LETTER *Special Section on Parallel and Distributed Computing and Networking*

Redundant TC Message Senders in OLSR

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SUMMARY In this letter, we reveal redundant control traffic in the optimized link state routing protocol (OLSR) for MANET. Topology control (TC) messages, which occupy a part of control traffic in OLSR, are used to exchange topology information with other nodes. TC messages are generated and forwarded by only nodes that have been selected as multipoint relays (MPRs) by at least one neighbor node. These nodes selected as MPRs are called TC message senders in this letter. One of solutions to reduce the number of TC messages is to reduce the number of TC message senders. We describe a non-distributed algorithm to minimize the number of TC message senders. Through simulation of static-node scenarios, we show 18% to 37% of TC message senders in RFC-based OLSR are redundant. By eliminating redundant TC message senders, the number of TC packets, each of which contains one or more TC messages, is also reduced from 19% to 46%. We also show that high density scenarios have more redundancy than low density scenarios. This observation can help to consider a cooperative MPR selection in OLSR.

key words: *OLSR, control traffic, multipoint relay (MPR) selection, topology control (TC) message*

1. Introduction

The optimized link state routing protocol (OLSR) [1] is a routing protocol for mobile ad-hoc network (MANET). OLSR is a proactive routing protocol on which each node exchanges regularly topology information with other nodes.

The key concept used in OLSR is the concept of multipoint relays (MPRs). Each node selects a subset of its neighbors as its MPR set. The MPR set has the following two properties: *(1) If a node n_i sends a message, and that message is successfully forwarded by all MPRs of n_i, then all (symmetric strict) 2-hop neighbors of n_i will receive that message. (2) Keeping the MPR set small ensures that the overhead of the protocol is kept at a minimum* [2].

Qayyum et al. [3] gives an analysis and an example of MPR set selection algorithm. They prove that the following MPR problem is NP-complete.

MPR Problem: *Given a network (i.e. the set of one-hop neighbors for each node), a node n_i of the network and an integer k, is there a multipoint relay set for n_i of size less than k?*

The heuristic algorithm proposed by Qayyum et al. [3] provides a near-optimal MPR set, and is employed in OLSR [1], which allows to use other algorithms having improvements.

The nodes which have been selected as MPRs have two roles: generating TC messages, and forwarding them. In contrast, other nodes that no neighbor selects as MPRs never generate or forward TC messages. Each TC message generated by node n_i advertises the links between generator n_i and the nodes which select n_i as an MPR.

In this letter, we consider minimizing the number of TC message senders, without any changes of the properties of the MPR set. The set of TC message senders is defined as a union of MPR sets of all nodes in the network. A preliminary consideration was shown in [4].

TC Message Senders Problem: *Given a network (i.e. the set of one-hop neighbors for each node), and candidates of MPR set for each node of the network, which combination of MPR set selected from the candidates of each node minimizes the number of TC message senders?*

For example, when there are several candidates of MPR set for a node n_i, the node should select the candidate that has larger number of common nodes with MPR set of neighbors of n_i than all the other candidates as its MPR set. The selection will reduce the number of TC message generators.

The total number of TC messages which are generated or forwarded by MPRs is approximated by (the number of TC message senders)×(the average number of forwarders for each TC message). These two terms affect the total number of TC messages. The MPR sets given through TC message senders problem decrease the first term. In this letter, we do not try to make the second term small, but we expect that the value of the second term is similar to that of OLSR.

To intuitively understand that TC message senders problem will reduce the total number of TC messages, we show an example network of eight nodes in Fig. 1. In this network, four nodes n_{11}, n_{12}, n_{31}, and n_{32} have the same two candidates of MPR set, $\{n_{21}\}$ and $\{n_{22}\}$. The remaining four nodes have two candidates $\{n_{31}\}$ and $\{n_{32}\}$ for each node. We consider $\{n_{21}, n_{31}\}$ as a solution of TC message senders problem. Each arrow shown in Fig. 1 is drawn from an MPR

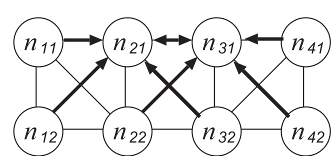

Fig. 1 An example solution of TC message senders problem.

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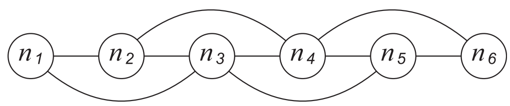

Fig. 2 An example network to compare MPR with MCDS.

selector to its MPR of this solution. In this solution, $\{n_{21}\}$ is the MPR sets of n_{11}, n_{12}, n_{31}, and n_{32}. $\{n_{31}\}$ is the MPR set of n_{21}, n_{22}, n_{41}, and n_{42}. Two MPRs n_{21} and n_{31} generate TC messages periodically, and forward the messages generated by each other. Therefore, the number of generated or forwarded TC messages in each period is four. On the other hand, the heuristic of OLSR may select n_{21} and n_{31} as TC message senders. However, the heuristic is not prohibited to choose MPR set $\{n_{21}\}$ for some nodes and $\{n_{22}\}$ for others. If three nodes n_{21}, n_{22}, and n_{31} are selected as MPRs by at least one node using the heuristic of OLSR, the number of TC messages in each period is six. In the worst case where four MPRs n_{21}, n_{22}, n_{31}, and n_{32} are selected using the heuristic, eight TC messages are generated or forwarded in each period. The TC message senders problem reduces the number of TC messages in this example.

A minimum connected dominating set (MCDS) is another candidate to reduce the number of forwarding nodes during the flooding process [5]. MCDS is out of the scope of this letter, since MCDS does not have the property *(1)* of MPR set described above. In other words, one of the differences between MPR and MCDS is that MPR guarantees the shortest path but MCDS does not, since MCDS only requires that every node has at least one neighbor in MCDS. The path through nodes in MCDS may have the length of the shortest path plus one. For example, we consider a six nodes network shown in Fig. 2. Each node $n_i (1 \le i \le 6)$ has up to four neighbors $n_j (i-2 \le j \le i+2$ and $1 \le j \le 6)$. In this network, one of the MCDSs is $\{n_3, n_5\}$. If the only nodes in this MCDS are used to create a path from n_2 to n_6, the path is (n_2, n_3, n_5, n_6) and the length of this path is three. In contrast, the path through MPRs is (n_2, n_4, n_6) which is the shortest path, since the MPR set of n_2 is $\{n_4\}$. As another difference, both time and message complexities of MCDS scheme are slightly higher than MPR scheme. Unfortunately, the concept of MCDS is not employed in any routing protocols of MANET currently.

The rest of this letter is organized as follows. In Sect. 2, the overview of OLSR is explained. The algorithm to find redundant TC message senders is explained in Sect. 3. Experimental results of computer simulation are described in Sect. 4. Finally, we conclude the letter in Sect. 5.

2. OLSR

OLSR is a proactive routing protocol for MANET. OLSR maintains both neighborhood information and topology information in each node. We denote the number of nodes in a MANET and i-th node as n and n_i, respectively.

Neighborhood information of each node is acquired from HELLO messages sent by other nodes. The information is used to disseminate topology information efficiently. As neighborhood information, each node n_i stores sets of one-hop neighbors, strict two-hop neighbors, MPRs, and MPR selectors of itself. These sets of n_i are denoted as $N(i)$, $N^2(i)$, $M(i)$, and $M^{-1}(i)$, respectively. All links between pair of nodes in $N(i)$ and nodes in $N^2(i)$ are also stored as the neighborhood information.

HELLO messages are broadcasted by all nodes periodically but never be forwarded. The first purpose of HELLO messages is to discover neighbors with symmetric link. As the second purpose, information of $N(i)$ and $M(i)$ included in a HELLO message of n_i is used to update $N^2(j)$ and $M^{-1}(j)$ when node n_j receives it. The MPR set $M(i)$ is calculated using $N(i)$, $N^2(i)$, and links between them. A node should select an MPR set such that each strict two-hop neighbor has at least one link to the node in MPR set.

Each MPR selectors set $M^{-1}(i)$ is a subset of neighbors $N(i)$. Each node in $M^{-1}(i)$ selects n_i as an MPR, i.e., $n_j \in M^{-1}(i)$ implies $n_i \in M(j)$ except for the delay of HELLO message delivery. To disseminate topology information, a TC message is flooded into entire network periodically. Each TC message informs the links between the TC message generator n_i and its MPR selectors $M^{-1}(i)$.

Topology information is acquired from TC messages. The information is used to calculate routing table. Since all TC messages are generated by MPR selectors and each TC message does not contain all links between the MPR selector and its neighbors, topology information of each node is partial information of actual topology. However, the first property of MPR set guarantees that the shortest path from itself to any other node is included in this partial topology information.

The heuristic algorithm [1] is used to calculate MPR set $M(i)$, whenever the information of $N(i)$, $N^2(i)$, and links between them is changed by any received HELLO message. MPR set $M(i)$ is selected by the algorithm, independently of the MPR selection of other nodes. It is not the matter for the heuristic algorithm that MPR set of the node includes many common nodes with the MPR sets of its neighbors, or less.

Currently OLSR version 2 [2] is discussed at IETF from Aug. 2005, as an update to OLSR [1]. Redundancy of TC message senders of this letter is also applicable to OLSR version 2.

3. Redundant TC Message Senders

To reveal the existence of redundant TC message senders in OLSR, we use a non-distributed MPR selection algorithm. The algorithm is not sufficient to be implemented in OLSR as an MPR selection scheme, due to its non-distributed nature. It is used to disclose a kind of boundary such as the minimal number of TC message senders. In this letter, we only show a central cooperative MPR selection algorithm solving TC message senders problem, instead of distributed cooperative MPR selection algorithms.

This algorithm consists of two parts: at first part each node finds all candidates of its MPR set by exhaustive search, and all candidates contains the minimum number of one-hop neighbors which satisfy MPR property described in Sect. 1; at the second part, which is not a distributed manner, a central entity aggregates the list of candidates from all nodes and solves the TC message senders problem described in Sect. 1 exhaustively. The MPR set selected for each node by the algorithm is announced to its neighbors through HELLO message as same as original OLSR.

To explain strictly, the number of the candidates of n_i is denoted as $c(i)$, and the set of the candidates of n_i is denoted as $C(i) = \{C(i,1), C(i,2), \ldots, C(i, c(i))\}$. $C()$ for each node is calculated at the first part of the algorithm. At the second part, $\Pi_{i=1}^{n} c(i)$ combinations are searched to find a combination $(s(1), s(2), \ldots, s(n))$ which provides the lowest number of TC message senders. The number of TC message senders for the combination is expressed as

$$\left| \bigcup_{i=1}^{n} C(i, s(i)) \right|,$$

where $1 \leq s(i) \leq c(i)$ for all $1 \leq i \leq n$. The candidate $C(i, s(i))$ is used as the MPR set $M(i)$, instead of the MPR set calculated by the heuristics of OLSR.

In contrast, the heuristic algorithm of OLSR finds just one of the candidates $C()$ for each node (or other larger MPR set) as the MPR set of the node. Each MPR set $M(i)$ selected by the heuristics algorithm may be equal to the best candidate $C(i, s(i))$. The redundancy of MPR selection is come from this multiple candidates of the MPR set.

4. Experimental Results

We compare the non-cooperative MPR selection scheme employed by OLSR [1] to the cooperative MPR selection scheme described in Sect. 3. We measure the number of TC message senders and the number of TC packets. Each TC packet encapsulates one or more TC messages.

We use ns-2 (ver. 2.29) with UM-OLSR v0.8.8 [6] as a simulator. The simulation environment is that each node has an IEEE 802.11 interface, communication radius is $r = 250$ m, all nodes are static and distributed randomly in a region of $r \times 4r\,\mathrm{m}^2$, the intervals of HELLO messages and TC messages are 2 and 5 seconds, respectively, and willingness is set at `will_default` to all nodes.

We assume that the nodes do not move during the simulation, then TC message senders of RFC-3626 OLSR are not changed after about 10 seconds from the beginning of the simulation. Therefore the number of TC message senders is counted at 20 seconds from the beginning. On the case of the cooperative MPR selection scheme, we solve the TC message senders problem only once per simulation. It is solved just before counting the number of TC message senders, and each node keeps the MPR set selected by the algorithm until the end of the simulation. The number of TC packets is counted from 20 to 60 seconds, including the packets sent originally by generator of TC message and the packets forwarded by MPRs.

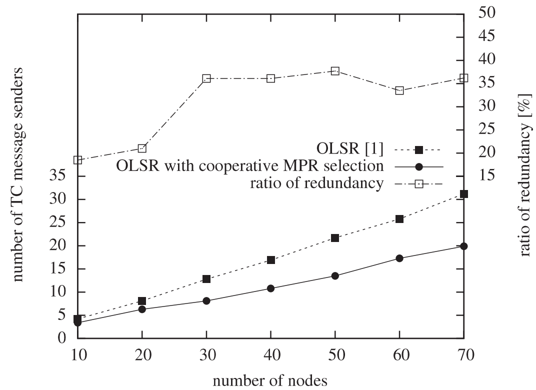

Fig. 3 Comparison of the numbers of TC message senders.

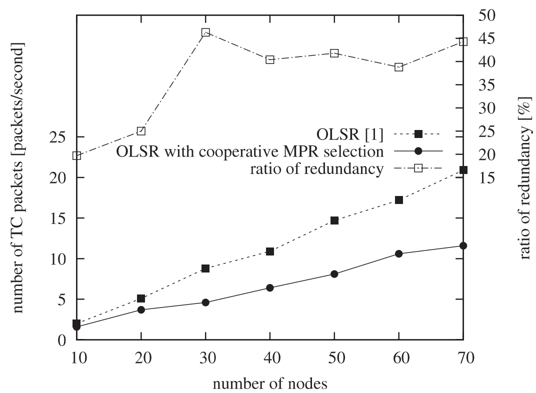

Fig. 4 Comparison of the numbers of TC packets.

The number of nodes n in a network is varied from 10 to 70. For each number of nodes, ten different node topologies are simulated and the averages of ten results are shown in the figures.

Figure 3 and Fig. 4 show the number of TC message senders and the number of TC packets on average every second, respectively. The number of TC packets is the total number of packets observed on the entire network. We counted TC packets, each of which may involve generated TC messages and/or forwarded TC messages. According to RFC 3626, each TC packet encapsulates one or more TC messages. Therefore, the number of TC packets is smaller than that of TC messages. This encapsulation helps to reduce overhead of UDP and underlying headers and to lower the probability of collision with other nodes' packets.

From the results, we divide the scenarios into two groups; the density of nodes is relatively low, i.e., $n \leq 20$, and relatively high, i.e., $n \geq 30$. On the low density scenarios, there are not so many candidates of MPR set. On these scenarios, the numbers of TC message senders have 18% to 21% redundancy, and the numbers of TC packets have 19% to 25% redundancy. In six topologies of them, we do not find redundancy.

On the other hand, high density scenarios mark high redundancy. The redundancy is between 33% and 37% in the number of TC message senders, and it is between 38%

and 46% in the number of TC packets. It implies that many nodes have enough number of candidates to select cooperative one on high density scenarios.

5. Conclusion

In this letter, we revealed redundant control traffic in OLSR. To reduce the number of TC messages which are the control messages in OLSR, we tried to reduce the number of TC message senders. We defined the TC message senders problem, to find redundant nodes which generate and forward TC messages. We explained a non-distributed cooperative MRP selection algorithm solving this problem. The algorithm is not sufficient to be implemented in OLSR, but is used to disclose the minimal number of TC message senders. Through simulation, we showed the redundancy over 18% up to 37%, in terms of the average number of TC message senders. For the number of TC packets, there exists 19% to 46% redundancy.

Since the number of forwarders for each TC message also affects the total number of TC messages, minimizing the number of TC message senders will be insufficient to minimize overhead of control traffic. We need to investigate the problem to reduce the number of forwarders in the future. We will consider distributed algorithms of cooperative MRP selection as a future work. The density of nodes is one of the key issues to consider them. We will evaluate the performance of distributed algorithms by comparing with the results of this letter as a kind of lower bound.

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