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RESEARCH ARTICLE

Enhancing OLSR Performance in Dense Networks: A Game-Theory Framework for Dynamic Node Readiness and Optimized MPR Selection

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Abstract – The network beyond any central framework is a wireless network, also acknowledged as a Mobile Ad-hoc Network (MANET), where each node can act as a host or router. In MANET, mobile nodes collaborate by advancing packets from source to destination nodes. When the traffic is in its pick point then more control packets are advanced so depreciating more transmission capacity and may cause packet dissipation. Nowadays, MANET is facing numerous issues like control packet overhead, energy efficiency, scalability, limited physical security, as well as lack of centralized management, also game theory is used to solve these issues. In this paper, we use two techniques in this scheme, readiness always as well as readiness never to alleviate the multipoint relay ratio in vastly populated areas. In this manner, nodes that have a low attraction with other nodes are rejected from the selection. In our research, we will mainly focus on applying game theory to decrease the control packets in a vastly populated network for OLSR routing protocol. The performances of the proposed work are analyzed by using parameters, namely ROR ratio, PDR ratio, MPR ratio, delay, and Throughput. Simulation is performed to ensure the proficiency of our proposed improved method. Our proposed improved method provides an essential reduction of the MPR ratio and improves the packet delivery ratio as contrasted to the conventional protocol.

Index Terms – Game Theory, MPR, NS3, OLSR, IOLSR, Readiness.

1. INTRODUCTION

Wireless nodes that can establish a network without network infrastructure are known as mobile ad hoc networks [1]. Multi-hop routing, self-configuration, self-management, self-healing, and scalability are features that attract networking businesses to Mobile Ad hoc Networks (MANETs) [2]. The main goal of MANET routing focuses on determining the best route between the source and destination nodes [3][4]. MANET can quickly create a network without a backbone or infrastructure [5][6]. In many circumstances, users cannot rely on the telecom infrastructure. Mobile ad hoc networks (MANETs) provide alternative communication when infrastructure is expensive or unavailable, eliminating the requirement for base stations or access points [7]. The routing method has difficulties because of dynamic topologies and few resources, which are important for data transmission between nodes [8][9]. Ensuring dependable communication between every node presents a substantial obstacle [10]. MANETs were first created to address situations where traditional connectivity was scarce. With effective routing, they are intended to increase network longevity and reduce energy usage [11][12]. Three categories of routing procedures are used in MANETs: proactive, reactive, and hybrid. Reactive methods such as AODV and DSR initiate routing only when requested by the destination from the source [6]. Routing tables are regularly refreshed by proactive protocols, such as OLSR, using knowledge about the global network topology [13]. For optimal effectiveness, hybrid protocols like ZRP incorporate elements from proactive and reactive techniques [14]. MANETs are widely used in military operations, particularly in situations like as network-centric warfare, aero-terrestrial operating bubbles, and cooperative engagement [15]. Additionally, a wide range of industries, including the military, government, disaster response, and civilian sectors, get benefitted from MANET technology [16]. The Multipoint Relays are unique nodes that OLSR selects. These MPRs avoid needless repetition in favor of helping spread crucial information throughout the network. Carefully choosing its MPRs, each node uses the fewest possible MPRs to reach any other node in two hops [17]. OLSR nodes utilize Hello messages to identify their immediate neighbors before selecting MPRs [18].

These interactions are used to assemble a routing table that includes information about nearby nodes and pathways to different network places. Furthermore, OLSR broadcasts TC signals that equip network topology information. Conveying routing messages to other nodes is the duty of MPRs, dynamically selected nodes. By lowering the quantity of transfers required to keep a connection, this strategy increases protocol efficiency. MPRs are essential to the OLSR protocol because they retransmit data when they get new messages. Routing performance is directly impacted by the establishment of several MPR nodes in the network during the implementation of this strategy [19]. When MPR-based design is used, control message overhead is greatly decreased, which improves OLSR performance in high-density, large-scale mobile networks [20][21].

Game theory is described as a mathematical model that studies how players interact with a predetermined scenario known as a game [22] and finds useful application in the examination of system functions in decentralized and self-organizing networks because of the players reasonable behavior [23]. Game theory, as in [24, 25, 26] serves as a discipline dedicated to demonstrating situations where decision-makers must take particular actions that can result in mutual, and sometimes conflicting, outcomes. In game theory, the outcome for each player depends on the actions of the other [27].

The foundational work in this field can be tracked back to the seminal textbook authored by Von Neumann and Morgenstern in 1944 [28]. Subsequently, John Nash made vital contributions [29, 30], with the celebrated Nash equilibrium being a cornerstone. Unsurprisingly, game theory has made its way into networking, often utilized to address routing and resource allocation challenges within competitive environments. The references related to this field are plenty, and space constraints prevent us from listing them all, but a selection of these papers can be found in [31]. Lately, game theory has emerged as an essential tool for resolving issues in communication networks [32]. It has been applied effectively to analyze and tackle numerous challenges in MANETs, with a particular focus on enhancing energy efficiency and dealing with self-interested nodes [33, 34]. MANETs have provided a strong foundation for the development of sensor networks and the Internet of Things (IoT), giving rise to a multitude of emerging applications. Projections indicate that the global count of connected IoT devices will surge to 75.44 billion by the year 2025, as outlined in [35]. Consequently, this will lead to a proliferation of interlinked wireless devices within a given area, forming a densely populated network. In the context of networking, a dense network indicates the presence of numerous nodes in a confined space, with node density surpassing a specified threshold and remaining relatively steady over extended periods, as defined in [36]. The existence of a dense network conveys the implication of elevated control overhead, as all nodes intermittently transmit control traffic. This, in turn, can diminish a node's battery power or lead to packet loss when application traffic is being transmitted.

In an equivalent context, our study focuses on lowering the MPR ratio and removing redundancies in high-density networks. We suggest a method where the readiness of a node to act as an MPR is tuned based on its surrounding node density. Each node participates in a computational exercise, with its readiness being guided by the number of immediate neighboring nodes. In the heuristic approach known as Optimized Link State Routing, the baseline readiness level is set at WILL_DEFAULT. Our goal is to fine-tune each node's readiness dynamically, influenced by the conditions of its adjacent nodes, to improve MPR selection in networks with high node density. This, in turn, contributes to an overall improvement in the routing algorithm's performance. To summarize our contribution briefly:

- Initially, we suggest a game-theoretical algorithm designed to assess a node's inclination to serve as a multipoint relay (MPR). In our proposed model, nodes exerting greater influence over their peers will experience an elevated readiness value.
- Secondly, all HELLO messages are arranged to prevent message duplication when calculating nodes. The groundbreaking aspect of this research lies in the fact that a node's readiness will be decided by the number of its immediate neighbors, which is calculated based on the HELLO messages broadcasted and received.

The rest of the paper is summarized as follows. Section 2 represents the literature review, section 3 represents the materials and methods, section 4 represents performance

RESEARCH ARTICLE

metrices and simulation results and finally section 5 represents the conclusion of this work.

2. LITERATURE REVIEW

The OLSR is perfect for high-density networks and offers the benefit of optimizing current bandwidth usage. There are notable restrictions with the OLSR routing protocol as well. The minimal MPRs are shown to be a improbable polynomial time (NP)-complete problem. There are thus many enhancements available to enhance MPR selection. On the other hand, we focused on MPR set minimization in dense networks in this research.

Patel Kavindra M et al. (2023): In this paper, authors have introduced a proposal to integrate QoS into the OLSR routing procedures. They aim to reveal a unique algorithm to designed specifically for the OLSR protocol, with the objective of increasing the QoS within the OLSR routing framework. In this work, the received power and distance cannot be used. Additionally, the authors aspire to create QoS variants of the OLSR routing protocol in NS2 [1].

Jaspreeth Singh et al. (2023): The paper introduces enhancements to OCI-OLSR, emphasizing improved control interval management, a refined MPR selection process, decreased neighbor hold time, and reduced flooding. Results indicate that the optimized OLSR version outperforms standard OLSR and AODV mechanisms across different parameters, thereby enhancing the network's overall performance and reliability. But sometimes node speed is slow due to heavy network traffic [6].

Gennady Kazakov (2023): The paper investigates the difficulties in establishing self-regulating portable mobile ad hoc networks by employing OLSR with MPR adjustment and ensuring quality control via the RSVP. The authors propose a novel method to improve the security of the OLSR protocol for MANETs by incorporating secure MPR selection using a "trust no one" principle and implementing a decentralized verification system. There is an inadequately established infrastructure for communications [7].

Noureddine Idboufker et al. (2023): This paper presents a robust method to improve the overall security of V2X networks, ensuring safe and secure communication between vehicles and their surroundings. It also achieves higher packet delivery rates, effectively identifies and isolates malicious nodes, and enhances the security of the OLSR protocol. There is a minimum number of nodes is used [17].

Ousama sbayti et al. (2021): In this study, the authors investigated the challenges of creating self-regulating portable mobile ad hoc networks (MANETs) using OLSR with optimizing multipoint relay. They also implemented the Resource Reservation Protocol to regulate the quality. Their evaluations and calculations led to recommendations for constructing and expanding self-organizing wireless networks. Reducing the ERS value and displaying the network performance for only one city may lead to disadvantages such as limited visibility into the network performance across multiple locations, potentially overlooking issues present in other areas [19].

Omuwa Oyakhire et al. (2020): In this study, the researchers invented a new algorithm designed to increase the performance of the OLSR protocol, specifically in mobile environments. By applying game theory, the algorithm incorporates all network nodes in a straightforward game to determine their level of willingness depends on their node density. Omuwa Oyakhire et al. suggested that every node has two willingness options: WILL_ALWAYS or WILL_NEVER. The data indicates that this updated version of OLSR surpasses the authentic in every performance measure, except for delay, which is not a big deal. In this work, the battery power of the nodes not considered and the amount of broadcasts are not considered [37].

Pardeep Kumar et al. (2019): The study introduces an enhanced routing approach aimed at addressing the frequent link breaks in Airborne Ad hoc Networks (AANETs). This enhanced method updated the MPR (MultiPoint Relays) selection criteria to enhance link quality, thereby diminishing the overhead on the communication link between two aircraft. This leads to increased bandwidth availability for sharing data packets. When contrasted to the standard OLSR protocol in both UDP and TCP settings, the new routing scheme, termed AOLSR, exhibits improvements in different performance metrics in the AANET context. Additionally, ALOSR also works better than other protocols, such as A-GR and GRAA [38].

Teruaki Kitasuka et al. (2015): In the study, the researchers measured the physical space between 2-hop neighbors in networks of relatively small density. They found that nodes located near the edge of a 2-hop disk, represented as $D_i(V_i, 2r_i)$ where r_i stands for the propagation range, are unlikely to be two-hop neighbors of node V_i. Based on this insight, Teruaki Kitasuka et al. hypothesized that a lower number of MultiPoint Relays (MPRs) could effectively reach all 2-hop nearby nodes in such slightly dense networks. There was only a static environment considered and there were no usages of a mobility model. This hypothesis was validated through simulations [39].

Sefali Prajapati et al. (2015): In the study, the researchers introduced a new technique to energy-efficient routing within the OLSR protocol by changing its MPR selection tactics but there was main issue is to degradation in higher density network. This change aims to increase the lifespan of MANET networks in terms of energy utilization. All examination will be conducted using the NS2 simulation platform and the OLSR routing protocol [31].

Teruaki Kitasuka et al. (2013): The shared MPR selection technique was introduced as a way to decrease the traffic associated with topology control in OLSR. In OLSR, Topology Control messages are created by nodes that are chosen as MPRs by their nearby nodes. The shared MPR choosing method involves neighbors sharing the same MPRs. To achieve this goal each node calculates its MPR set depends on not only the coverage within two hops of its one-hop neighbors but also the coverage levels it receives from those one-hop neighbors. Every neighbor computes the coverage level for their MPRs and communicates this information to other neighbors passing a HELLO message [40].

Leonardo Maccari et al. (2012): Demonstrating that suppressing locally is insufficient to attain the primary objective of MPR selection, which is to locally pick MPRs while suppressing both their overall count and the protocol overhead from TC broadcasts. There was constraining the number selected MPR to a strict and minimal required quantity. Furthermore, suggesting a solution that, through a minor adjustment to the initial algorithm, outperforms the long-standing heuristic method without adding any additional overhead [41].

Teruaki Kitasuka et al. (2011): They performed a study in densely populated multi-hop networks, examining the density of MPRs in such networks. They clarify three key factors aimed at increasing the quantity of MPRs: (1) ensuring that each MPR is positioned at a sufficient distance from its picker; (2) grouping MPRs of a node closely together; and (3) even when two nodes are in close proximity, they tend to choose different MPRs in dense networks. These factors lead to a higher MPR density. Concerning the third factor, Teruaki Kitasuka et al. evaluate the routing overhead and MPR ratio associated with TC messages through simulations conducted in densely populated networks but the heuristic cannot feasible for the OLSR protocol [42].

Teerapat Sang. et al. (2011): They introduced and put into practice an algorithm designed to diminish the control overhead of OLSR in MANET by employing game theory principles. The algorithm was successfully executed, explaining the presence of a mixed Nash Equilibrium point. The primary performance metrics considered were Network Reachability Objective and Average Throughput. Across all situation, it was observed that both NRO and Average Throughput decreased for the enhanced OLSR when compared to the standard OLSR, regardless of the transmission speeds [43].

Kenji Y., Tsuyoshi et al. (2010): They introduced a collaborative MPR selection technique with the aim of improving the consolidation of messages within a single control packet. In their simulation, Kenji Y. et al. illustrate that this cooperative MPR selection technique effectively minimizes the volume of routing packets in high-density networks while preserving network reachability at a level comparable to the traditional MPR selection method. The node density was not taken into an account [44].

SeUng Hyeon et al. (2010): They introduced a novel routing protocol named GRAA, which takes ideas from geographic routing protocols, known for their adaptability in coping with highly dynamic topology changes. To adapt to the unique characteristics of aircraft ad hoc networks, they put forward a hybrid-forwarding technique that leverages mobility patterns acquired through aircraft-to-ground communication. Also, in this situation where utilizing mobility patterns is impractical, they present a forwarding strategy based on a neighboring table with directional information. This technique is combined with opportunistic network technology. At last, they validate the enhanced performance through simulations and assess the impact of the proposed technique and it's not feasible to employ the mobility model [45].

DeMarcus Thomas et al. (2010): This paper's main emphasis is on creating a multicast routing protocol tailored specifically for MANETs. In MANETs, nodes function with a certain amount of battery strength and have the ability to move freely within a network that forms dynamically. To summarize, the results from M-FORP indicate that it had the highest average hop count values but also displayed the most consistent tree lifespans for multicast. In contrast, MNVSP gained significantly lower hop count values but had shorter lifetimes for multicast trees. Excessive battery consumption caused by high levels of data overhead and information loss across transmission. BEMRP provides higher edge count values but, on the flip side, had the lowest performance in terms of multicast tree lifetimes [46].

S. Suhaimi, K. Mamat et al. (2009): This paper outlines the technique taken to create a practical test scenario aimed at augmenting the "willingness" factor within the OLSR protocol. Additionally, it explains the prerequisites and implementation essentials for OLSR in ad hoc nodes. In summary, the simulation was conducted successfully, and the outcomes illustrate the enhancement of OLSR nodes in optimizing the use of battery power sources in MANETs by improving the "willingness" aspect of the OLSR protocol. There was a restricted quantity of devices involved and the mobility was not taken into an account [47].

F. Ahourai et al. (2009): In this paper, a game theory-based strategy for addressing selfish routing in Wireless Mesh Networks was introduced. This strategy relies on a multi-agent system structure, where each node contains both a router agent and a manager agent. The manager agent utilizes the Stackelberg strategy and takes its actions before the other agents. The study showcases that this problem can be modeled as a Nash-Stackelberg or leader-followers game. To manage such challenges, this paper suggests a heuristic approach that combines simulated annealing and evolutionary

RESEARCH ARTICLE

algorithms for problem-solving. The conventional techniques for solving the game theory models like that gradient estimation-based methods are not widely considered [48].

Fatos Xhafa et al. (2009): This paper introduces strategies based on MANETs and nearby explore approaches to handle the challenge of optimally positioning coincide nodes within WMNs. The difficult scenario relates to a predefined distribution of client coincide nodes across a grid region. The authors performed experiments to assess the effectiveness of these methods when used independently and as initializations for evolutionary algorithms. The ad hoc techniques provide high speed but exhibit some limitations regarding the maximum efficiency of the solutions they produce. Nevertheless, they prove to be worthy when employed as initializations for genetic algorithms. Among these techniques, the ad hoc method centered around the hotspot concept exhibited superior performance in the latter case [49].

Floriano De Rango et al. (2008): The suggested changes to the MPR (MultiPoint Relays) selection process within the OLSR protocol, grounded in the Willingness idea, boosting the network's lifespan while maintaining performance. EE-OLSR surpasses OLSR in aspects such as throughput, average node lifespan, connection duration, preservation of normalized control overhead and node longevity. Available battery capacity for route calculation was not taken into an account [50].

Wu et al. (2006): Discuss various upgrades aimed at creating a more compact Connected Dominating Set by utilizing compact two-hop data to encompass the two-hop neighbor set of each node. The authors demonstrate that the expanded MPR (MultiPoint Relays) provides a stable local approximation ratio in contrast to the logarithmic local ratio found in the conventional MPR. Wu et. al. introduced an extension that relies on full two-hop information. Multipoint Relay and REMPR exhibit the lowest performance across all ranges and energy conscious utilization of MPR was not taken into consideration [51].

Ou liang et al. (2006): In this paper, the authors demonstrated the concept of a least CDS as an alternative technique to minimize the quantity of transmitting nodes required for the overflowing process. For any pair of nodes in the CDS, there exists a route connecting them that includes nodes within the Connected Dominating set and each node within the network possesses at least a single neighboring node within the CDS (Connected Dominating Set). Selecting a CDS can be seen as building the network's backbone. Additionally, CDS can serve as an appropriate replacement of MPR (MultiPoint Relays) for broadcasting packets to the whole network, and it is more effective in reducing control traffic compared to MPR [52].

Laurent Viennot et al. (2006): In this paper, the authors have successfully demonstrated that determining the smallest possible amount of a multipoint relay set is a problem classified as NP-complete. The selection of multipoint relays is a technique that can effectively diminish the broadcasting overhead in wireless networks. When considering each source, a lower number set of multipoint relays results in a greater benefit in terms of reduced broadcasting costs but cannot achieve an approximation factor [53].

Mark Felegyhazi et al. (2006): The authors have presented the application of noncooperative game theory in the domain of wireless networking. Through the use of four straightforward examples, they have demonstrated how wireless networking challenges can be explained as corresponding games, and they have performed analyses to predict player behavior. Mark Felegyhazi et. al. concentrated on the fundamental principles of non-cooperative game theory, firstly examining games with complete information. They have depicted devices as the players in these models, although scenarios may arise where the players are different participants, such as network operators and another participants player information are not identified [54].

C. Gomez et al. (2005): It identifies a different path in the event of a link failure and establishes the theoretically determined Route Connectivity Length while analyzing its relationship with OLSR (Optimized Link State Routing) parameters, comparing these theoretical findings with tested network experiments. C. Gomez et. al. has demonstrated that increasing the transmission rate of OLSR messages contributes to improving end-to-end path connectivity [55].

Aleksandr Huhtonen et al. (2004): This paper will center its attention on two renowned algorithms, namely the AODV and the OLSR Routing Protocol. It will delve into the qualities of ad hoc networks and elucidate how they differentiate themselves from conventional wired networks. Aleksandr Huhtonen et al. explained that reducing control traffic message overhead comes at the cost of heightened latency when seeking new routes [56].

Thoms Clausen et al. (2004): Discusses OLSRv2 protocol for MANETs. This protocol work as a table-oriented, proactive technique, meaning it periodically shares structure details with other routers in the network. OLSRv2 effectively diminishes message overhead when compared to the traditional flooding method but does not accurately pick multipoint relays or transmit control message [57].

Vivek Srivastava, James Neel et al. (2003): This paper outlines the concept of modeling different interactions within MANETs as a game. This technique enables the development of equilibrium-promoting mechanisms that support individual users to engage in socially-beneficial actions. The authors are performing a survey of recent literature that emphasizes on utilizing game theory analysis to MANETs, emphasizing its relevance in areas such as medium access control, waveform

RESEARCH ARTICLE

adjustment, routing, power control and node participation [58].

Thomas Clausen et al. (2003): In this paper, the authors have represented the updated OLSR protocol for MANETs. This is an enhancement of the conventional algorithm for link states, adjusted to meet the needs of wireless LANs. This modification significantly reduces the volume of messages contrasted to the conventional flooding method. Furthermore, an additional way to maximize this is by restricting the spread of control messages across the network. OLSR excels in offering best routes and is especially well-suited for large, vastly populated networks, thanks to the MultiPoint Relays (MPR) technique that performs effectively in such scenarios [59].

Amir Qayyum, Laurent V. et al. (2002): This study explores the concept of multipoint relays (MPRs) and their role in maximizing the distribution of disseminate messages throughout portable networks. MPRs are a tactic aimed at limiting superfluous repetitions when propagating a broadcast signal across the network. The text explores into the underlying principles and operation of MPRs and states a heuristic for choosing these MPRs within a portable wireless scenario.

Amir Qayyum et. al. also delves into the intricacy of these hypotheses and set up that calculating a minimal-size multipoint relay set falls under the class of NP-complete problems. The multipoint relaying technique begins to experience packet loss and causing various nodes to miss the message [60].

Anis Laouti et al. (2002): This study assesses the effectiveness of the OLSR protocol. Although most of the outcomes presented by the authors can be applied to different arrangements of medium access control and physical layers, the simulation results were produced using an IEEE 802.11 standard. This paper primarily focuses on examining the extra load caused by control packet loss during route establishment. The rate of lost packet in the control packets and the shortage of routes because of this loss of control packets. Furthermore, we investigate the benefits of fully optimizing the OLSR protocol [61].

Jacquet et al. (2001): The examination focused on OLSR Multipoint Relay overflowing in two network environments: the arbitrarily graph technique for enclosed networks and the arbitrarily disk graph technique for open networks. The central components of this protocol revolve around multipoint relays (MPRs). When there is modification in the network's topology, it leads to the dissemination of topological details of every node freely accessible in the network but the movement effect of the node is not calculated [62].

Qayyum et al. (2000): In this paper, the authors conduct an investigation and suggest a heuristic approach for selecting MPR sets. They explain that solving the MPR problem characterized is NP-complete. The heuristic algorithm, as developed by Qayyum and others, offers an MPR set that is close to maximum and is utilized within the OLSR protocol. OLSR permits the utilization of other algorithms with modifications. MPR significantly decreases the need for redistributing broadcast messages, while maintaining a high acceptance rate for these messages. In pure flooding the error rate was too high where all the nodes were not able to receive the packet [63].

2.1. Problem Statement and Hypotheses

The study mentioned above reveals several significant efforts in this field including they improve the MPR selection method in broad networks, adjusted the node readiness to conserve energy in broad networks, changed the node readiness based on battery function, and used shared sets to eliminate MPR redundancy.

To mention there are some specified drawbacks including the inability to use received power and distance, the minimum number of nodes, the disregard for battery power and broadcasted nodes, the consideration of only static environments, the inability to retransmit broadcast packets, degradation in higher density networks, decreased average throughput, excessive battery consumption resulting in data overhead, the neglect of energy-conscious MPR utilization.

2.1.1. Problem Statement

If we consider these two papers, Kitasuka et al. [39]and the one by Omuwa Oyakhire et al. [37], both use game theory in their work. Kitasuka et al. [39] utilize shared MPR sets, whereas Omuwa Oyakhire et al. [37] rely solely on received HELLO messages. However, modifying node readiness based on received and broadcasted HELLO messages has not been considered. This study differs from previous studies in that it takes into account portable broad networks while minimizing the MPR ratio and boost the PDR ratio as compared to the standard technique.

2.1.2. Hypotheses

Here are five hypotheses based on our work and the findings from the literature review:

H1- Game theory based OLSR will diminish control packet overhead in high density MANETs by boosting Multipoint Relay (MPR) Selection.

H2- Modifying node readiness based on surrounding node density will lower MPR ratio and enhance Packet Delivery Ratio (PDR) in high density networks.

H3- Readiness based MPR selection will diminish Routing Overhead Ratio (ROR) by minimizing control traffic, particularly in dense networks.

RESEARCH ARTICLE

H4- Game-theoretical node readiness will reduce redundant HELLO transmissions and decrease End-to-End (EtE) delay in MANETs.

H5- Improved OLSR will demonstrate more stable throughput than traditional OLSR, especially as network density increases.

3. MATERIALS AND METHODS

3.1. The Choice of Multipoint Relay

Multipoint relaying reduces retransmissions in broadcast packets by limiting re-transmitters to several neighbor nodes. This compact set strategically selects neighbors serving the same network region as the complete collection. Multipoint relays (MPRs) technology ensures high probability and minimizes flooding of broadcast messages. Figure 1 illustrates a situation where a source node requires 49 retransmissions to spread a message across 3 hops. On the other hand, a source node requires 11 retransmissions when disseminating a spread message using MPRs, as represented in Figure 2. The source node requires knowledge about its 1-hop and 2-hop neighbors in order to compute MPRs. The source node uses this knowledge to determine the minimum amount of its immediate neighbors. It needs to completely enclose the two-hop neighbors [60].

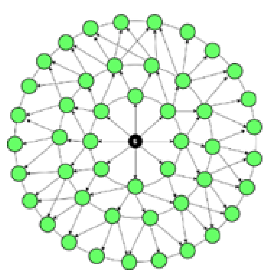

Figure 1 Broadcast Without MPR

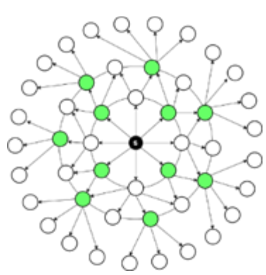

Figure 2 Broadcast With MPR

We provide one heuristic [63] for selecting multipoint relays. In order to choose multipoint relays for node v_1, let us assume $N_1(v_1)$ and $N_2(v_1)$ to be the neighbors of v_1 with one hop and two hops respectively. Consider the multipoint relay set $M_1(v_1)$, selected by node v_1. The following is the heuristic:

Step 1. The process begins by initializing the multipoint relay set as empty, denoted as $M_1(v_1)$.

Step 2. Initially, the set of multipoint relays $M_1(v_1)$ is determined by selecting the one-hop neighbor nodes in $N_1(v_1)$ that exclusively serve as the neighbor of a node in $N_2(v_1)$. These selected nodes are then added to $M_1(v_1)$.

Step 3. As long as there is at least one node in $N_2(v_1)$ that is not included in the multipoint relay set $M_1(v_1)$, the following applies:

- Determining the amount of uncovered nodes in the set $N_2(v_1)$ in relation to the covered nodes in the set $N_1(v_1)$ involves counting the number of nodes that are covered by each node in $N_1(v_1)$ that is not present in $M_1(v_1)$.
- Incorporating the node of $N_1(v_1)$ into $M_1(v_1)$ that possesses the highest numerical value.

The heuristic investigates whether or not step 2 is present in the multi-point relay set, which enables the selection of 1-hop neighbor nodes to function as MPRs. In doing so, the MPR set is optimized, and the quantity of exposed nodes at the beginning of step 3 is decreased.

Here we discuss how to share MPRs with a neighbor in this section. From Figure 3, we see that there is a node v and v_1 and v_2 are the two-hop neighbor of v, where $w \in w_1 \cap w_2$, the v_1 and v_2 chose w as an MPR to cover v. However, v_3 has no two-hop neighbors with w_1 and w_2, thus, v_1 and v_2 do not have any MPR to share [39].

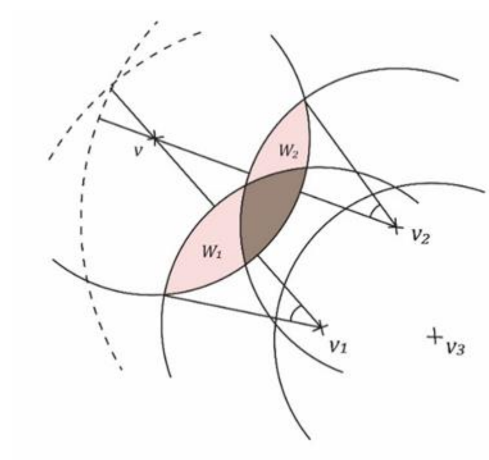

Figure 3 Share MPRs With a Neighbor

3.2. Node Readiness and Hello Message Broadcasting and Receiving of OLSR

Each router has two readiness options, WILL_FLOODING and WILL_ROUTING, which must be between WILL_NEVER and WILL_ALWAYS. WILL_FLOODING indicates the router's readiness to flood TC messages as a flooding MPR. WILL_ROUTING indicates the router's desire to be a routing MPR and intermediate router on routes. The lowest readiness value, WILL_NEVER, prevents a router from doing the operation. This protocol will not work if too many routers set WILL_FLOODING or WILL_ROUTING to WILL_NEVER. Administrative or other measures must be taken to prevent this. The fraction of routers with WILL_NEVER readiness values that is “too many” depends on the network topology, which in a MANET may vary dynamically.

Readiness allows certain routers, like those with a constant power supply, to take on more network operations, while others, like battery-operated ones, may avoid such chores. Only routers that cannot flood or route should be set with WILL_NEVER. All symmetric 1-hop neighbors will choose a flooding or routing MPR with a readiness value of WILL_ALWAYS [57]. Each node regularly broadcasts its HELLO messages, comprising neighbor information and connection status by broadcasting control messages. All 1-hop neighbors get them but do not forward them. HELLO messages contain:

- The addresses of neighbors who share a bidirectional link.
- The addresses of neighbors heard by this node but not yet authenticated as bi-directional links. A node considers the connection to the sender bi-directional if its address is in a HELLO message.

Each node may build its MPR selection table from HELLO messages [64]. OLSR must identify neighbors and their communication links. HELLO messages are sent regularly for this. Figure 4 shows a simple HELLO neighbor-finding session. A_1 delivers a blank HELLO and B_1 registers A_1 as an asymmetric neighbor since the HELLO message does not include its address. B_1 delivers a HELLO proclaiming A_1 an asymmetric neighbor. A_1 sets B_1 as a symmetric neighbor since this message contains its address. A_1 sends B_1 a HELLO this time, and B_1 registers A_1 as a symmetric neighbor [65].

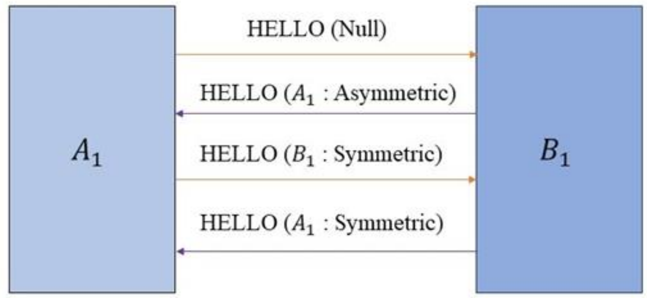

Figure 4 HELLO-Based Neighbor Finding

If node N has not received a broadcast message from any of its MPR selectors, it will retransmit it. The selector node’s HELLO messages show this set’s changeability [59]. At network startup, each node broadcasts message of "HELLO" to its surrounding areas, which includes their connection status. It does not relay HELLOs from its nearest neighbor. HELLO messages let nodes learn about their 2-hop neighbors. From among its symmetric 1-hop neighbors, a node selects its own MPR node [31].

3.2.1. Hello Message Format of OLSR

A technique that is analogous to the overall packet structure is used. This is done to account for MPR selection signaling, link sensing, and neighborhood detection and provide for future additions. As a result, the format that is being suggested for a HELLO message is the one that is shown in Figure 5. The specific task of every section of the OLSR header format is given below:

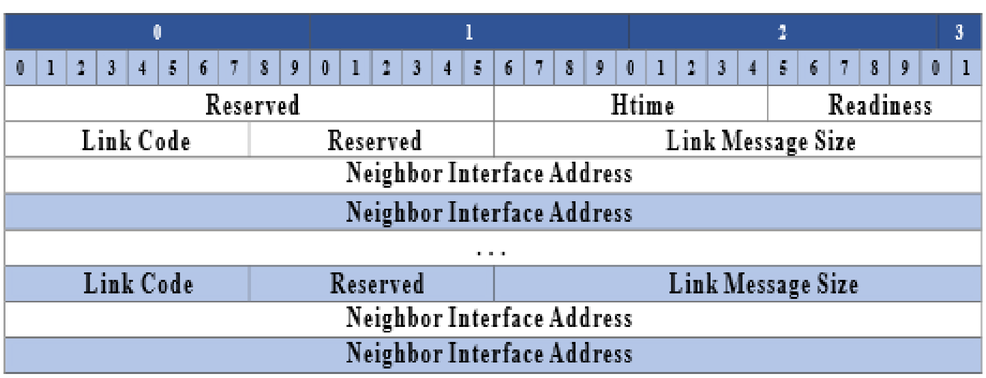

Figure 5 OLSR Message Header Format [59]

3.2.1.1. HELLO Emission Interval (Htime)

This parameter indicates the node's HELLO emission interval on this interface. The four highest and lowest Htime field bits reflect the HELLO emission interval. Htime field is shown as follows using equation (1).

$$\text{HEI} = C.\left(1+\frac{h}{16}\right).2^{l} \quad (1)$$

Htime field's upper four bits are denoted by h, and its lower four bits by l.

3.2.1.2. Readiness

A node's readiness to act as a traffic relay is indicated in this field. Any node that has the Readiness WILL_NEVER MUST never choose it as MPR. In all cases, the MPR should be chosen from among the ready nodes. A node's default readiness SHOULD be WILL_DEFAULT.

3.2.1.3. Link Message Size and Link Code

Bytes in a link message are counted from one Reference Code area to the next, specifying the relationship between the sending interface and its neighbors. It also establishes a neighbor relationship.

3.2.1.4. Neighbor Interface Address

An address that may be used to communicate with the interface of a neighboring node.

3.2.1.5. HELLO Message Generation

HELLO Message Generation is done by broadcasting the Link, Neighbor, and MPR sets. These "local topology discovery" activities share periodic information within a node's vicinity. A HELLO message is produced by the regional data repository using the MPR, Link, and Neighbor Set as its inputs.

Each interface must execute link sensing to identify connections to adjacent interfaces. In order to locate neighbors, a node is required to broadcast the whole of its evenly distributed 1-hop neighborhood on any one of its interfaces. Thus, a HELLO message for an interface will display its linkages and the neighborhood [59].

3.2.2. Readiness Value of OLSR

Due to the lack of the APM file, the core OLSR implementation sets the default value to 3. Here a node makes use of AC or DC power. For safety, the readiness is set to 3 because if the node just utilizes a little amount of battery energy, the entire system will run out of power without warning, causing data loss.

If users do not choose to deploy battery-related modules, they have the option of setting the readiness to the value (1-3) or the default value. Plug-ins for power availability compute readiness. AC power utilization of 7 will determine readiness.

The readiness value 1-3 represents the battery power source's balance. Since the node can reliably acquire AC power, the value should be changed from 6 to 7. Battery energy varies readiness from 1 to 3 to 0 to 7, enhancing the depth of the potential outcomes and optimizing node capacities. When power resources and readiness are optimized, it guarantees that all nodes have sufficient amounts of DC power, which increases their MPR chances. Figure 6 summarizes the readiness calculation [48].

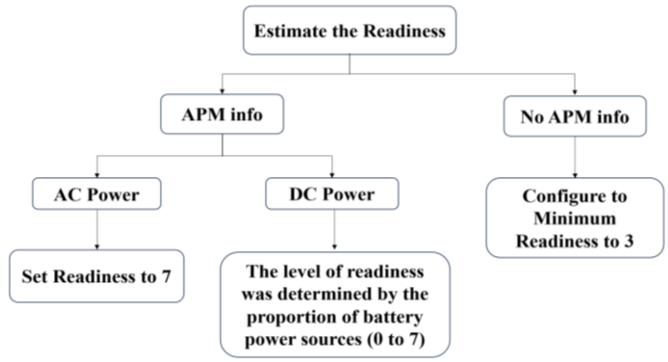

Figure 6 Readiness Calculation Flow Diagram

Table 1 Readiness and Its Values [59]

Degree of Readiness	Value
WILL_NEVER	0
WILL_LOW	1
WILL_DEFAULT	3
WILL_HIGH	6
WILL_ALWAYS	7

OLSR readiness scores vary from 0 to 7, with higher values indicating more routing participation. Specific values and meanings:

- 0: Node will not forward packets as an MPR.
- 1: Low MPR readiness for nodes with low resources or connection.
- 3: Default MPR readiness.
- 6: High readiness, suggesting a greater MPR chance.
- 7: Special usage or future extensions.

OLSR considers the node's connection quality, degree, and MPR coverage while computing readiness value.

3.3. Game Improvement Model for IOLSR

The following equation (2) is a definition of the game that was used here, which was adapted from FDG [54]:

$$G_p = [P_i, T_i, U_i] \tag{2}$$

where P_i is the player set, T_i is the Tactics set for the ith node (T_i = {Readiness_always, Readiness_never}), and U_i represents the Cost function of ith players.

The analogy between the game and an ad-hoc wireless network is seen in Table 2.

International Journal of Computer Networks and Applications (IJCNA)
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Table 2 The Analogy Between the Game and an Ad-Hoc Wireless Network

The Components of a Game	The Components Containing a Wireless Ad-hoc Network
Players	Network Node
Tactics	Two Tactics are considered here: i. Readiness Always ii. Readiness Never
Cost function	Then number of nodes after a time period.

Depending on its own and the other node's tactics, each node will get the cost function. We can mathematically represent the Cost function using equation (3).

$$U_i = \begin{cases} G_p & if\ T_i = readiness\ never\ and\ \exists T_j = readiness\ always \\ G_p - f(c_i) & if\ T_i = readiness\ always \\ 0 & if\ T_i = readiness\ never \end{cases} \quad (3)$$

where $f(c_i)$ is the cost function paid by node i, which conducts Update, and G_p is the gain gained by nodes that do not execute update while others perform update. Suppose that if the cost function is identical across all nodes ($f(c_i) = C_i$), then Table 3 may be used to show the cost matrix for every player.

Table 3 i^{th} Player Cost Function Matrix

		$\boldsymbol{P_i - 1\ Players}$	
		At least ith Readiness Always	Readiness Never
ith Player	Readiness Always	$G_P - C_i$	$G_P - C_i$
	Readiness Never	G_P	0

If the possibility that one player would choose readiness always is R_a, then the probability that another player will select readiness never is equal to 1 - R_a. Therefore, the possibility of this happening is equal to $(1 - R_a)^{P_i-1}$, assuming all $P_i - 1$ players choose the readiness never option. The formula for calculating the chance that at least one player would choose readiness always is as follows: $1-(1-R_a)^{P_i-1}$. Following equation (4) is an example of how the mixed strategy Nash equilibrium may be formed using Table 3.

$$\left(((1 - R_a)^{P_i-1})(G_p - C_i)\right) + \left((1-(1 - R_a)^{P_i-1})(G_p - C_i)\right) = (1-(1 - R_a)^{P_i-1})(G_p) \quad (4)$$

The following equation (5) may be used to determine the probability of selecting readiness always:

$$R_a = 1 - (C_i/G_p)^{1/(P_i-1)} \quad (5)$$

When the probability of choosing readiness always is equal to $1-\left(C_i/G_p\right)^{1/(P_i-1)}$, the mixed strategy Nash Equilibrium is valid. This was made clear by equation (5), stating that this condition met the requirement.

As can be seen in equation (5), the probability of selecting readiness always is influenced by the variables P_i, C_i and G_p. Given that P_i and C_i remain unchanging, the likelihood of selecting readiness always is determined only by the gain that G_p Offers. The gain obtained by updating grows in proportion to the speed, S, as well as the movement probability, M_p, of the nodes in an environment where the random waypoint model [56] is implemented. As a result, the gain may be stated using equation (6).

$$G_p = K.\mathrm{S}.M_p \quad (6)$$

where K is a constant, S is used to describe the speed, and M_p is used to denote the probability of movement. The speed of each node is determined by chance by the normal distribution using equation (7).

$$S = [S_{MIN}, S_{MAX}] \quad (7)$$

where $S_{MIN}\ and\ S_{MAX}$ stand for the lowest possible speed and the highest possible speed, respectively. Because a short pause time indicates a high chance of movement, the amount of time spent pausing may be understood to be equivalent to the probability of movement. As a result, the probability of movement of the node, denoted by M_p, may be stated using equation (8).

$$M_p = 1 - \left(\sum_{\forall i} t_p/T\right) \quad (8)$$

Where t_p indicates the pause time of the node, and T indicates the total amount of time that has elapsed. In each node, the game is repeated at 5 seconds, which is the default for the HELLO protocol. As a result, throughout each round of the game, each node is required to compute the probability of readiness always being ready and then utilize this value as a decision threshold (d_t). The decision maker, abbreviated as d_m, is an integer between 0 and l that is chosen at random. Each node will make a comparison of these two values and select its tactics to produce the probability readiness always based on the mixed tactics of the Nash equilibrium as described in equation (9).

$$\begin{aligned} &if\ \ d_m \le d_t \quad then\ select\ \text{readiness always} \\ &if\ \ d_m > d_t \quad then\ select\ \text{readiness never} \end{aligned} \quad (9)$$

In the event that the node makes the decision to use the readiness never strategy for the HELLO message as its tactic,

RESEARCH ARTICLE

the next round of the game will begin within the time limit that has been defined, depending on the simulation scenario. In addition, during regular operation, each node that makes up the OLSR is required to identify itself by broadcasting the HELLO messages at least once per TC interval. Because of this, it is generally accepted that the node will instantly pick the tactics readiness always option if the tactics readiness never option has been chosen for the five most recent games in a row.

3.4. Modified Node Readiness Algorithm

This section outlines the Modified OLSR algorithm in dense networks. The flowcharts in Figure 7, Figure 8 and Figure 9 depict the steps involved. The node Readiness is determined constructed on the node count, and all nodes in the network will undergo a surplus way while broadcasting HELLO messages. In Figure 9, the indexing of broadcasted and received HELLO messages is illustrated, with each node processing the sender's IP address and creating a unique index. This index is then used to count one-hop neighbor nodes for determining the node Readiness. The MPR selection algorithm is modified by both Algorithm 1, Algorithm 2 and Algorithm 3 while the remaining parts of the OLSR algorithm remain unchanged.

Step 1. Start

Step 2. Initialize network topology and node attributes

Step 3. Repeat until convergence or maximum iterations reached

Step 3.1 For each node N in the network Compute the Readiness score $R(N)$ for node N based on its attributes and neighbors

(i) Use the algorithm "Readiness Based on Node Count" to calculate $R(N)$ based on node count

(ii) Incorporate additional factors or metrics as desired to refine the Readiness calculation

Step 3.2 Update the MPR set for node N

(i) Set MPR_set(N) = empty set

(ii) For each 1-hop neighbor X of N

(a) Compute a score $S(X)$ for X based on $R(X)$, node count, and additional parameters

$$S(X) = R(X) * a + C(X) * b + f(sim\_time[X], sim\_time[0])$$

(Where a and b are weights for readiness and node count respectively)

($f(sim\_time[X], sim\_time[0])$ is a function to determine the contribution based on arrival time)

(b) Calculate $Pass\_Time[X] = sim\_time[X] - sim\_time[0]$

If $Pass\_Time[X] < t_1$,

then increase the value of $sim\_time[X]$

Else

Count the number of 1-hop neighbors of X (NodeCount(X))

If $sim\_time[X] > t_2$ and NodeCount(X) <= T, then:

Set Readiness (X) = WILL_NEVER

Else:

Set Readiness (X) = WILL_ALWAYS

Step 3.3 Update routing tables and control traffic

(i) Use MPR_set(N) information to optimize routing and minimize control traffic

(ii) Exchange routing information with neighboring nodes as per the OLSR protocol

(iii) Update routing tables and control traffic parameters based on the broadcast and received information

Step 4. End

Algorithm 1 Improved OLSR Algorithm Based on Readiness

Step 1. Start

Step 2. For each node N in the network

(i) Count the number of 1-hop neighbors of N(NodeCount (N))

(ii) Set Readiness (N) = 1 / (1 + NodeCount (N))

(The reciprocal of the node count is used to assign higher Readiness to nodes with fewer neighbors)

Step 3. End

Algorithm 2 Readiness Based on Node Count

Step 1. Initialize an empty data structure to store the index of Hello messages for each node (e.g., a dictionary or a list of sets).

Step 2. For each Hello message broadcast and received:

(i) Extract the IP address of the sending node that are broadcasted.

(ii) Check if the IP address already exists in the data structure:

(a) If the IP address is already present, ignore the Hello message as it is a duplicate from the same node.

(b) If the IP address is not present, proceed to the next step.

RESEARCH ARTICLE

Step 3. Add the IP address to the data structure and associate it with the index of the Hello message broadcast and received.

Step 4. Repeat steps 2-3 for all Hello messages broadcasted and received.

Algorithm 3 An algorithm to Scale All Hello Messages Broadcasted and Received by Each Node While Ignoring Duplicate Messages from the Same Node

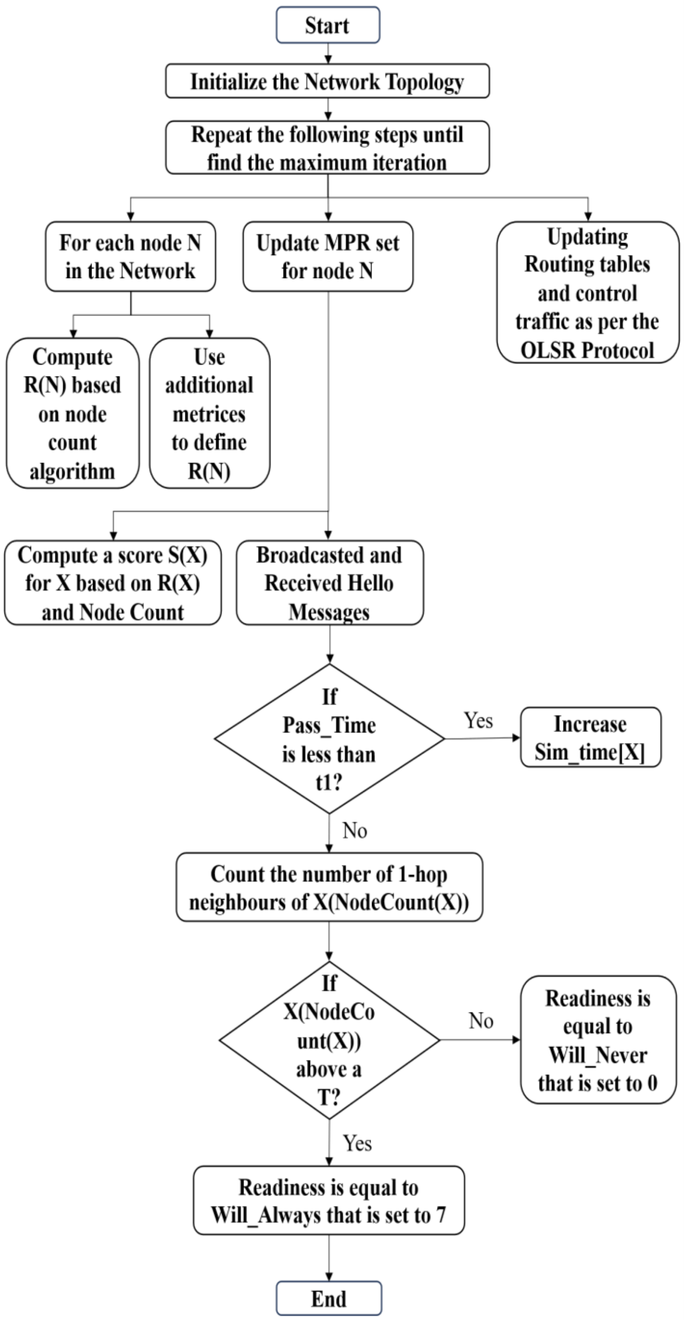

Figure 7 Flowchart of Algorithm 1

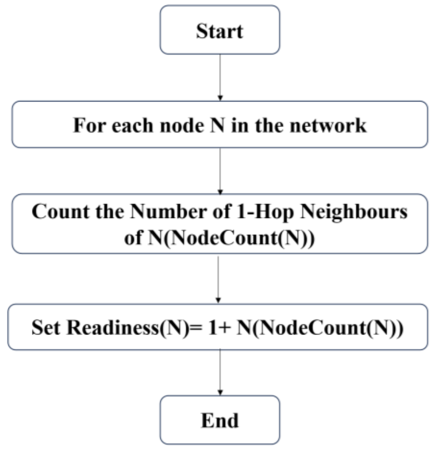

Figure 8 Flowchart of Algorithm 2

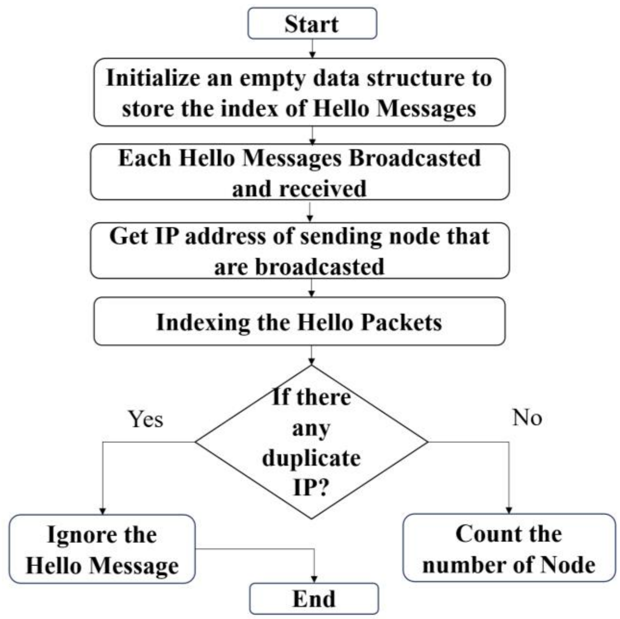

Figure 9 Flowchart of Algorithm 3

4. RESULT AND DISCUSSION

4.1. Simulation Parameters

The simulator in our simulation is ns-3 (version 3.29). The simulation environment consists of nodes with IEEE 802.11 interfaces that are randomly dispersed across a 300 × 300 square meter area and have a transmission range of 50 meters. HELLO messages are sent for the entire 5 s, while TC messages are sent every 8 seconds. The "WILL_DEFAULT" readiness setting is used by all nodes. The source node delivers a 12800-bit packet to the destination node every 0.1 seconds, with a stop duration of zero, guaranteeing that the nodes move continuously during the simulation. UDP is utilized as a transport protocol. Each scenario is run for 900

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RESEARCH ARTICLE

seconds; however, the first 100 seconds are ignored in order to focus on the following 800 seconds while measuring routing traffic. The simulation is run ten times, with nodes set at random each time. Table 4 contains a summary of the simulation arrangements.

Table 4 Simulation Parameters

Parameter	Value
Network Simulator	Network Simulator - 3
Simulation time	900 seconds
Simulation Area	300m × 300m
Number of nodes	50, 100, 150, 200, 250, 300 and 350
Protocol used	OLSR
Nodes deployment	Random Way Point
Number of seeds	15
Transport protocol	UDP
Transmission range	50m
IP	IPv4
Physical layer method	PHY 802.11n
MAC Protocol	IEEE 802.11
Transmit power	0.0015W
Packet Size	16 kilobyte/sec
Node speed (m/s)	0-1
Pause time	0 seconds

4.2. Performance Metrices and Simulation Results of OLSR and IOLSR

Figure 10, 11, 12, 13, 14 portrays the simulation findings for each statistic. The outputs of both the typical OLSR and the more enhanced OLSR, labeled as "OLSR" and "Improved OLSR" (or IOLSR), respectively, are displayed in each graph. Five metrics are used in this study: the MPR Ratio, the ROR Ratio, the EtE Delay, the PDR Ratio and the Throughput.

4.2.1. Multi-Point Relay ratio (MPR Ratio)

The Multipoint Relay Ratio are derived by dividing the total amount of nodes by the Multipoint Relay. MPR Ratio is given in equation (10).

$$Multipoint\ Relay\ Ratio\ = \frac{Multipoint\ Relay}{Number\ of\ nodes\ in\ the\ network} \tag{10}$$

Figure 10 illustrates the Multi-Point Relay ratio comparison between OLSR and Improved OLSR. In dense networks, the Multi Point Relay ratio will eventually reach 1 [52]. From Figure 10 we see that there is over 5% redundancy when the number of nodes is 150. Now the redundancy is reduced when the number of nodes is 300 to 350 (5% in 150 nodes and 2% in 350 nodes). In this scenario, the redundancy is high when the amount of nodes is low, and consequently, the redundancy is reduced when the number of nodes is increasing, and this reduction rate is reduced from 5% to 2-1%. The reason behind this, decreasing the percentage of redundancy in the case of more nodes means decreasing the MPR Selection Rate. The lower the MPR Selection Rate, the lower the number of duplications of Hello Message and the complexity of the network will be less.

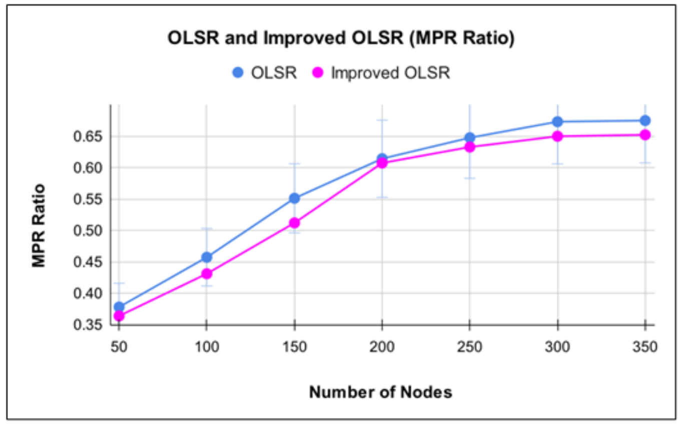

Figure 10 MPR Ratio

4.2.2. Routing Overhead Ratio (ROR)

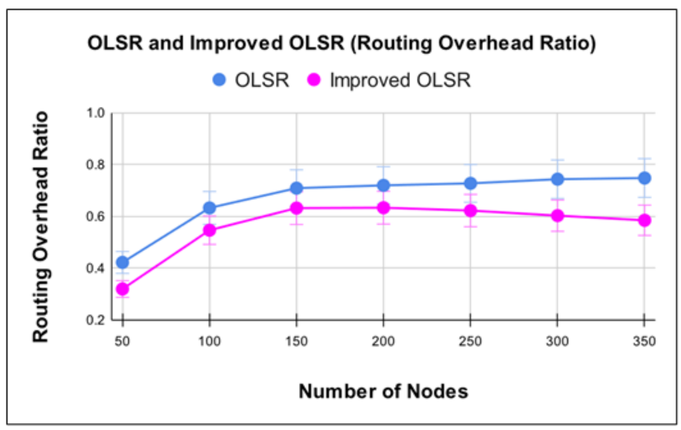

Figure 11 ROR

It is derived by dividing the total amount of data packets successfully transported throughout the network by the total amount of control overhead messages sent. OLSR routing overhead equals the sum of the HELLO messages, and Topology Control is given in equation (11).

OLSR ROR = HELLO messages + Topology Control (11)

Figure 11 illustrates the Routing Overhead ratio juxtaposition between OLSR and Improved OLSR. From Figure 11 we see

RESEARCH ARTICLE

that there is a distinct difference in Routing Overhead Ratio between OLSR and Improved OLSR. This difference is 1% in a low-dense network (150 nodes) and 2.5% in a high-dense network (350 nodes).

This scenario shows a notable reduction in the ROR ratio. This diminution stems from the selection of fewer MPRs. As a result, it implies that ample bandwidth will be available for each node.

4.2.3 Packet Delivery Ratio (PDR)

PDR is the amount of packets acknowledged divided by the total amount of packets conveyed. PDR is used to assess how well deliveries were made. It may be determined using equation (12) and shows the success rate of a routing mechanism.

$$PDR = \frac{\sum Number\ of\ packets\ successfully\ received\ by\ the\ destination\ (R_n)}{\sum Total\ number\ of\ packets\ sent\ by\ the\ source\ (S_n)} \quad (12)$$

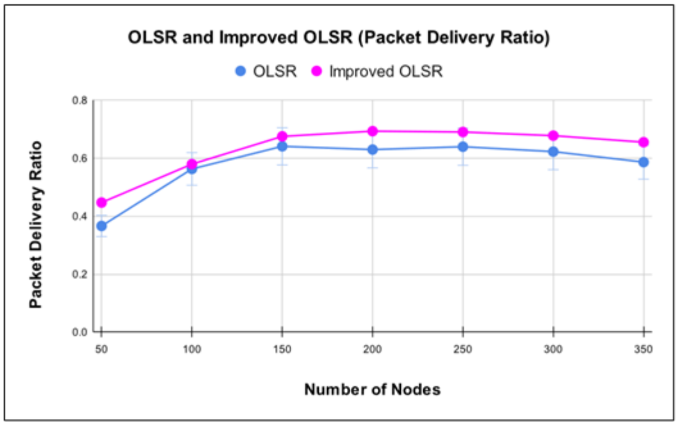

Figure 12 PDR

Figure 12 illustrates the Packet Delivery ratio comparison between OLSR and Improved OLSR. In networks with small to medium density, PDR ratios have decreased noticeably. In the case with 50 nodes, both the improved and traditional OLSR indicate a PDR of less than 42%. The reason for this low PDR lies in the periodic recalculation of route links due to the extensive movement of all network nodes; however, the limited availability of different links leads to significant packet loss. In networks with medium to high density, the presence of various links, regardless of node movement, results in a greater PDR. A noticeable enhancement in the PDR ratio is observed, except for 150 nodes, where the rise is 3%.

4.2.4. End-to-End Delay (EtE Delay)

The time it takes to convey a packet through numerous nodes. Because delay is tied to time, it's in milliseconds. Network quality improves with lower delay values. Equation (13) calculates average delay.

$$Delay = \frac{Time\ packet\ received - Time\ packet\ sent}{total\ package\ received} \quad (13)$$

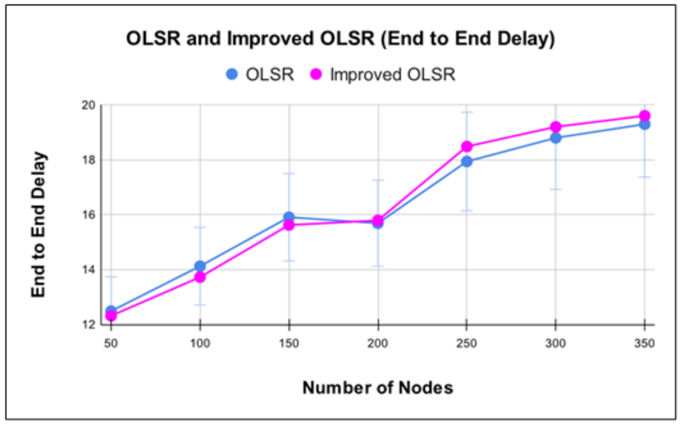

Figure 13 EtE Delay

Figure 13 illustrates the End-to-End Delay comparison between OLSR and Improved OLSR. OLSR works as a proactive protocol with low latency, given that the routes are easily accessible when needed. In a low-dense network scenario, the delay is about 12.1 to 12.3 ms for OLSR and IOLSR. As traffic increases to 200 nodes, the delay is about 16 ms for OLSR and IOLSR. When traffic is at its pick point, the delay is approximately 18-19 ms for both OLSR and IOLSR. From this analysis, we can say that this delay is negligible for both OLSR and IOLSR.

4.2.5. Throughput

Throughput: Throughput is specified as the average rate of ecstatic message delivery over a conveyance channel. It assesses the amount of worthwhile data that is conveyed from the entry nodes to the targeted nodes without loss, within the encountered time interval. Equation (14) calculates the throughput.

$$Throughput = \frac{P_{recv} \times S_{packet}}{T_{total}} \quad (14)$$

Figure 14 compares the throughput performance of the traditional OLSR protocol with the Improved OLSR protocol across varying node densities, ranging from 50 to 350 nodes. Both protocols show a consistent decrease in throughput as the number of nodes increases, reflecting the common behavior in MANETs where network congestion and control overhead increase as more nodes are added. At 50 nodes, both OLSR and Improved OLSR exhibit similar throughput, close to 100 units. However, as the network size increases, the throughput of OLSR declines more sharply, dropping to approximately 75 units at 350 nodes, while improved OLSR remains more stable, only decreasing to about 80 units at the same node count. The Improved OLSR protocol likely includes enhancements such as better management of routing overhead, more efficient route selection or optimization of

RESEARCH ARTICLE

control messages, which contribute to its more stable throughput under increased node densities.

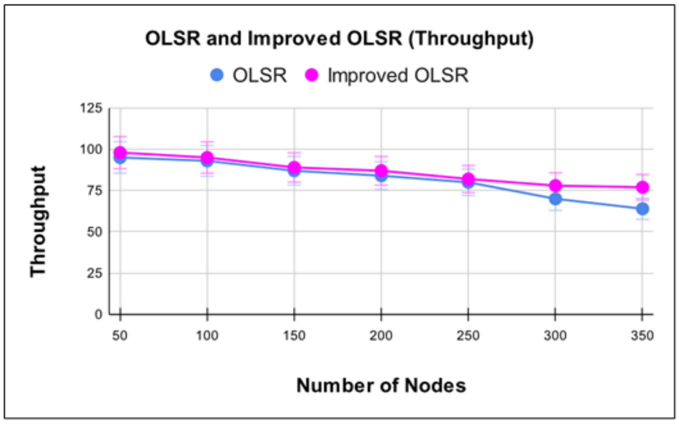

Figure 14 Throughput

In this analysis, we are comparing our enhanced protocol with the one presented by Kitasuka et al. [39]and another one represented by Omuwa Oyakhire et al. [37]. In both cases, the goal is to minimize the MPR ratio within closely connected networks. Kitasuka et al. [39] suggests employing shared MPR sets to reach this goal, while our approach employs node density as a means to drop the MPR ratio. Through a comparative examination, we observe that both methods substantially diminish the MPR ratio. However, a subtle distinction arises when our method is applied to extremely dense networks. Kitasuka et al. [39] use 300 nodes for a dense scenario and Omuwa Oyakhire et al. [37] use 200 nodes for a dense network, whereas we consider 350 nodes for a dense network scenario.

In practical scenarios, we do not know how many nodes we need to handle. To summarize the simulation results, we can see that the MPR ratio value of IOLSR is slightly lower than that of conventional OLSR. Our result satisfies the intuition of the performance that lower the MPR selection rate, the lower the number of duplications of Hello messages. If we calculate the average ROR value of OLSR and IOLSR, we find that IOLSR has a lower ROR value than conventional OLSR. The PDR value is much higher for every scenario for IOLSR than OLSR. The EtE value is quite similar for both OLSR and IOLSR. IOLSR has an improved throughput, more stable than OLSR in dense networks.

Here, we compare our value to Kitasuka et al. [39] and Omuwa Oyakhire et al. [37], and we find that our MPR ratio is much lower than their value, and we find the lower MPR ratio. From Table 5, if we compare our IOLSR value for the MPR ratio for node 200, which is 0.60, with Omuwa Oyakhire et al. [37], whose MPR ratio for node 200 is 0.63, we can observe the difference. If we consider a broder network scenario with 350 nodes, we find that the MPR ratio for this scenario is 0.65, which is slightly higher than the ratio for the 200-node scenario mentioned earlier. But this MPR ratio is acceptable in the 350-node scenario because decreasing the percentage of redundancy with more nodes means decreasing the MPR selection rate. The lower the MPR selection rate, the lower the number of duplications of Hello Message and the complexity of the network will be less. Table 5 represents the details of performance analysis result simulation value.

Here’s a comparison of our findings with Kitasuka et al. [39] and Omuwa Oyakhire et al. [37] is shown in Table 6.

The proposed model (IOLSR) enhances the performance of the OLSR routing protocol by integrating game theory with dynamic node readiness based on local node density. Each node strategically chooses between readiness always and readiness never using a nash equilibrium approach, reducing unnecessary MPR selection in dense networks. The model further avoids HELLO message duplication through a broadcast indexing mechanism, and assigns higher readiness to nodes with fewer neighbors or stable power sources. These innovations collectively reduce control overhead (ROR), lower the MPR ratio, improve packet delivery (PDR), and maintain stable throughput even as network density increases making the protocol more scalable, energy efficient and suitable for real-time mobile applications.

Table 5 Details of Performance Analysis Result

Number of Nodes	MPR		ROR	
	OLSR	IOLSR	OLSR	IOLSR
50	0.377991	0.363852	0.42260	0.320120
100	0.457297	0.431036	0.63295	0.546896
150	0.551250	0.512022	0.70925	0.632370
200	0.614330	0.607420	0.72004	0.633810
250	0.647699	0.632891	0.72775	0.622650
300	0.673210	0.650010	0.74373	0.603210

350	0.675070	0.652340	0.74829	0.585230
	PDR		EtE Delay	
	OLSR	IOLSR	OLSR	IOLSR
50	0.366580	0.447491	12.488985	12.318207
100	0.563428	0.579978	14.126827	13.728331
150	0.641450	0.675776	15.911039	15.626394
200	0.630207	0.693727	15.691446	15.793928
250	0.640092	0.690834	17.942465	18.488969
300	0.623180	0.678240	18.803730	19.204750
350	0.586930	0.655740	19.302580	19.609210
	Throughput			
	OLSR	IOLSR		
50	95	98		
100	83	95		
150	87	89		
200	84	87		
250	80	82		
300	70	78		
350	64	77		

Table 6 Our Findings vs Kitasuka et al. [39] and Omuwa Oyakhire et al. [37]

Metric	Our Findings (IOLSR)	Kitasuka et al. [39]	Omuwa Oyakhire et al. [37]
MPR Ratio	Significantly reduced MPR ratio, particularly in dense networks (350 nodes) (Satisfied the condition of H1)	High redundancy with 300 nodes in dense network	MPR ratio reduced, nut still moderate
Packet Delivery Ratio (PDR)	Improved PDR in all scenarios, especially in medium to high density networks (Satisfied the condition of H2)	PDR not significantly addressed	PDR improves in medium to high density networks
Routing Overhead Raio (ROR)	Lower ROR (2-2.5% reduction in high density networks) (Satisfied the condition of H3)	Not specifically reported	ROR reduced slightly (1% in 150 nodes, 2.5% in 350 nodes)
End-to-End (EtE) Delay	Similar EtE delay for OLSR and IOLSR, negligible increase in high density scenarios (Satisfied the condition of H4)	Not reported in detail	Minimal effect on delay
Throughput	Improved throughput, more stable than OLSR in dense networks (Satisfied the condition of H5)	Not reported in detail	Throughput improves with network density

5. CONCLUSION

This work introduces a method designed to enhance the Optimized Link State Routing protocol for mobile contexts. This method is grounded in game theory, with all nodes engaging in a basic game to determine node readiness based on its density. Each node can opt between two readiness states: READY_ALWAYS or READY_NEVER. We executed our design in Network Simulator 3.0 and set it against the genuine OLSR protocol. In our study, we looked into MPR selection within wireless multihop networks of high density. We examined the proximity to a two-hop neighbor in these networks and noted that nodes near the edge of a two-hop disk are unlikely to be a two-hop neighbor of source node. Based on this, we hypothesized that a limited number of MPRs might encompass all two-hop neighbors of a given node, even in networks with high density. The data revealed our modified protocol surpassed the standard OLSR across most metrics, with the exception of a slight end-to-end delay. Our test simulations suggest the algorithm is viable for real-time tasks, notably for multimedia tasks within multihop networks.

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RESEARCH ARTICLE

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