MULTIPOINT RELAY PATH FOR EFFICIENT TOPOLOGY MAINTENANCE ALGORITHM IN OPTIMIZED LINK STATE ROUTING-BASED FOR VANET

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ABSTRACT

The Optimal Link State Routing (OLSR) protocol employs multipoint relay (MPR) nodes to disseminate topology control (TC) messages, enabling network topology discovery and maintenance. However, this approach increases control overhead and leads to wasted network bandwidth in stable topology scenarios due to fixed flooding periods. To address these challenges, this paper presents an Efficient Topology Maintenance Algorithm (ETM-OLSR) for Enhanced Link-State Routing Protocols. By reducing the number of MPR nodes, TC message generation and forwarding frequency are minimized. Furthermore, the algorithm selects a smaller subset of TC messages based on the changes in the MPR selection set from the previous cycle, adapting to stable and fluctuating network conditions. Additionally, the sending cycle of TC messages is dynamically adjusted in response to network topology changes. Simulation results demonstrate that the ETM-OLSR algorithm effectively reduces network control overhead, minimizes end-to-end delay, and improves network throughput compared to traditional OLSR and HTR-OLSR algorithms.

KEYWORDS

OLSR, Mobile ad hoc, Multipoint relay, VANETs, Topology maintenance, Message Control

1. INTRODUCTION

Vehicular ad hoc networks (VANETs) have emerged as a promising technology to enhance road safety, traffic efficiency, and passenger comfort in modern transportation systems [1] [2] [3]. VANETs enable vehicles to communicate with each other and with roadside infrastructure, creating a dynamic network that facilitates the exchange of critical safety and traffic-related information [4]. Efficient routing protocols are crucial for VANETs to support reliable and timely data dissemination, enabling effective vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication [5] [6]. Traditional routing protocols designed for static networks may not be well-suited for the highly dynamic and rapidly changing topology of VANETs [7] [8].

Numerous researchers have proposed various VANET routing protocols to address the challenges posed by the dynamic nature of vehicular networks. Some studies have focused on enhancing the performance of existing protocols, while others have proposed entirely new approaches. Research efforts have centered around optimizing routing decisions, minimizing end-to-end delay,

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increasing network throughput, and ensuring better scalability in large-scale VANET deployments.

The Optimized Link State Routing (OLSR) protocol is a distributed active routing protocol [9][10]. It minimizes the transmission of topology control messages and forwarding operations by employing HELLO and topology control (TC) messages to distribute link status and topology information throughout the network [11] [12]. To maintain overall network topology updates, the OLSR protocol requires frequent exchange of control information. Compared to the dynamic source routing (DSR) and ad ho con-demand distance vector (AODV) protocols, OLSR offers higher network throughput and lower end-to-end delay, making it suitable for large-scale dense networks with a significant number of nodes [13] [14] [15]. The OLSR protocol utilizes a broadcast mechanism for discovering link information and network topology, but this approach can lead to redundant retransmissions and wastage of radio resources. Although this algorithm effectively reduces the propagation of redundant TC messages, it introduces complexity due to area division and inter-area communication. The OLSR protocol achieves topology discovery and maintenance by periodically flooding TC messages. Compared to traditional link-state routing protocols, the OLSR protocol's multipoint relay (MPR) mechanism significantly reduces the content and forwarding quantity of TC messages. While several routing protocols have shown promising results, most of them struggle to maintain an efficient topology representation due to their limited adaptability to VANET's mobility patterns and the rapidly changing network topology. Therefore, a critical research gap remains in designing a routing protocol that strikes a balance between maintaining a current topology with minimal overhead and ensuring efficient data delivery. It's important to note that enhancements like the MPR Path algorithm are developed to address some of these challenges, but they may not be a one-size-fits-all solution. VANET research and development continue to focus on improving routing protocols to meet the unique requirements and constraints of vehicular networks.

The primary motivation behind this paper is to propose an enhanced link-state routing protocol (ELSRP) for VANETs. ELSRP aims to address the challenges associated with maintaining an up-to-date and efficient network topology in highly dynamic vehicular environments. To optimize link-state routing, this paper proposes an efficient topology maintenance based on an optimized link-state routing (ETM-OLSR) algorithm. This algorithm eliminates redundancy in the MPR set selection process and dynamically adjusts the content of TC messages based on changes in the node's MPR selection set. By intercepting the minimum amount between the stable amount and the fluctuating amount, this algorithm effectively reduces overhead. Moreover, by utilizing historical change information, the sending interval of TC messages is dynamically adjusted, enabling low-overhead maintenance of network topology.

2. RELATED WORK

To order to address the issue of excessive overhead during topology discovery and maintenance in the OLSR protocol, various approaches have been proposed. One approach involves extending the selection dependency conditions of the Multipoint Relay (MPR) set to the local database of three-hop neighbors, providing new information to aid in MPR selection [16]. This reduces redundant forwarding of TC messages [14] [17]. Another proposal suggests using a global optimal MPR set instead of a local optimal MPR set. It prioritizes selecting one-hop neighbor nodes that have already been selected as MPR nodes by other nodes, effectively reducing the number of nodes without increasing control overhead or the number of TC messages [18] [19]. Additionally, a combination of traditional MPR selection and the ant colony algorithm has been introduced [20]. This approach incorporates pheromones and implements compensation-punishment rules in the MPR set selection process. It also considers the current mobile state information of nodes in the calculation process, resulting in a reduction of the MPR set redundancy. In [21] proposes a heuristic MPR selection algorithm. Nodes exchange mobility status through HELLO messages and preferentially select nodes with less mobility as MPR nodes to improve link retention time. In [22] adds node location information in the HELLO packet, considers link stability when selecting MPR, reduces the number of MPR node switching, and increases the effective time of routing table entries. In [23] introduced energy factors in the MPR set selection process, and selected nodes with high residual energy as MPR nodes first, which prolongs the overall life of the network to a certain extent, but the number of selected MPR nodes is not the least. In [24] proposes a residual prediction optimized link state routing (HTR-OLSR) protocol based on the OLSR protocol. When the state information of adjacent nodes is unknown, a residual prediction algorithm is introduced to obtain the required information from other nodes and adjust the HELLO-Interval and TC-Interval in the original protocol to 1 and 3, respectively. The inaccuracy of node energy level prediction is reduced by frequently obtaining node data information. To address these issues, an OLSR protocol based on geographic forwarding rules was proposed in [25][26]. This protocol leverages the geographic location information of nodes to divide the network into virtual areas, thereby avoiding repeated transmissions between different areas during the broadcasting of control messages.

3. PRELIMINARY STUDY

3.1. Traditional MPR selection algorithm

In the OLSR protocol, the MPR (Multipoint Relay) set is determined using a greedy strategy. Each node sequentially adds its one-hop neighbors with the largest number of two-hop neighbors to the MPR set until all two-hop neighbours are covered. This process is illustrated in Figure 1, depicting the broadcast relay flooding. However, when using the traditional MPR selection algorithm, node S calculates its MPR set as {b, c, d, f}. However, the actual minimum MPR set required is {b, d, f}, indicating the presence of redundancy in the calculated MPR set. Since only nodes in the MPR set are allowed to send and forward TC (Topology Control) messages, an increase in the number of elements in the MPR set leads to more nodes sending TC messages. This, in turn, results in an increased number of TC message-forwarding instances and higher control overhead.

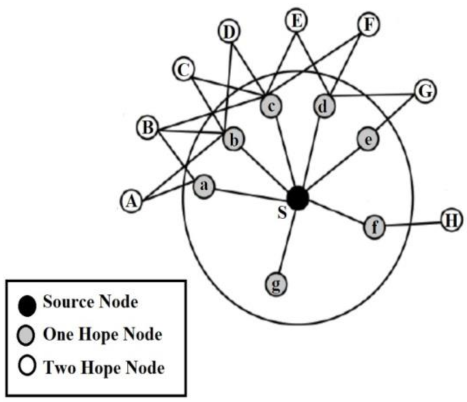

Figure 1. Schematic diagram of broadcast relay flooding

Figure 2 provides a comparison of the network topology before and after a change in the OLSR protocol. The shaded nodes in the figure represent the MPR nodes responsible for generating and forwarding topology control messages. In addition, it is evident that the MPR selection sets of each node, calculated based on the topology change, are presented in Table 1.

Table 1. MPR selection set of nodes before and after topology change

Network node	MPR selection set before change	MPR selection set after change
A	{C,D,E,F,H}	{B,C,D,E,F,H}
B	{H,M}	{H,M}
C	{}	{A,C,K,M}
D	{A,E,K,M}	{F,K}
E	{F,K}	{}
F	{}	{}
H	{A,B}	{}
K	{}	{}
M	{B,C,D}	{}

Furthermore, the figure and table reveal that the dependency relationship between MPR sets in the network changes when the network topology changes. In comparison to the pre-change topology, node A's MPR selection set gains one additional element, node D's set undergoes a changes, while the MPR selection sets of nodes B and E remain unchanged. In the original OLSR protocol, the TC message sent by node A would include the addresses {B, C, D, E, F, H}. However, {C, D, E, F, H} have already been sent in the previous cycle, resulting in redundant transmission and bandwidth wastage. Additionally, node D's MPR selection set undergoes minimal changes, and sending the entire set would only increase network control overhead. To address these issues, the proposed algorithm optimizes the sending process of TC messages. By selectively including only the necessary changes in each cycle, the algorithm reduces redundancy and prevents unnecessary bandwidth consumption. This results in more efficient utilization of network resources and reduced control overhead, enhancing the overall performance of the network.

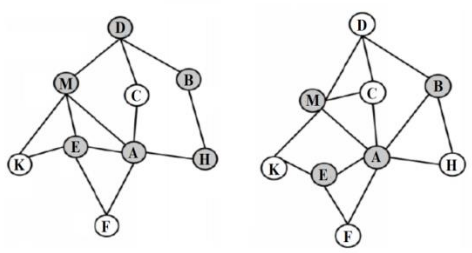

Figure 2. Comparison a) before and b) after topology change

In the original protocol, TC messages are sent at a fixed period, which will lead to the following two problems: 1) When the network topology changes, the fixed sending interval cannot notify the entire network of the topology change in time, which may lead to untimely update of the network topology and packet loss 2) When the network topology around the node is relatively stable, a shorter sending cycle will lead to an increase in network control overhead and end-to-end delay.

The traditional Multipoint Relay (MPR) selection algorithm is used in various ad hoc networking protocols. This algorithm is a fundamental component for minimizing control overhead and ensuring efficient message propagation in wireless networks. Understanding the workings of the traditional MPR selection algorithm is crucial for comprehending its role in optimizing network performance.

3.2. Generation of TC messages and its mechanism

TC messages help vehicles in a VANET gain awareness of the current network topology which offers important information about neighboring vehicles and their connectivity, allowing each vehicle to understand its immediate communication environment. In addition, TC messages provide real-time updates about network changes, such as vehicles entering or leaving the communication range. This dynamic information is essential for maintaining effective communication.

In the traditional OLSR protocol, the MPR (Multipoint Relay) set is calculated before sending the TC (Topology Control) message. Each node independently selects its MPR set based on the following rules:
The MPR set of a source node should only consist of one-hop symmetric neighbors.
The selected MPR set should cover all two-hop neighbors of the node while minimizing the number of elements in the set.

The TC message can only be sent when a node's MPR selection set is not empty. The content of the TC message includes the addresses of the nodes in the MPR selection set. Although all nodes in the network can receive and process the TC message, only the nodes in the MPR set are allowed to forward the message.

Following the protocol specifications outlined in RFC3626 [11], the sending, receiving, and processing procedures of TC messages involve the following steps:

Step 1: The node checks if its MPR selection set is empty. If not, it adds the contents of the MPR selection set to the body of the TC message for broadcasting.

Step 2: Upon receiving a TC message, the node checks if there is an entry in the repeat table with the same message source address and a message sequence number greater than or equal to the current TC message. If such an entry exists, it means that the updated TC message has already been processed, so the node discards the message without further processing. If there is no matching entry, the process continues to step 3.

Step 3: If the "T_last" field of the entry in the topology table matches the source address of the TC message sender and the corresponding sequence number is greater than the sequence number in the TC message, it indicates that the message has expired and should be discarded without further processing. Otherwise, the process proceeds to step 4.

Step 4: If the "T_last" field of the entry in the topology table matches the source sender address of the TC message, the entry is updated according to the content of the TC message. If there is no matching entry, a new entry is added with "T_last" set to the address of the TC message source and "T_dest" set to the content part of the TC message.

Step 5: If the last hop address of the TC message is in the MPR selection set and the value of the "TTL" (Time-to-Live) field in the message is greater than or equal to 1, the node decrements the value of the "TTL" field by 1, and then broadcasts and forwards the TC message.

These steps ensure the proper handling of TC messages in the OLSR protocol, facilitating the dissemination of topology information while minimizing redundancy and control overhead.

TC messages play a pivotal role in VANETs by disseminating critical network topology information, facilitating efficient communication, and enabling adaptive routing decisions. Understanding the intricacies of TC message generation is fundamental for optimizing vehicular ad hoc networks.

4. PROPOSED METHOD

To solve the above problems, this paper proposes a low-overhead ETM-OLSR algorithm.

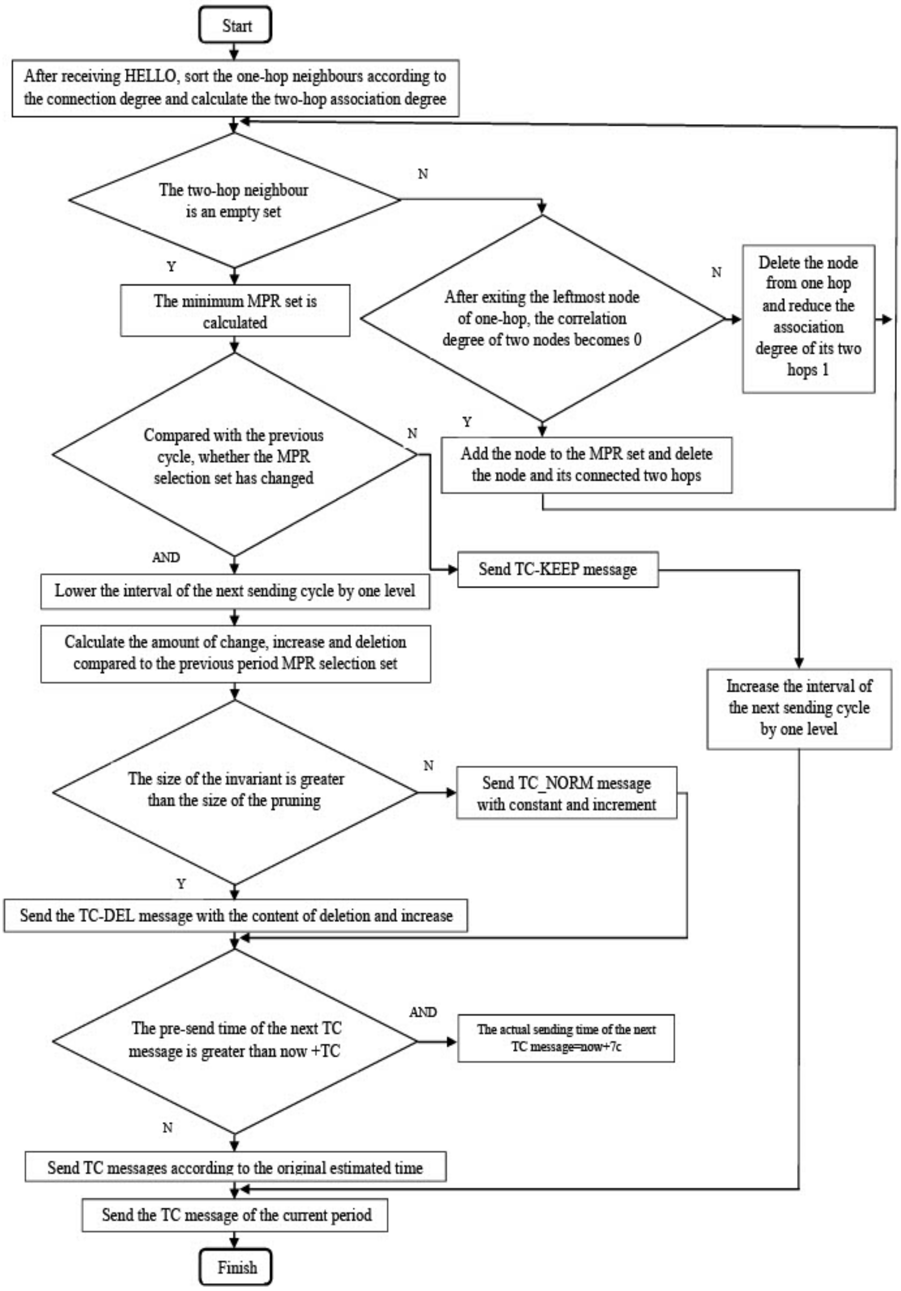

Figure 3.ETM-OLSR algorithm

This algorithm first removes the redundancy existing in the traditional MPR selection algorithm, and reduces the number of TC messages generated and the number of forwarding times; secondly, the ETM-OLSR algorithm adaptively adjusts the TC sending interval up and down according to the changes in the network topology to achieve network topology maintenance. When the topology changes around the node are small, the variable information is used instead of the full amount of information to reduce the redundant transmission of topology information.

The proposed low-overhead topology maintenance algorithm, and the algorithm flow are shown in Figure 3. The ETM-OLSR algorithm first uses the minimum MPR selection mechanism to remove the one-hop neighbors from the MPR selection according to the connection degree from small to large, and then adds the key one-hop neighbor nodes to the MPR set in turn to remove the redundancy existing in the traditional MPR selection algorithm. When the current MPR selection set is not empty, the node judges whether the current MPR selection set has changed compared with the previous sending cycle, sends TC_KEEP, TC_NORM, and TC_DEL messages accordingly, and dynamically adjusts the size of the sending cycle, thereby reducing network topology information redundant transmission improves the adaptability of the network. The ETM-OLSR algorithm allows each node in the network to grasp the topology information of the entire network with less control overhead. Due to the characteristics of the wireless channel, it is susceptible to interference and packet loss, which may cause some TC messages to be lost and cause error iterations. Therefore, after every five TC sending cycles, a normal TC message, that is, a TC reset message, needs to be sent once to correct the topology of the entire network. When a new node joins, because it can only obtain part of the network topology information, when it has data to transmit, it can first send the data packet to the MPR neighbor, and then forward it to the entire network by the MPR neighbor. After the TC reset message arrives, it will the entire network topology can be obtained for normal process communication.

4.1. Algorithm Design

For the entire network nodes to master their own topology information, the MPR nodes in the network will periodically flood TC messages. The message content consists of all the addresses that have selected themselves as MPR one-hop neighbors and can only be selected by the MPR node. The traditional MPR selection algorithm uses a greedy strategy to calculate the MPR set and uses the two-hop connection degree of the one-hop neighbor connection as the only basis for MPR selection. It does not consider the correlation between the reverse two-hop neighbor and the one-hop neighbor, which may generate redundant MPR. nodes, affecting network performance. The topology flattening of broadcast relay flooding is shown in Figure 4.

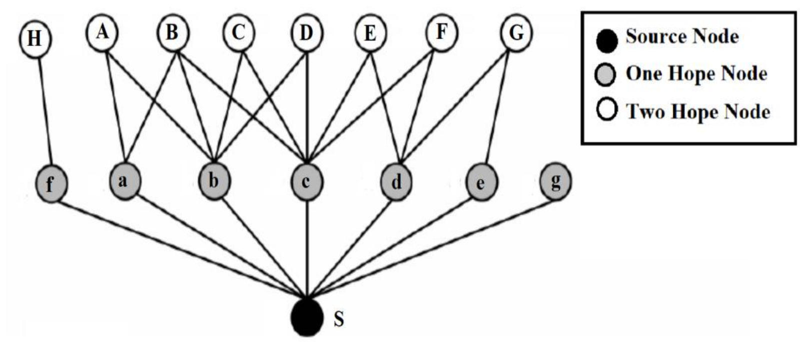

Figure 4.Topological Flattening Of Broadcast Relay Flooding

Based on of the above analysis, this section proposes a minimal MPR set selection strategy. An example of taking the selection steps of the minimized MPR set are as follows:

Step 1: Calculate the connection relationship between one-hop neighbors and two-hop neighbors, f={H}, a={A, B}, b={A, B, C, D}, c={B, C, D , E, F}, d={E, F, G}, e={G}, g={}. According to the number of connected two-hop neighbors, sort the one-hop neighbours from small to large and delete the nodes with a connection degree of 0. The sorted one-hop neighbors can be obtained as N1(i)={e, f, a, d, b, c}.

Step 2: Calculate the number of connected one-hop neighbors for the two-hop neighbors N2(i)={A, B, C, D, E, F, G, H}, and get the degree of association Link={2, 3, 2, 2, 2, 2, 2, 1}.

Step 3: If N2(i) is empty, go to step 5; otherwise, try to exit the selection of MPR with the nodes in N1(i) in order from left to right, and judge whether to connect the node to the node in N2(i) corresponding to after the count value in the link array is decremented by 1, whether the values of the corresponding elements are all greater than or equal to 1 after deduction. If yes, it means that the node is a redundant node, remove it from N1(i), decrement the corresponding element in the link array by 1, and continue to step 3; otherwise, go to step 4.

Step 4: Add the node to the MPR set and remove it from N1(i), remove the two-hop neighbors connected to the node from N2(i), and continue to step 3.

Step 5: At this time, N2(i) is empty, and the calculation of the minimum MPR set ends. In step 3, the one-hop neighbors are tried to exit the MPR set selection in the order of the connection degree from small to large. The topology as the one-hop neighbors g, e, a, and c exit the MPR selection in turn, and the nodes f, d, and b, in turn, are selected as an MPR node, and the MPR set {b, d, f} selected at this time is the minimum MPR set.

The TC message adaptive sending mechanism is divided into the sending content adaptive sending mechanism and the sending cycle adaptive sending mechanism.

1) TC message content adaptive sending mechanism

In an ad-hoc network, the MPR selection set of the current TC transmission cycle is composed of the MPR selection set of the previous transmission cycle minus the deletion amount plus the new increment, as:

$$\xi_{\mathrm{cur}} = \xi_{\mathrm{last}} - \xi_{\mathrm{del}} + \xi_{\mathrm{add}} = \xi_{\mathrm{keep}} + \xi_{\mathrm{add}} \tag{1}$$

Where is the content of the MPR selection set in the previous period; and are the unchanged, increased, and deleted parts of the current MPR selection set compared with the previous period, $\xi_{\mathrm{keep}} = \xi_{\mathrm{cur}} \cap \xi_{\mathrm{last}}$. From Eq. (1) It can be seen that when the network topology does not change drastically, the content of the current TC message and the content sent last time will have a large redundancy, and if it is sent repeatedly, it will cause more waste of network bandwidth. In response to this problem, the ETM-OLSR algorithm proposes an adaptive transmission mechanism for TC content. The content of the improved TC message is as:

$$\xi_{\mathrm{cur}} = \begin{cases} \xi_{\mathrm{keep}} + \xi_{\mathrm{add}} & \xi_{\mathrm{keep}} \leq \xi_{\mathrm{del}} \\ \xi_{\mathrm{del}} + \xi_{\mathrm{add}} & \xi_{\mathrm{keep}} > \xi_{\mathrm{del}} \end{cases} \tag{2}$$

The content of the current cycle TC message can be dynamically adjusted according to the change in the network topology. According to the change in the MPR selection set, the TC message is divided into three types. The specific sending steps are as follows:

(1) When the topology around the node changes, if, the TC_DEL message is composed of the deletion and the new increment; otherwise, the TC_NORM message is composed of the invariant and the new increment.

(2) When the topology around the node remains unchanged, send the topology-keeping message TC_KEEP with an empty message body, and the node updates the lifetime of the topology entry after receiving the message.

To adapt to changes in the improvement mechanism, the TC message packet format divides the reserved field into two parts, TC_Type and Del_len, which respectively indicate the type of the current TC message and the first Del_len addresses in the message body are the deleted parts. The value of the Del_len field is in the message type. TC_KEEP and TC_NORM are 0, and the improved TC message format is shown in Figure 5.

0	8	16	24	32
ANSN			TC Type	Del Len
Del/keep MPR Selector Address				
Del/keep MPR Selector Address				
...				
Add MPR Selector Address				
Add MPR Selector Address				
...				

Figure 5.Improved TC Message Packet Format

Table 2 provides a comparison of topology changes and the content of TC messages sent by the original protocol and the improved protocol, as depicted in Figure 2(a) and Figure 2(b). It becomes apparent that after the topology change, only nodes A, B, D, and E possess non-empty MPR selection sets. As per the original protocol, these nodes would pack the addresses within their MPR selection sets into TC messages and transmit them. However, with the improved mechanism, the MPR selection set of node D undergoes the following changes: a decrease of {E}, an invariant set of {A, K, M}, and an increase of {C}. Since the decrease is less than the invariant set, the current content sent by node D becomes {E, C}. Similarly, node A only needs to send the increment {B} as its MPR selection set remains unchanged. Nodes B and E also retain their MPR selection sets, necessitating the transmission of a TC_KEEP message with an empty message body. By selectively including the necessary changes in the TC messages, the improved protocol streamlines the content of TC messages, making them more concise and reducing unnecessary information propagation. This leads to a more efficient topology maintenance process, resulting in improved network performance and reduced control overhead.

Table 2. Contents of Original and Improved Protocol TC Messages After Topology Change

Network node	Original protocol	Improved sent content
A	{B,C,D,E,F,H}	{B}
B	{H,M}	{}
D	{A,C,K,M}	{E,C}
E	{F,K}	{}

4.2. TC Message Cycle Adaptive Sending Mechanism

The OLSR protocol employs a fixed sending period for TC messages, denoted as Tmid=5s. However, this constant value fails to effectively adapt to the dynamic nature of network topology in ad hoc networks. When the network topology undergoes frequent changes, the timely update of topology information becomes challenging, resulting in an increased packet loss rate. Conversely, in periods of relative stability, a shorter sending period leads to elevated network control overhead.

To address these limitations, the ETM-OLSR algorithm introduces a flexible approach to TC message transmission intervals. It divides the current TC transmission interval, referred to as TC emission Interval or TCEI, into five levels: Tmin, Tless, Tmid, Tlong, and Tmax. These levels are arranged in ascending order of duration, with Tmid as the midpoint, based on the original 5s transmission cycle. The selection of the TC value is determined by the frequency of network topology changes. When topology changes occur more frequently, a smaller TC value is set to ensure timely updates. The sending frequency of the current TC message is determined by considering both the historical sending cycle size and the status of link information retention.

- When the node’s MPR selection set changes, that is, when the MPR selection set increases or decreases elements, if the last sending cycle TClast>Tmid, it indicates that the network topology around the node has not changed in at least one cycle in history, and the network is currently being replaced by stable changes to an unstable state, and the next sending cycle should be reset to TCnext=Tmid; otherwise, TCnext will drop one level based on TClast.

- When the node MPR selection set remains unchanged within a sending cycle, if TClast<Tmid at this time, it indicates that the topology around the node is relatively unstable in history, and the network is changing from unstable to stable at this time, then the next one sending cycle TCnext. It should be reset to Tmid; otherwise, TCnext will raise one level based on TClast.

When the topology relationship changes, to make other nodes in the network perceive the topology change, the MPR node should send the changed topology information as soon as possible. The analysis of the fast-sending time of TC messages is shown in Figure 6. It can be seen that t1 is the time when the TC message was sent last time, t2 is the current time, t3 is the current time plus the time point of the changed TC, and t4 is the expected next sending time. Assuming that the MPR selection set of the node changes at time t2, according to the ETM-OLSR algorithm, the sending time of the next TC cycle is reduced by one level. If t3<t4, to send out the changed topology information as soon as possible, the next TC message can be sentfrom time t4 ahead of timetotime t3.

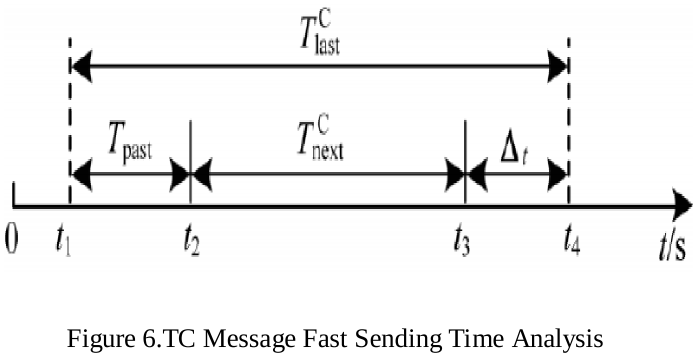

Figure 6.TC Message Fast Sending Time Analysis

4.3. Performance Analysis of ETM-OLSR Algorithm

The performance of a self-organizing network is influenced by various factors due to its dynamically changing network topology. These factors primarily include the total node count within the network, the rate at which nodes transmit packets, packet sizes, node movement speeds, and more [6].

In the context of the OLSR protocol, the update and maintenance of routing information occur through periodic exchanges of HELLO and TC messages among nodes. Several network-related operational parameters are defined as follows:

N: The overall count of nodes in the self-organizing network.

NMS: The total number of selected MPR (MultiPoint Relay) nodes within the network. Its value is determined by both the network size N and the algorithm used for MPR selection.

Nm: The average count of MPR nodes that each node in the network selects.

Shell: The mean length of an individual HELLO message sent.

STC: The average length of a single transmitted TC (Topology Control) message.

Thello: The time interval between consecutive HELLO message transmissions.

TTC: The time gap between successive TC message transmissions.

Consequently, during the operation of the self-organizing network, the total length of the HELLO messages generated by an individual node, denoted as "i," within the network, is calculated per unit time as:

$$\mathrm{L_{hello}} = \mathrm{S_{hello}} \times 1/\mathrm{T_{hello}} \tag{3}$$

Likewise, the length of TC (Topology Control) messages that a MultiPoint Relay (MPR) node, denoted as "j," can generate within the network, is computed per unit of,time as:

$$\mathrm{L_{S\_TC}} = \mathrm{S_{TC}} \times 1/\mathrm{T_{TC}} \tag{4}$$

Considering multi-point relay, the same TC message needs to be forwarded to its $\mathrm{N_m}$ MPR neighbor nodes, so the total TC message length that MPR node j needs to forward in unitsoftime is:

$$\mathrm{L_{T\_TC}} = (\mathrm{N_{MS}} - 1) \times \mathrm{N_m} \times \mathrm{S_{TC}} \times 1/\mathrm{T_{TC}} \tag{5}$$

Only MPR nodes generate and forward TC messages, then the total routing overhead generated by the entire ad hoc network per unit time is:

$$T_0 = \sum_{i=1}^{N} \mathrm{S_{hello}} \times 1/\mathrm{T_{hello}} + \sum_{i=1}^{\mathrm{N_{MS}}} (1 + (\mathrm{N_{MS}} - 1) \times \mathrm{N_m}) \times \mathrm{S_{TC}} \times 1/\mathrm{T_{TC}} \tag{6}$$

It becomes evident that decreasing the size of HELLO and TC messages, along with reducing the count of Multipoint Relay (MPR) nodes in the network, has the potential to mitigate the control overhead associated with the OLSR protocol. This paper introduces the Enhanced Topology Management OLSR (ETM-OLSR) algorithm, which employs an adaptive approach for sending TC messages, leading to a reduction in STC (Single TC message length) while increasing TTC

(Time between TC message transmissions). Additionally, the algorithm utilizes a minimum MPR set selection mechanism, effectively curbing the number of MPR nodes in the network, thus contributing to a noteworthy reduction in the topology maintenance cost of the OLSR protocol. This reduction in control overhead enhances network throughput, marking a significant advancement.

5. Result and Discussion

Select the standard OLSR protocol, the HTR-OLSR protocol in reference [24],and the ETM-OLSR protocol in this paper as the analysis and comparison objects, and compare and analyze the success rate of sending packets, end-to-end delay, and throughput between them through simulation experiments.

5.1. Simulation Parameter Setting

This paper uses the OPENT simulation software to simulate and compare OLSR, HTR-OLSR, and ETM-OLSR protocols and set up 5 simulation scenarios. The specific parameters of the simulation are shown in Table 3. Assuming that the transmitting and receiving power of each node in the experiment is the same, the maximum communication distance of the node is 200m, and the range of TC message transmission cycle variation $\{T_{min}, T_{less}, T_{mid}, T_{long}, T_{max}\}$ is set to {3s, 4s, 5s, 6s, 7s}. In this experiment, each scene was tested 5 times, and the average value of the experimental results was taken to mainly investigate the impact of different moving speeds on network performance.

Table 3. Simulation parameters setting

Unit	Value
Number of nodes	90
Node speed (m per Sec.)	(10,15,20,25,30)
Node communication distance (m)	220
Simulation scene (m^2)	1500×1500
Link bandwidth (Mb per Sec)	10
Data link layer	802.11g
Packet size (Byte)	1024

5.2. Model Validation

Figure 7 illustrates the throughput comparison among OLSR, HTR-OLSR, and ETM-OLSR algorithms. The ETM-OLSR algorithm demonstrates an average throughput that is 7.84% higher than the HTR-OLSR algorithm, as reported in the literature [24]. Moreover, it achieves a 10.14% higher throughput compared to the standard OLSR. This improvement can be attributed to the minimum MPR selection algorithm, which reduces the number of MPR nodes and subsequently decreases the transmission and forwarding of TC messages. Additionally, the ETM-OLSR algorithm incorporates a TC adaptive sending mechanism to optimize the content of TC messages, effectively reducing network control overhead and enhancing throughput. In scenarios where node speed increases, resulting in faster network topology changes and a higher probability of packet loss, the throughput experiences a significant drop. However, the ETM-OLSR algorithm addresses this by adaptively reducing the sending interval of TC messages, promptly updating the altered network topology, and improving the reception success rate of data packets. Moreover, the TC data packet size in this algorithm is smaller compared to the other two algorithms, effectively reducing redundancy.

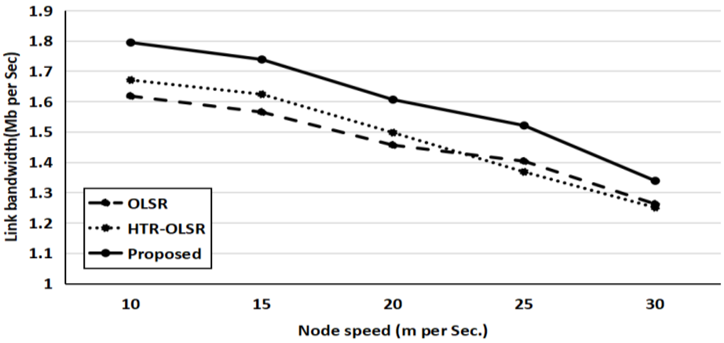

Figure 7.Comparison of throughput of OLSR, HTR-OLSR and proposed algorithms

Figure 8 provides a comprehensive comparison of the end-to-end delay among three routing algorithms: OLSR, HTR-OLSR, and our improved ETM-OLSR algorithm. The results show that the enhanced ETM-OLSR algorithm excels in minimizing end-to-end transmission delay, presenting a notable advantage over the other algorithms. Specifically, the ETM-OLSR algorithm demonstrates a lower end-to-end transmission delay, averaging approximately 10.23% lower than the HTR-OLSR algorithm and a more significant reduction of about 19.76% when compared to the standard OLSR algorithm. This reduction in delay is of paramount importance in vehicular ad hoc networks (VANETs), where timely communication is essential for applications such as safety-critical messages and traffic management. The feature of the ETM-OLSR algorithm is its adaptability to the varying pace of node movement. In VANETs, the network topology experiences frequent changes when vehicles move rapidly. To address this challenge, our proposed algorithm dynamically adjusts the sending frequency of TC (Topology Control) messages. By doing so, it ensures that nodes within the network promptly acquire the latest topology information about other nodes. This ability to maintain a low end-to-end delay even in fast-paced scenarios enhances the algorithm's suitability for VANETs, where rapid information dissemination is critical for safety and efficiency.

In contrast, the HTR-OLSR algorithm attempts to reduce the end-to-end transmission delay by decreasing the sending interval of both HELLO and TC messages. While this approach does lead to some reduction in delay, it introduces a consideration of energy factors during the MPR (Multipoint Relay) selection process. As a result, the chosen MPR nodes may not always be the shortest path to relay messages, which can lead to increased latency in message delivery.

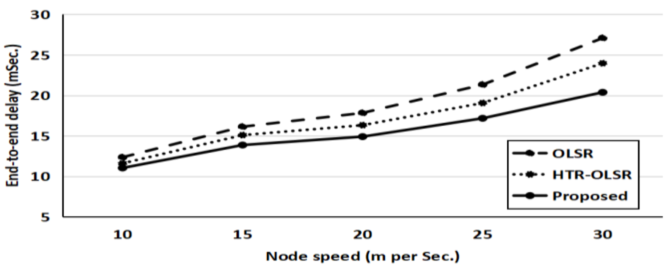

Figure 8. Comparison of end-to-end delay between OLSR, HTR-OLSR and proposed algorithms

Figure 9 provides an insightful comparison of the packet-sending success rates among three routing algorithms: OLSR, HTR-OLSR, and our proposed ETM-OLSR algorithm. The results demonstrate that the ETM-OLSR algorithm outperforms the other two algorithms, exhibiting a higher success rate in terms of packet delivery.Specifically, the ETM-OLSR algorithm showcases a remarkable improvement in packet-sending success rates. On average, it demonstrates a 3.38%

increase in success rate compared to the HTR-OLSR algorithm and a more substantial improvement of approximately 8.65% when compared to the standard OLSR algorithm. This enhancement is crucial in vehicular ad hoc networks (VANETs), where reliable and timely data delivery is vital for various applications, including safety-critical messages and traffic management.

Conversely, it's worth noting that all three algorithms experience a decrease in packet-sending success rates when compared to the HTR-OLSR algorithm, as highlighted in previous studies (reference [24]). This decrease becomes particularly pronounced as the movement speed of nodes accelerate. Rapid movement leads to frequent changes in the network topology, resulting in a shorter effective time for nodes to maintain accurate topology and routing information. Consequently, this leads to an increase in packet loss rates across the network.

To address this challenge, our proposed ETM-OLSR algorithm incorporates an adaptive mechanism for TC (Topology Control) message transmission. It leverages historical change information regarding the network topology surrounding each node. In scenarios where rapid network topology changes occur frequently, the algorithm accelerates the transmission of TC messages. This proactive approach ensures that routing table entries affected by topology changes are promptly updated, reducing packet loss rates and enhancing the overall reliability of data delivery.

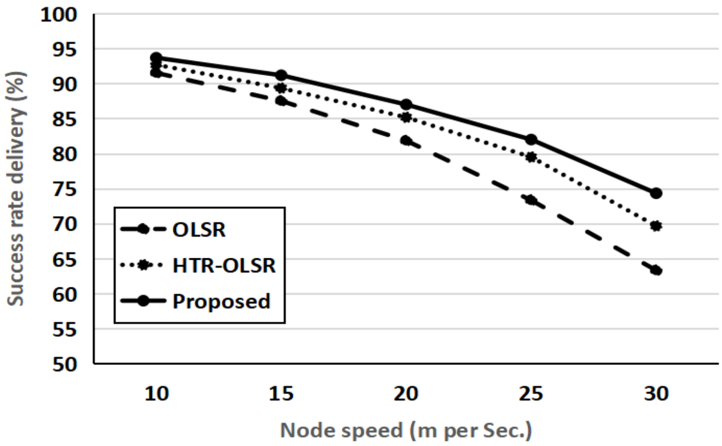

Figure 9. Comparison of success rate using OLSR, HTR-OLSR and proposed algorithms

6. CONCLUSION

This paper introduces the ETM-OLSR algorithm, an efficient topology maintenance approach tailored for VANETs. This algorithm has demonstrated significant advantages over existing OLSR and HTR-OLSR algorithms, contributing to the improvement of vehicular communication systems. The key contributions and advantages of the ETM-OLSR algorithm can be summarized as follows:

- The algorithm enhances routing efficiency by optimizing the process of selecting the Multipoint Relay (MPR) set, reducing control overhead.

- ETM-OLSR adaptively adjusts the transmission of TC messages based on topology change messages, enhancing network adaptability and reducing unnecessary message broadcasting.

- The ETM-OLSR algorithm contributes to better network throughput, ensuring that data packets are delivered more efficiently, which is particularly crucial for real-time VANET applications.

In summary, the ETM-OLSR algorithm not only increases packet-sending success rates but also intelligently adapts to the dynamic nature of VANETs. This adaptability makes it a promising choice for optimizing data transmission performance in vehicular networks, especially in scenarios with rapid network topology changes. Future research directions will focus on further refining VANET mechanisms, including neighbor discovery, to mitigate redundancy and improve the overall network efficiency. The ETM-OLSR algorithm lays a strong foundation for the continued development of efficient and adaptive routing protocols, paving the way for safer and more efficient vehicular communication systems.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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