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Original Paper

An enhanced optimized link state routing (E-OLSR) protocol for efficient control messaging and load management in shortwave ad hoc networks

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ABSTRACT

In shortwave self-organizing networks, periodic messaging can consume significant channel resources, increase network control overhead, and waste limited bandwidth, leading to a sharp decline in network communication performance. In order to solve these problems, an Enhanced Optimized Link State Routing (E-OLSR) protocol for a shortwave ad hoc network with low delay is put forward in this paper. The E-OLSR protocol combines an adaptive control message scheduling and a load-aware routing method by modifying the OLSR to enhance the process of route discovery and the MultiPoint Relay (MPR) selection algorithm. The protocol minimizes unnecessary overhead by adapting control message intervals to network conditions and by prioritizing critical updates messages. Meanwhile, load-aware routing is used for traffic balancing, congestion avoidance, and delay reduction. The proposed E-OLSR was experimented extensively on various network sizes ranging from 10 to 50 nodes. Simulation results demonstrate that the E-OLSR yields substantial improvements in terms of control overhead, packet delivery success rate, end-to-end delay, and throughput. Specifically, E-OLSR reduces control overhead by approximately 15% compared to II-OLSR and 25% compared to OLSR in a network with 50 nodes. Also, it achieves an 8-15% higher packet delivery success rate, decreases end-to-end delay by 30-40%, and improves throughput by 20-30% across varying network sizes. These results highlight the efficiency and reliability of E-OLSR in addressing the challenges of low-latency shortwave networks.

Keywords: *Adaptive control messaging, Load-Aware routing, Low-Latency routing, Multipoint relay selection, Optimized link state routing*

1 INTRODUCTION

Although the Optimized Link State Routing (OLSR) protocol is effective in a range of applications, it encounters significant challenges when applied to shortwave ad hoc networks [1]. These networks operate in areas with an unpredictable topography, such as those encountered in military operations and disaster relief efforts. In such environments, wireless links may become unstable because of obstacles like terrain features, buildings, and foliage, or changes in antenna orientation and received signal quality [1, 2] . This instability leads to asymmetrical links in which the quality of the link differs in the forward and the return direction, and intermittent connectivity in which the link often goes up and down [3]. The asymmetry and instability of wireless channels in shortwave ad hoc networks can severely undermine the performance of the network. Conventional OLSR protocols are dependent on periodic control messages to maintain the most recent routing information. However, this method may suffer from inefficient bandwidth utilization, overhead of control packets, and longer end-to-end delay in a highly dynamic environment [4]. Thus, communication becomes unreliable and fails to operate in a timely manner. This is critical in cases where fast and reliable communication is needed, such as coordinating military movements or disaster response [5].

The OLSR protocol is widely used in ad hoc networks due to its efficiency in maintaining routing tables through periodic control messages. However, in shortwave self-organizing networks, the periodic messaging required by OLSR can consume significant channel resources. This increases network control overhead, and wastes limited bandwidth, leading to a sharp decline in network communication performance. Various enhancements to the OLSR protocol have been proposed to address these challenges [6, 7]. Among these, the STEP system was developed to improve user traffic prediction in cellular networks, a crucial aspect for improving network performance and reducing latency [8]. In 2022, a comprehensive review was provided for communication technologies in Internet of Vehicles, emphasizing the OLSR protocol in ad hoc networking for vehicular communication [9]. In [10], a study was dedicated to exploring the potential of device-to-device communications in 6G, underscoring the importance of low-latency links for future network applications. The study in [11] proposed a robust SDN-based architecture for heterogeneous time-sensitive networking, addressing critical latency and reliability issues. Recently, an investigation was conducted on the application of 5G technologies in data link systems, highlighting the transition to ultra-reliable low-latency communications [12]. In [13], the authors discussed 5G's military applications, showcasing the necessity for private network architectures to support low-latency and high-security requirements.

The work in [14] conducted a stochastic geometry analysis on mmWave cellular networks, providing insights into their applicability in low-latency scenarios. Recent work has reviewed evolving HPC requirements, with a focus on optical networks for low-latency data transmission [15]. Similarly, challenges in sustainable smart cities have been explored, particularly the role of low-latency communication technologies [16]. Further studies surveyed resource management in 6G networks, highlighting advanced strategies to meet stringent latency demands [17]. In mobile ad hoc networks, significant improvements were demonstrated through their proposed protocols [3].

Significant research efforts have focused on low-latency optimization [18–20]. The study in [18] explored radio resource management in 5G and Wi-Fi vehicular scenarios, providing key insights into maintaining low latency in hybrid networks. Also, the work in [19] discussed symbiotic radio, presenting a novel approach to spectrum sharing that could enhance low-latency communications. Research presented in [20] explored multicast communication difficulties in MANETs, which depend solely on peer-to-peer connections between mobile devices in infrastructure-less environments. Due to unpredictable connectivity and frequent topology changes, the authors in [20] adopted a model named the Publish/Subscribe model. This model leverages intermediary brokers for efficient message dissemination.

The review study in [21] conducted a comprehensive survey on graph-based deep learning techniques applied to communication networks. This review provided insights on the potential of graph-based deep learning techniques to make networks more efficient, robust, and scalable. In [21], the main focus was on applications in areas such as 5G, and IoT underscored its importance for advancing modern communication systems. The study in [22] suggested a method in a manner of graph clustering for data assimilation by adaptive covariance tuning. The authors utilize state-observation mapping to improve localization in high-dimensional systems. Further research in [23] gave a temporal multiplex network interpretation of the rock–paper–scissors dynamics. This work emphasizes the links between temporal dynamics and network structure. This interdisciplinary approach has potential applications in fields like ecology, economics, and social systems.

Nevertheless, even though there have been serious attempts to improve the OLSR protocol, the current solutions are not always able to adequately handle the specifics of shortwave ad-hoc networks. These networks, having a dynamic and unstable nature, are plagued with problems like link asymmetry, intermittent connectivity, and a highly variable topography [3]. A lot of research studies have been devoted to enhancing OLSR by focusing on individual aspects, such as control message scheduling and Multipoint Relay (MPR) selection. However, few studies have tried to address together several of the aforementioned obstacles [19]. The challenges for a dedicated network control mechanism in these dynamic environments requires an integrated solution which addresses the issues of overhead, communication performance and reliability. In the conventional OLSR, there is no redundancy check or prioritization based on link reliability or coverage overlap. Instead, the focus in MPR selection of the OLSR is to select the set of 1-hop neighbors that is minimal in size and reaches all 2-hop neighbors. It does not consider the link quality or connectivity degree.

This paper proposes an Enhanced Optimized Link State Routing (E-OLSR) protocol tailored for low-latency shortwave ad hoc networks. Our E-OLSR protocol integrates adaptive control message scheduling and load-aware routing. These mechanisms aim to improve route discovery and MPR selection. By dynamically adjusting control message intervals based on network stability and prioritizing critical updates, the protocol minimizes unnecessary control overhead and ensures efficient use of bandwidth. Additionally, the introduction of load-aware routing balances network traffic, reduces congestion, and minimizes communication delays, making the protocol highly suitable for challenging shortwave network scenarios.

This paper is organized into five sections including the current introductory section on OLSR. Section 2 is dedicated to reviewing related work. Section 3 introduces the proposed algorithm, while Section 4 details the evaluation and discusses the obtained results. Finally, Section 5 concludes the work and suggests future research directions.

2 RELATED WORK

This section surveys two main categories of work. First, we review studies concerning the end-to-end delay in communication. Second, we review research works about the MPR selection algorithms.

2.1 The end-to-end delay in communication

The end-to-end delay in communication within shortwave self-organizing networks can be significantly impacted by various factors, including the types of radio stations used, such as vehicle-mounted, handheld, and backpack radios, each with differing signal transmission power and coverage areas [8]. Additionally, terrain, antenna orientation, and individual differences in reception performance contribute to the presence of asymmetric links within the network [14]. The OLSR protocol, designed to utilize only symmetric links, may result in redundant forwarding by relay nodes when creating routing entries to the destination node in the routing table, thereby increasing the end-to-end communication delay [11]. This redundancy can also cause relay nodes along the transmission path to become overloaded, leading to an imbalance in the node load across the network [10]. For instance, as illustrated in Figure 1, an asymmetric link between node E and node F requires the OLSR protocol to route data packets through an intermediate node D, which increases the transmission delay [3]. When nodes A, B, and C communicate with nodes E, G, H, and I, all data packets are forwarded by node D. Due to limited shortwave bandwidth resources, node D becomes overloaded, causing a network load imbalance. This imbalance results in increased queuing delays for data packets passing through node D, leading to network congestion and higher packet loss rates, which significantly degrade network performance [17, 19] .

2.2 The traditional mpr selection algorithm

The traditional MPR selection algorithm is a fundamental component of the OLSR protocol. Its main objective is to minimize the number of Topology Control (TC) messages that flood the network. This ensures that all nodes quickly and efficiently acquire the complete network topology, thereby reducing network control overhead [9]. However, the traditional MPR selection algorithm employs a greedy approach that prioritizes one-hop neighbor nodes based on the number of two-hop nodes to which they connect, which often results in a suboptimal and redundant set of MPR nodes [3].

The problem is further worsened by redundant MPR nodes flooding TC messages in the network, which dramatically increases the network control overhead. This exponential growth of control messages is even more serious in a shortwave network, where the available bandwidth is scarce and susceptible to variability [19]. The constrained and time-varying nature of shortwave channel bandwidth reduces the available instantaneous frequency bandwidth for communication, increasing the likelihood of network congestion. Therefore, message packets may accumulate, and control messages' routing information may expire. This potentially leads to network collapse in severe cases [11].

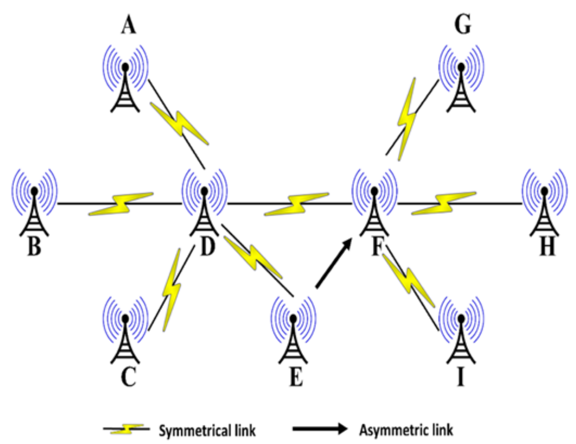

Fig. 1 Schematic diagram of data transmission

Moreover, the traditional MPR selection algorithm does not account for link reliability between nodes. When multiple one-hop neighbor nodes offer the same connectivity and coverage, the algorithm randomly selects an MPR node without considering the quality of the link between the selected MPR node and the local node. This oversight can lead to higher packet loss rates, as less reliable links are more prone to failure and degradation, adversely affecting network performance [17].

3 PROPOSED ALGORITHM

In order to solve the aforementioned problems faced by the shortwave ad hoc network OLSR routing protocol, this paper proposes a low-latency shortwave ad hoc network OLSR protocol, which improves the route discovery and selection mechanism and the MPR selection algorithm of the original OLSR protocol. To address the issue of high communication delay caused by asymmetric links in shortwave ad hoc networks, this paper proposes a common neighbor detection mechanism to detect asymmetric links in the network. Asymmetric links are used in route calculation to reduce communication delay and improve network performance.

3.1 Preliminaries and design rationale for e-olsr

In the OLSR routing protocol, nodes calculate the routing table by sending HELLO and TC messages. When running the OLSR protocol, the length of the HELLO message sent by each node in the network per unit time can be expressed as follows:

$$\mathrm{Len}_{\mathrm{Hello}} = \mathrm{SL}_{\mathrm{Hello}} \times \frac{1}{T_{\mathrm{HELLo}}} \tag{1}$$

where $\mathrm{Len}_{\mathrm{Hello}}$ and T_{HELLo} represent the average length of a HELLO message and its broadcast cycle, respectively. Therefore, the length of the TC message sent by the MPR node per unit time can be formulated as follows:

$$\mathrm{Len}_{TC} = \mathrm{SL}_{TC} \times \frac{1}{T_{TC}} \tag{2}$$

where SL_{TC} represents the length of a TC message, and TTC represents the broadcast period of the TC message. Since TC messages need to be broadcast to the entire network, and each TC message needs to be forwarded by the MPR neighbor nodes, the length of a TC message per unit time can be expressed as follows:

$$\mathrm{Len}_{T\_TC} = (N_{EM} - 1) \times N_M \times \mathrm{SL}_{TC} \times \frac{1}{T_{TC}} \tag{3}$$

where N_{EM} represents the number of MPR nodes in the entire network, and NM represents the average number of MPR nodes selected by any node in the network.

The total control overhead generated by the entire network per unit time can be expressed by:

$$\begin{aligned} \mathrm{TOTAL} &= \sum_{i=1}^{M} \mathrm{Len}_{\mathrm{asy\_link\_notice}} \sum_{i=1}^{M} \mathrm{Len}_{\mathrm{Hello}} \\ &\quad \sum_{j=1}^{N_{EM}} \left(\mathrm{Len}_{TC} + \mathrm{Len}_{T_{TC}} \right) \\ &= \sum_{i=1}^{M} \mathrm{Len}_{\mathrm{asy\_link\_notice}} + \sum_{i=1}^{M} \mathrm{SL}_{\mathrm{Hello}} \mathrm{X} \frac{1}{T_{\mathrm{Hello}}} + \\ &\quad \sum_{j=1}^{N_{EM}} \left(1 + (N_{ES} - 1)\, \mathrm{XN}_M\right) \mathrm{XSL}_{TC} \mathrm{X} \frac{1}{T_{TC}^{0}} \end{aligned} \tag{4}$$

where $Len_{asy\_link\_notice}$ represents the length of the asymmetric link notification message sent by each node in the network per unit time.

Reducing either the number of MPR nodes in the entire network or the length of control messages can reduce network control overhead. The improved protocol uses the BLR-MPR selection algorithm when selecting MPR nodes. This effectively reduces the number of MPR nodes in the network. Because TC messages are sent regularly and flooded throughout the network, the number of TC messages in the network can be significantly reduced. Asymmetric link notification messages are not sent regularly, and the sending timing is determined by the actual network environment. Therefore, the E-OLSR protocol can effectively reduce the control overhead of the network.

Since the routing algorithm of the E-OLSR protocol supports asymmetric links, the paths containing asymmetric links are selected for packet transmission. Hence, a balance is achieved between the load of each node in the network and its surrounding communication links, which reduces the packet loss rate. Additionally, the BLR-MPR algorithm selects the node with the greatest link reliability will be selected as the MPR node when the coverage and connectivity of one-hop neighbor nodes are the same. This enables the proposed E-OLSR to improve the reliability of data packet transmission. Also, the E-OLSR protocol supports backup routing, which enhances the robustness of routing. Therefore, compared with the OLSR protocol, there will be a corresponding improvement in the data packet delivery success rate.

With respect to the total end-to-end delay as Latency, the total delay of the N-hop link is calculated as follows:

$$\text{Latency} = \sum_{i=1}^{N} d_{\text{i}} \tag{5}$$

where d_i represents the total point-to-point delay incurred by the i-th hop.

While latency is broadly defined as the time required for a packet to traverse from the source to the destination, in this work, we specifically measure and report end-to-end delay, which provides a practical, network-level assessment of latency.

The asymmetrical link detection method is outlined in Figure 2. When node A, node B, and node C in the network periodically exchange HELLO control messages, node C (a common one-hop neighbor of node A and node B) detects an asymmetric link. After node B establishes a symmetric link, it immediately parses the locally cached HELLO messages of node A and node B. When node C parses node A's HELLO message, if it finds that node A's HELLO message contains node B's neighbor entry and the neighbor type is marked as an asymmetric neighbor, but node B's HELLO message does not contain any information about node A. This indicates that an asymmetric link exists between nodes A and B from node B to node A. Thus, node C unicasts and forwards the HELLO message of the downstream node A of this asymmetric link to the upstream node B of the asymmetric link, informing node B that there is a forward asymmetric link to node A. This HELLO message does not contain the common neighbor entries of node A and node B. The source address of the message is set to the address of the downstream node A of the asymmetric link, and the reserved field of the HELLO message packet is marked as "1", indicating that this message is an asymmetric link notification message. Upon receipt, node B parses the value of the reserved field and learns that this is an asymmetric link notification message. It immediately parses the content of the message and updates its neighbor information table.

The update process of the neighbor table is as follows:

1. Add node A to the one-hop neighbor table, and the link status is marked as F_{ASYM}, which is a forward asymmetric link.

2. Add the neighbor table entries with forward asymmetric links and symmetric links of this HELLO message to the two-hop neighbor table one by one. The one-hop neighbor connected by these two-hop neighbors is node C.

The common neighbor detection mechanism effectively detects the asymmetric link in the network. Therefore, the upstream node of the asymmetric link can use this asymmetric link during routing selection to reduce the length of the packet transmission path and reduce the end-to-end delay. When multiple paths with the same length to the destination node are calculated, the path with the largest number of asymmetric links is selected for transmission. At the same time, when a route fails, another path with the shortest length and the highest number of symmetric links is selected from the routing table as a backup route. This ensures the robustness of the route while maintaining low latency and saving network resources.

3.2 Blr-mpr selection algorithm

The MPR node set selected by the traditional MPR selection algorithm using a greedy algorithm may be redundant. Redundant MPR nodes will also flood TC messages to the entire network, increasing control overhead and exacerbating the channel load. When the connectivity and coverage of neighbor nodes are the same, a node will be randomly selected as the MPR node of the local node; however, this node likely has poor link reliability, which will cause routing failure and message packet loss that increases the communication delay.

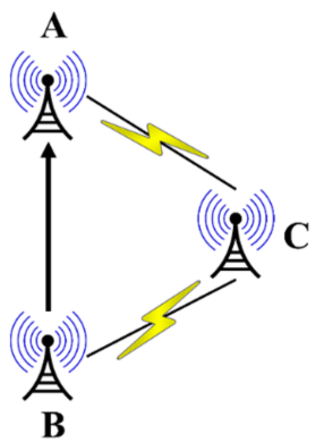

Fig. 2 Types of links

To this end, in this work, we propose an MPR selection algorithm based on link reliability (MPR Selection Algorithm Based on Link Reliability BLR-MPR) to optimize the traditional MPR selection algorithm.

This work uses the success rate of receiving HELLO messages from a one-hop node to define the reliability of the link from one-hop node to this node. The specific operation steps are as follows:

Step 1: The node locally counts the number of HELLO message packets received from all one-hop nodes.

Step 2: Extract the "sequence number" field from the header of the last HELLO message received by each one-hop node to obtain the number of HELLO messages sent by one-hop neighbor nodes.

Step 3: Calculate the success rate of HELLO messages received from one-hop neighbors, that is, the ratio of the number of HELLO messages received from one-hop neighbors to the number of HELLO messages sent by them.

The specific BLR-MPR selection algorithm is as follows:

Step1: Initialize the MPR set S to be an empty set.

Step 2: Check the number of symmetric links established by two-hop neighbor nodes and one-hop neighbor nodes. If the two-hop neighbor node of the local node has only established a bidirectional link with one one-hop neighbor node, add the one-hop neighbor node to set S.

Step 3: Calculate the connectivity of all nodes in the one-hop neighbors, and select the node with the largest connectivity to add to S. If the connectivity degree is the same, select the node with the largest coverage; if the connectivity degree and coverage degree are the same, select the node with the highest link reliability among multiple one-hop neighbor nodes. Then, one-hop nodes are added to the set S.

Step 4: Repeat Step 3 until the nodes in set S can cover all two-hop neighbor nodes of the local node.

Step 5: Sort the elements in the set S according to the degree of connectivity from largest to smallest, and check in turn whether the other nodes in S can reach all the two-hop nodes of the local node without including the node with the largest degree of connectivity. If it can be reached, all two-hop nodes, indicating that the node with the largest connectivity is the redundant node MPR point in the currently selected MPR set, directly remove the node from S; if the remaining nodes cannot reach all two-hop nodes, it means that the node must be used as an MPR node and will not be processed. After traversing and checking all one-hop nodes in set S, the algorithm ends.

The operation flow of the BLR-MPR selection algorithm is shown in Figure 3. The MPR selection algorithm in the original protocol selects the MPR set based only on the number of one-hop neighbors and its connected two-hop neighbors. Nodes with high connectivity are often redundant nodes, which can lead to redundancy in the MPR set. The BLR-MPR selection algorithm first selects the initial round of MPR node sets through greedy thinking, and then reversely optimizes the MPR node set selected in the first round, starting with the nodes with the largest connectivity, and eliminating the nodes selected in the first round. Redundant MPR nodes reduce network control overhead. Secondly, when the coverage and connectivity of one-hop neighbor nodes are the same, the node with the highest link reliability is selected as the MPR node, which reduces the packet loss rate. The algorithm terminates once the selected set of nodes achieves full coverage. Prior to finalizing the process, the proposed BLR-MPR checks for redundancy in the selection and removes any redundant nodes from the set.

4 RESULTS AND DISCUSSION

The OLSR protocol, II-OLSR protocol and the E-OLSR protocol proposed in this article were selected for analysis and comparison.

4.1 Simulation parameter settings

This article uses the OPNET Modeler 14.5 simulation software on the Windows 10 platform to conduct simulation experiments on the OLSR protocol, II-OLSR protocol, and the proposed E-OLSR protocol. The simulation is configured with node counts varying from 10 to 50, i.e., 10, 20, 30, 40, and 50. Using up to 50 nodes provides a meaningful context to observe algorithmic behavior and performance trends as the network size increases, without incurring excessive complexity or simulation overhead. While other parameter settings including number of traffic flows, packet size, link bandwidth, and the number of simulations were kept constant across all scenarios. This is to analyze the impact of network size on the proposed E-OLSR performance.

The simulation parameters are shown in Table 1. Five simulation experiments were performed for each simulation scenario, and the simulation results are the average of the five experimental results.

4.2 Analysis of simulation results

Control overhead refers to the total length of control messages sent by nodes in the network. Figure 4 demonstrates that the E-OLSR protocol outperforms the II-OLSR protocol and the standard OLSR protocol in terms of control overhead. The E-OLSR protocol demonstrated a significant reduction in control overhead compared to both OLSR and II-OLSR. By optimizing the selection of MPR nodes and adapting control message intervals, E-OLSR reduced redundant transmissions, achieving up to 25% lower overhead in high-density networks. When the number of nodes is 10, the control overhead of the E-OLSR protocol and the OLSR protocol are basically the same. The reason is that the asymmetric link notification message in the E-OLSR protocol occupies a part of the network control overhead. When the number of nodes in the network gradually increases, the BLR-MPR selection algorithm of the E-OLSR protocol optimizes the traditional MPR selection algorithm and reduces the number of MPR nodes in the entire network. This is

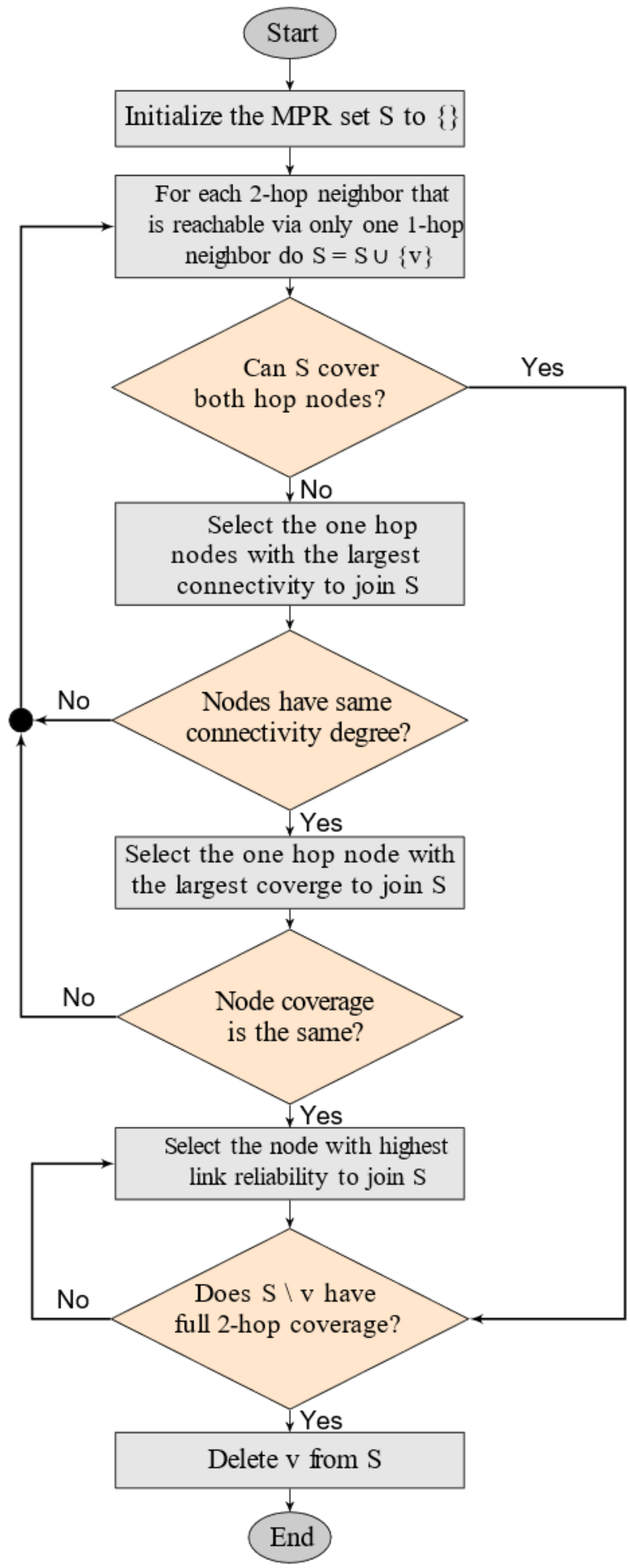

Fig. 3 The operation flow of the BLR-MPR selection algorithm

Table 1 Comparison of Classification Results.

No. of Nodes	Flows / Item	Packet Size (b)	Link BW (kb/s)	Simulation Time (s)	Simulation times/times
10	3	1024	200	1000	5
20	3	1024	200	1000	5
30	3	1024	200	1000	5
40	3	1024	200	1000	5
50	3	1024	200	1000	5

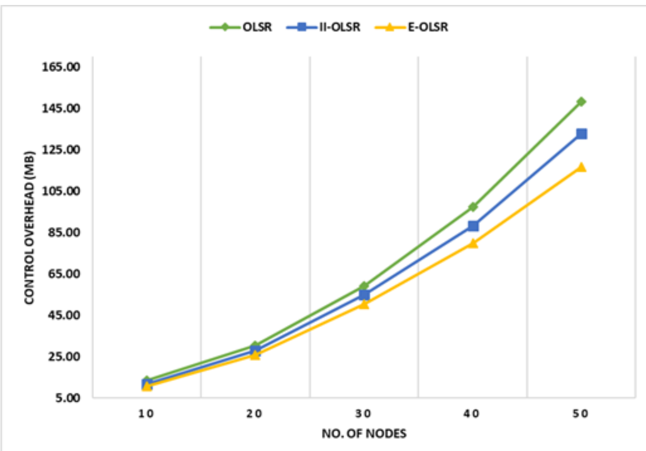

Fig. 4 Control overhead comparison

because TC control messages are only sent by MPR nodes and are distributed throughout the network flooding, thus significantly reducing the number of flooding TC messages in the network.

Figure 5 presents the results of the E-OLSR protocol in terms of packet delivery success rate. In comparison to other protocols, the E-OLSR is generally the best compared to the standard OLSR protocol and the II-OLSR protocol in terms of packet delivery success rate.

E-OLSR consistently achieved a higher packet delivery success rate than standard OLSR, with improvements ranging from 8% to 15%. Specifically, an 8% improvement was observed for a network size of 10 nodes, while a 15% improvement was achieved for a network size of 50 nodes. The improvement percentage is calculated as follows:

$$\text{Improvement} = \frac{|f(EOLSR) - f(OLSR)|}{f(OLSR)} \times 100,$$

where f is the evaluation metric, i.e., throughput, control overhead, packet delivery success rate, or end-to-end delay.

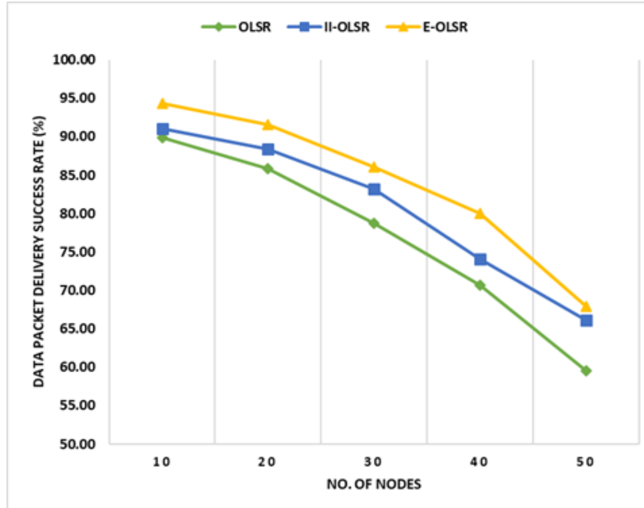

Fig. 5 Comparison of data packet delivery success rates

The BLR-MPR algorithm's prioritization of reliable links minimized packet loss, particularly in scenarios with unstable connectivity. When the amount of traffic volume remains unchanged, because the II-OLSR protocol reduces control overhead, it reduces the total amount of network layer data and the probability of channel congestion, thus improving the success rate of data packet delivery. The E-OLSR protocol uses the BLR-MPR selection algorithm to improve the reliability of packet transmission and optimizes the traditional MPR selection algorithm, effectively reducing network control overhead and channel load. Also, the routing scheme of the E-OLSR protocol utilizes asymmetric links to balance the load of nodes in the network and has a backup routing mechanism to enhance the robustness of routing.

Figure 6 highlights the superiority of the E-OLSR protocol in comparison to the standard OLSR protocol and the II-OLSR protocol in terms of end-to-end delay. Because the IIOLSR protocol uses incremental information instead of complete information, it reduces both control overhead and channel load.

The adaptive scheduling and load-aware routing mechanisms of E-OLSR resulted in the lowest end-to-end delays across all scenarios, reducing delays by up to 40% compared to OLSR. This demonstrates the protocol's ability to effectively balance traffic and avoid congestion. As a result, the end-to-end delay is better than the standard OLSR protocol. The common neighbor detection mechanism proposed by the E-OLSR protocol allows nodes to significantly reduce route discovery delays, and it can use asymmetric links during routing, reducing the path length of packet transmission, and balancing nodes and their surrounding links in the network. Secondly, the E-OLSR protocol proposes an MPR selection algorithm based on link reliability, which means it selects a more reliable link for data transmission which reduces the probability of retransmission. At the same time, the BLRMPR selection algorithm also reduces system control overhead and channel load, which decreases the queue processing delay of data packets.

In Figure 7, the E-OLSR protocol exhibits a higher throughput than both the standard OLSR and the II-OLSR. It maintains 20-30% higher values in all scenarios. The combination of reduced overhead, enhanced routing, and reliable link selection contributed to sustained network performance even under challenging conditions. Because the II-OLSR protocol reduces both network control overhead and channel load, more data packets are successfully transmitted within the same time, and the network throughput is increased. From the above analysis, it can be seen that the BLR-MPR algorithm of the E-OLSR protocol incorporates link reliability into the MPR node selection index, which further reduces the number of MPR nodes in the network, that reduces both the control overhead in the network and the channel load, which can improve the transmission success rate of data packets.

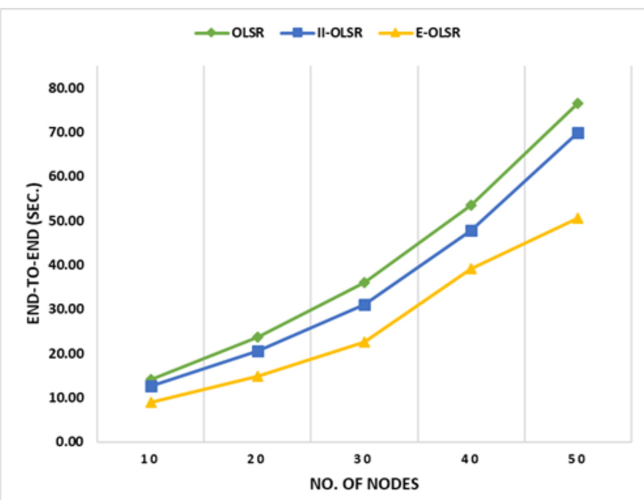

Fig. 6 End-to-end delay comparison

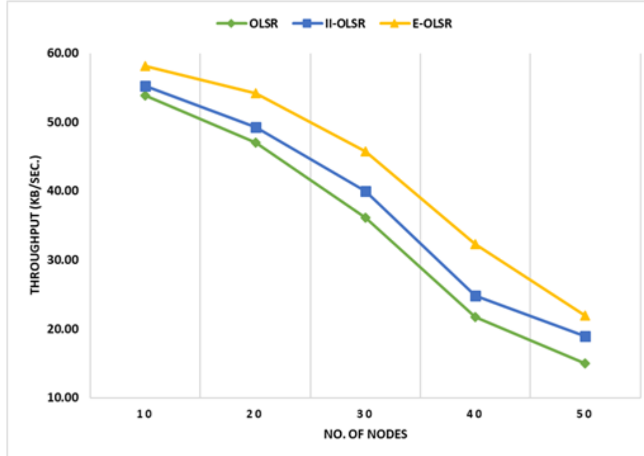

Fig. 7 Throughput comparison

5 CONCLUSION

To address the challenges of high channel occupancy and communication delays when applying the OLSR protocol to shortwave ad hoc networks, this paper proposes a low-latency OLSR protocol specifically designed for such environments. The proposed protocol incorporates a common neighbor detection mechanism to identify and utilize asymmetric links within the network.

These mechanisms enable the protocol to reduce the path length for packet transmission and balance the load across nodes and their surrounding links. In our study, the main observations are as follows:

- Our E-OLSR protocol significantly reduces control overhead, increases throughput, decreases end-to-end delay, and improves packet delivery success rates in shortwave ad hoc networks. Specifically, the proposed E-OLSR consistently improved packet delivery (by 8–15%), reduced end-to-end delay (up to 40%), increased throughput (by 20–30%), and lowered control overhead (up to 25%) compared to standard OLSR.

- By incorporating a common neighbor detection mechanism and leveraging asymmetric links for route selection, the E-OLSR protocol reduces the path length for packet transmission and balances the network load across nodes and their surrounding links.

- The BLR-MPR selection algorithm enhances the reliability of packet transmission, ensuring more stable and efficient network communication.

Possible scenarios that call for bidirectional transmission verification can be considered for future investigations. This investigation has a goal to customize the OLSR protocol for a larger audience of applications. However, given the shortcoming of the low power available at the shortwave devices, the study of energy consumption of proposed E-OLSR still remains a key point for further analysis.

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DECLARATIONS

Conflict of interest

The authors declare that no conflict of interest exists.

Consent to publish

N/A

Ethical approval

N/A

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