANETs including easier implementation due to the following ways: (i) Easier to implement since no infrastructure is needed.

The first strategy relies on systems that compensate nodes for assisting in the transmission of other people's packets [9]. The works present the concepts of service fees and virtual currency. They use two models in their approach: a packet wallet and a packet exchange. In the second model, intermediary nodes relay every message, and the recipient covers the cost of the entire data transmission, whereas in the first version, the sender incurs changes for transmission. The authors examine the use of virtual currency as a way to incentivize users for their participation in packet forwarding. The study suggests a method for determining the cost of forwarding services to prevent selfish behavior in mobile ad hoc networks.

The topology control method maintains network connectivity by adaptively adjusting the transmission power, thereby conserving energy [10]. To generate the network topology, most topology control methods rely on information about neighboring locations, directions, and other relevant details. Global positioning systems (GPS) and other positioning techniques can be used to collect location data. The angle-of-arrival (AOA) method can be used to obtain directional information. While location-based approaches yield more precise topologies, they also incur higher costs in terms of equipment. Some solutions assume that a specific number of nodes have GPS capabilities, while others communicate with nodes equipped with GPS to ascertain their location, aiming to reduce hardware costs.

3 METHODS AND MATERIALS

3.1 Modelling of mobile ad hoc networks

In order to address problems in engineering, physical and social disciplines, biological research, and natural history, graph theory provides a natural framework for mathematically describing many complex engineering systems. It has several applications in these domains. A graph made up of nodes and links can be used to depict any system, according to this concept [11].

One can have both sparse and directed networks. Issues such as errors, malfunctions, and attacks are common occurrences among network elements. If there is a specific probability associated with the operational success or failure of these entities, the graph is referred to as a stochastic graph.

Any infrastructure-based building system, including mission-critical military equipment, water supply systems, transit systems, security networks, environmental monitoring networks, and communication networks, has historically been modeled as a probabilistic graph, with connectivity serving as the primary criterion for determining network reliability. Nevertheless, the unique features of MANET make it impossible to directly apply the methods and tools used to model and analyze the reliability of infrastructure-based networks.

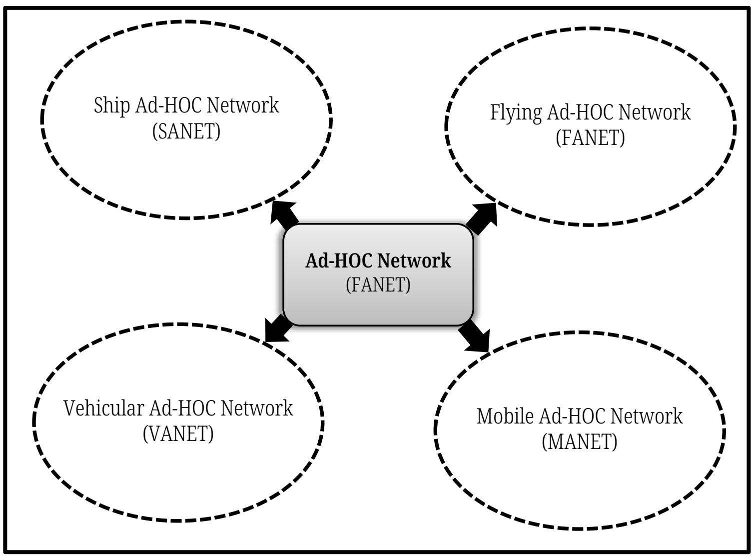

Fig. 2. Ad Hoc network types

In Latin, “ad hoc” translates as “for this purpose.” Local area networks, or LANs, are another term for ad hoc networks. These networks connect nodes to each other independently, without relying on centralized wireless networks such as base station networking. Without any Wi-Fi routers or access points within 100 meters of one another, we can set up an ad hoc network in which all the device nodes (computers) communicate directly to share information [12]. In an ad hoc network, there is no fixed topology because of node mobility. To transmit a message to a different node in the ad hoc network, a node must act as a router and relay the message to the intended recipient.

Routing in wireless ad hoc networks is the process of sending data from an origin to a destination across the network. The protocol for routing is a method for routers to exchange routing information and for routing to be executed. It enables routers to retain their routing databases and share routing information. At the network layer, the routing protocol is responsible for collecting information about the network’s current status and identifying the optimal transmission path. The router can create and update a routing table to facilitate data packet forwarding in the future using this information. Since multi-hop routing is necessary to facilitate communication among nodes in a wireless ad hoc network and because this technique relies on the design of the routing protocol, the routing is significantly influenced by the planning and implementation of the protocol.

This work’s main contribution is providing readers with an overview of wireless ad hoc networks and their routing procedures at a macro level, along with a wealth of relevant papers for further reading [13]. It does this by briefly introducing several fundamental concepts and understandings of wireless ad hoc networks, including their definition, categorization, features, uses, and growth. It also includes examples of some typical wireless ad hoc networks. To the best of our knowledge, no prior study has explored a comparison of this nature.

4 IMPLEMENTATION AND EXPERIMENTAL RESULTS

After implementing the numerical model on a mathematical computer platform, the experimental results were obtained. According to the system representation, it achieves several research goals, including reducing network load and making efficient use of energy. On the other hand, it also asserts that the system will increase throughput while maintaining the delay limitations.

The comparison results of the communication burden in the network are presented in Table 1, with the other four methods serving as baselines for validation. The evaluation of the numerical modeling considers the MATLAB environment, which includes sink placement and mobility of 400–900 nodes. Evaluation parameter 1 describes the system’s ability to handle security while processing network components and adapting to changing traffic conditions. This means that factors such as latency and other characteristics of network performance should not be impacted by the architecture of the security protocol. It is evident that the system significantly reduces the network load by evaluating and updating reputation. In other words, this suggests that capacity and other computing and network assets are being utilized effectively. Similarly, the cost of energy use illustrates the amount of energy used by various methods during network operations as a whole.

As seen in Figures 3 and 4 [14], the results of the measures of successful data transfer within a specific interval of time are indicated by bandwidth and the rate at which packets are dropped. Time complexity is illustrated in see Figure 8, showing the duration required, how long it takes to execute the suggested approach, and the total number of network activities involved.

MATLAB has been used for modeling and simulating the system. This is due to MATLAB being one of the most widely used software modeling platforms because of its ability to interface with many instruments, providing programming solutions, oversight, and connections for testing and rapid development.

Table 1. Lists the requirements for the hardware and software needed to use mat lab in this investigation

OS	Windows 10 with type-64 bit and *34
Computer	3.00 GB
Clock-frequency	2.99 GB
RAM	5.00 GB
MATLAB	301a

However, the system achieves superior results by optimizing the cost of communication and computation, which minimizes network stress despite these challenges.

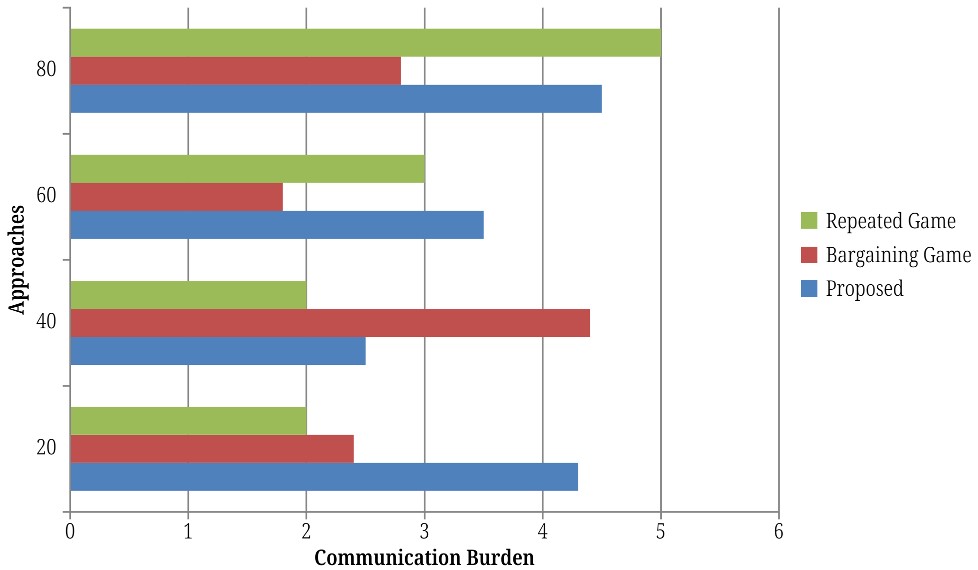

Fig. 3. An examination of network load

The developed cooperative message transmission and forwarding scheme, along with the associated equations, calculates the rate of effective packet delivery. They ensure minimal computational effort and superior throughput performance from both theoretical and experimental viewpoints.

Throughput analysis demonstrates that the suggested approach encourages each node to select the action corresponding to a higher level of packet delivery. The proposed approach utilizes a cooperative evolution-based gameplay model to incentivize each node in package forwarding within suitable scenarios. This approach indicates that by optimizing cooperative transmission forwarding, the probability of packet drops is significantly reduced. Additionally, the evolutionary gaming approach reduces the entire network's burden by facilitating successful data transfer and recovery with an improved value of v. This approach also enables nodes to optimize their value in terms of pay-off. The method takes into account successful packet delivery even on shaky networks where bandwidth constraints and channel fading may occur.

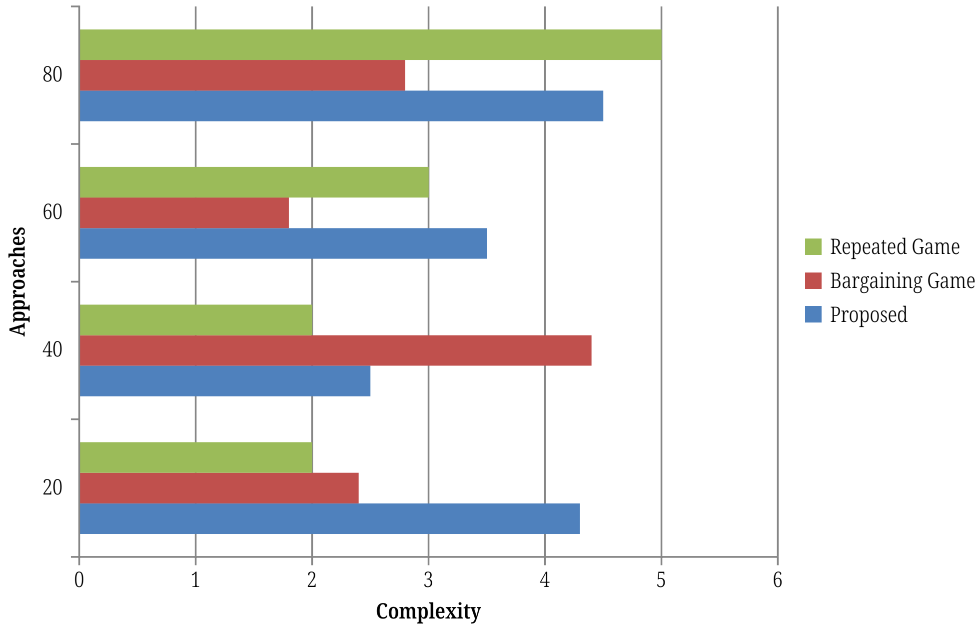

Fig. 4. Comparative evaluation of sec's time-consuming nature

Additionally, the memory requirement evaluation reveals that the suggested system only uses about seven MB of memory. On the other hand, some methods consume significantly more memory. For example, the bargaining game model utilizes the maximum memory allocation, which is approximately 30 MB, during runtime operation. Sophisticated game design in a collaborative packet forwarding scenario has been found to not only minimize execution time but also promote data exchange among nodes. The suggested algorithm's simulation time within the computational environment is referred to as its execution time. It consists of every communication activity in a single communication cycle. According to the analysis, the suggested solution takes four seconds to execute, whereas the other methods take significantly longer.

This indicates that the developed approach greatly enhances both computing and communication performance while meeting all potential network constraints. Three important elements are primarily taken into account in the experimental analysis to examine how the system performs in terms of energy and network efficiency, as well as how the evolutionarily stable states manifest themselves during the game formulation. These variables include the cooperative reward factor, the upper bound of the retransmission factor, and the probability of successfully forwarding packets using the cooperative strategy and 1-hop model. The scenario in which destination nodes receive more data packets compared to the data sent by the source in the form of a ratio is referred to as the potential for higher data packet transmission in the current study. Furthermore, and this is very different from the benchmark systems, the study ensures that the system design significantly improves network performance across all possible QoS aspects. The suggested approach somewhat motivates and promotes self-centered nodes to forward packets, increasing the likelihood of successful packet transmission despite varying network dynamics.

The study also evaluated the network overhead measure, which indicates the ratio of successfully sent messages to the total number of packets forwarded. The experimental results also showed that the system introduces a cooperative smart game mode where the allocation of incentives based on shared intelligence has taken this method to a new level to manage the data packets in the faulty radio links. Over time, the algorithm maintains lower network overhead because it assesses each node's trust factors based on its reputation. This ensures that packet forwarding occurs reliably for communication. Additionally, the system simulated the game-based solution in a way that motivates a self-centered node to take action by relaying or forwarding the data packet through a collaborative reward approach.

5 CONCLUSION

Encouraging packet forwarding even in the face of erratic radio connectivity is crucial in the MANET routing and connectivity scenario. Without a centralized authority, ensuring minimum energy consumption while meeting QoS limitations and achieving higher throughput results is challenging in MANETs. MANETs consist of resource-constrained, self-configuring portable nodes that move in various directions and experience rapidly changing topologies.

The baseline analytical technique is utilized in the framework design as a reference model by evaluating previous studies related to it. Though the results indicate that the suggested method reduces the rate of packet drop more than the others, there is still room for improvement in various IoT network devices. Another important point to note is that while the system assessment only takes into account 900 mobile nodes, it is observed that up to 700 nodes, the network load on the system is minimal. However, when the number of nodes is increased to 900, the system encounters a rise in network stress attributed to the expansion in data size.

It is observed that, without affecting the network's lifespan, the clustering method reduces both the density of clusters and the number of re-elections when the communication range for specific nodes is altered.

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