Efficient Unicast-based MultiHop Local Repair for Wireless Multicast MANET

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摘 要

無線隨意式網路(MANET)中，Multicast Ad hoc On-Demand Distance Vector (MAODV) 繞路協定在行動節點之間具有 dynamic、self-organizing 和 on-demand multicast routing。在 MAODV 中，當來源端希望傳送資料給多個接收端時，將會建立起 Multicast Tree。可是，在此環境下的行動節點因為移動和有限的電力等特性，導致原本存在於樹上的節點發生斷線的情形。為了解決此問題，MAODV 協定提供修復機制，是由發生斷線的下游節點廣播 Route Request (RREQ)封包，嘗試尋找路徑重新連接到樹上。雖然，有限制 RREQ 封包的 TTL，但是大量的廣播控制封包，卻造成網路的負擔和電力快速消耗。在本篇論文中，我們提出 unicast-based multihop local repair protocol (MHLR)的修復機制，可以有效減少控制封包數量、提高修復成功率及降低修復的時間，進而增加效能和降低資料延遲。在模擬數據中，我們所提出的方法在修復成功率及控制封包的負擔皆優於其他的方法。

關鍵詞：無線隨意網路、修復、群播

Abstract - The multicast Ad hoc On-Demand Distance Vector (MAODV) routing protocol is proposed for achieving dynamic, self-organizing and on-demand multicast routing among mobile nodes in Mobile Ad hoc Networks (MANETs). In MAODV, a multicast tree is established when a sender wants to send data to many receivers. Unfortunately, in MANET wireless links may be lost occasionally due to the nodes on the multicast tree that are unreachable. For solving the problem, the MAODV protocol provides a local repair mechanism that tries to find an alternative route to multicast tree by broadcasting the RREQ message from the downstream node of the broken link. Although the local repair mechanism works with a specified TTL to limit the repair range of RREQ, large number of the broadcast RREQ messages result in extensive control messages and significant power consumption for transmitting these broadcast messages. Therefore, in this paper we propose an unicast-type multihop local repair protocol (MHLR) to recovery the lost links on the tree efficiently while increasing network reliability, minimizing the number of control messages and shortening the repair delay. Meanwhile, the optimal number of hops of neighbor table is also analyzed. Numerical results indicate that the proposed approach outperforms other repair approaches in the fixed successful rate, control message overhead.

Keywords* － *MAODV, local repair, reliability, ad hoc network, MANET

I. INTRODUCTION

Recently, several research techniques and applications have been presented extensively for easy accessing information through heterogeneous wireless networks. Two main types of such wireless networks can be classified into the single hop and the multihop wireless networks. In the single hop wireless networks, an infrastructure network is required for mobile nodes to communicate with other nodes via the nearest access point (AP) or hot spot. In the multihop wireless networks, without an infrastructure network, each mobile node plays as a wireless router to route packets. The multihop wireless network is also called Mobile Ad hoc Network (MANET). MANET has several advantages of convenient access of shared resources, supporting mobile computing and self-organizing of mobile nodes. Since the structure of an ad hoc network changes dynamically due to nodes mobility, it lacks a fixed network topology. Some challenges are involved in MANET, including broken wireless links, limited power energy and limited transmission range. Therefore, an efficient local repair algorithm is required to overcome above-mentioned problems in ad hoc networks.

The routing strategies in ad hoc networks can be classified into the proactive and on-demand routing strategies [1]. In the proactive strategy, the routing state information of mobile nodes is exchanged periodically with neighbor nodes. It has the advantages of fast routing but causes large energy consumption for maintaining the up-to-date routing table. Topology Broadcast Based on Reverse Path Forwarding (TBRPF) [2], Fisheye State Routing (FSR) [3], and Optimized Link State Routing Protocol (OLSR) [4] are some examples of the proactive strategy, in which the link state algorithm is adopted by these protocols. On the other hand, the on-demand strategy does not provide the periodical exchange of link state information. Therefore, a route discovery procedure is required to find an optimal route before packets transmission. Without maintaining the link state among mobile nodes, mobile nodes save obviously energy power. Thus, the operation lifetime of the on-demand ad hoc network is extended. Dynamic Source Routing (DSR) [5] and Ad hoc On-demand Distance Vector (AODV) [6] are two typical protocols of the on-demand strategy. The advantage of DSR is unnecessary to maintain the routing table periodically, but DSR still has two disadvantages of route discovery flooding and non-scalable for large scale of ad hoc networks. On the other hand, in AODV, the destination node only replies the first arrival RREQ back to the source node and AODV keeps only one routing entry for each direction of an active route. AODV is thus more scalable than DSR.

Many researches [7-8] have compared the performance among these routing strategies and shown that the on-demand strategy outperforms the other routing strategies. Moreover, in ad hoc networks, a wireless link sometimes may be lost due to nodes mobility or out of power. This problem causes the ad hoc networks inefficient, which becomes worse in the on-demand ad hoc protocols, e.g., DSR and AODV. Assume that a broken link is at the next-hop link of an intermediate node in DSR. If the intermediate node can find an alternative route to the destination node in its route cache, packets will be sent along the alternative route. Otherwise, the intermediate node discards these packets and sends a RERR message back to the source node. Consequently, the fixed successful rate depends on the mobility rate and the accurate of alternative routes in individual routing cache. In contrast to DSR, nodes in AODV [6] try to repair the broken link locally by broadcasting RREQ to the destination node. If the procedure of local repair is failure, a RERR message will be sent back to the source node. Although the local repair mechanism works with a specified TTL to limit the repair range of RREQ, large number of the broadcast RREQ messages results in extensive control messages and power consumption. How to reduce the power consumption for extending the lifetime of ad hoc networks is an important issue. Furthermore, Perkins *et al.* [7] compared the performance of DSR and AODV, and indicated that AODV is better than DSR in terms of less delay, more scalable, more packets delivery rate, less MAC layer overhead and unnecessary of the route cache. Therefore, in this paper, we focus on solving the problem of local repair mechanism in the on-demand AODV protocol to increase the fixed successful rate, mobile reliability and network utilization.

Several local repair approaches [9-13] have been proposed to reduce the processing delay of broken links in AODV. In [9], Konduru *et al.* proposed a proactive technique in AODV, called broadcast AODV (BCAODV), to reduce packet delays especially when the node mobility is high. In BCAODV, receiver nodes periodically broadcast beacons throughout the network to keep routing entries in other nodes. Although BCAODV may reduce the probability of link broken, it causes large amount of beacon overhead and still does not repair broken links when the active route is broken. In [10], Lee *et al.* proposed a backup AODV routing protocol by overhearing all RREP messages that are not destined to it and stores the routing information to its alternative routing table. The overhearing method is not obeyed by the MAC layer protocols. Therefore, the MAC layer protocol will not receive the packets that are not belongs to it. Moreover, the scheme does not perform well under heavy traffic networks due to overhearing large amount of useless RREP.

Based on [6], Lee *et al.* [11] proposed a local repair scheme with a TTL threshold to limit the range of the repair RREQ message. Results showed that the scheme works well in large networks (e.g., ten or more hops), but it does not have significant improvement for short routes. In [12], Wang *et al.* proposed a backup node setup mechanism to reconnect quickly when the transmission route fails. The establishment of backup nodes is computed from all possible routes. The backup nodes record several alternative routes to destination; therefore, the upstream node of a broken link can send an alter message to the backup node to initialize the repair process. It is thus suitable for DSR rather than AODV. Nevertheless, the idea of backup node can apply to the local repair mechanism in AODV. To improve the performance of AODV, Gwalani *et al.* [13] proposed a modified AODV, AODV-PA, to include the accumulation feature from source routing, e.g., DSR. AODV-PA can decrease the number of route discovery cycles as compared to the basic AODV, but it does not improve the fixed successful rate. The primary reason is that the paths accumulation information is only updated during the period of path discovery rather than the period of data routing/forwarding.

Existing multicast routing protocol in MANET can be classified two types, mesh based protocol and tree based protocol. First, in the mesh based protocol, On-Demand Multicast Routing Protocol (ODMRP) [14] is the typical mesh based protocol. The source uses periodically broadcast a JOIN-REQUEST (JQ) message for joining to the group. The receiver receives a JQ message will reply a JOIN-REPLY to source that joining procedure is successful. In ODMRP, only uses a broadcast-type message management all receivers, it is not explicit control packets to provide JOIN or LEAVE to maintain tree. Moreover, ODMRP brings two disadvantages, including amount of control overhead and long fixed delay. Several approaches based on ODMRP have proposed for reducing control messages and providing extra control packets to maintain tree, including PacthODMRP [15] and On-Demand Multicast Routing Protocol with Multipoint Relays (ODMRP-MPR) [16]. In PatchODMRP, proposed a ADVT message to repair broken links by forwarding group (FG) node. The TTL of ADVT message is set to two or three hops that the scope of flooding is limited. All of the group members receives the ADVT message will reply a PACTH message to the initial of ADVT node that repairing is successful. Although it can repair broken link in real time, the fixed successful rate reduces under high mobility. In [16], ODMRP-MPR proposed multipoint relays (MPR) to reduce control messages. Each node determines MPR by the set of $S(x)$ and $Q(x)$. Although, ODMRP-MRR can reduce control messages more than that ODMRP, it has to maintain these two sets of $S(x)$ and $Q(x)$.

Second, based on AODV the tree based protocol -- Multicast Operation of the On-Demand Distance Vector Routing Protocol (MAODV) [17] is proposed to establish multicast tree, in which a broadcast-type RREQ and RREP message are adopted for local repair. Furthermore, it also use Hello message to determine link broken. When link is broken, the downstream node of link broken will initialize local repair by broadcast RREQ with TTL within the value of hop count to leader. If the tree node received RREQ and the value in RREQ is large than the value of hop count to leader of the tree node, the tree node will reply RREP to the initialized RREQ node that repairing is successful. Meanwhile, the value of another branch of the tree node is large than the value in RREQ, it can not reply RREP to repair broken link. Thus, it can not to guarantee high fixed successful rate.

In [18], the On-Demand Associability-based Multicast Routing for Ad Hoc Mobile Network (ABAM) is proposed. The multicast sender broadcasts Multicast Broadcast Request (MBQ) message to the network. The receiver replies MBQ-REPLY back to the multicast sender. After that sender sends MC-STEUP to receivers to indicate that the joining produce is completed. When link is broken, the upstream node of link broken initializes to repair by broadcast a Local Query (LQ). The number of hop count of LQ message is determine by the distance of branch node. The downstream of broken node receives LQ message will reply LQ-REPLY back to the initialized LQ node and then send MC-SETUP to the downstream node for successful the repair produce. If the LQ process fails, the downstream node broadcasts a JQ message to reconnect the multicast tree. Thereby, ABAM can not real time repair and long fixed delay under high mobility.

In Family ACK Tree (FAT) [19], each node records Grandparent ID (GID), Parent ID (PID), and Children ID (CID) in ACK table. There are two type control messages to be exchanged among of each node on a family ACK tree including Subgroup ID advertisement (Ad) and Retransmission request (RTQ). In FAT, the repair produce is backtracking toward the root. If the parent of the node is gone, the grandparent will become foster parent. The repair produce repeat until the foster parent is found. Thus, the worst case, the repair will go to the root that long fixed and low fixed rate.

Therefore, in this paper, we propose a multihop local repair approach to repair the broken links. The main idea of the proposed approach is that sends the neighbor information of multiple hops within to the original periodical Hello message. Based on the up-to-date information of multihop neighbor, we propose a set of four unicast-type repair messages - FREQ (Fixed Request), FREP (Fixed Reply), FERR (Fixed Error) and FUPDATE (Fixed Update) message, to repair the broken links efficiently. Moreover, these messages are all unicast-type messages rather than the broadcast-type RREQ message in [17]. In consequence, the control message overhead of the proposed approach is minimized significantly while improving the fixed successful rate.

The rest of this paper is organized as follows. In Section II the proposed unicast-based multihop local repair approach is detailed. Section III presents the numerical results of the proposed repair approach and other approaches by simulations. Finally, conclusions are given in Section IV.

II. HIGH RELIABILITY MULTICAST REPAIR APPROACH

For increasing reliability in MAODV, the unicast-based multihop local repair approach is proposed, which consists of two-type messages: the maintain messages and the repair messages. First, the maintain messages, including

- an extended Hello message,
- an extended Group Hello message, and
- extended MACT message,

are adopted to update and maintain the information of multihop neighbor nodes and the tree information. Second, a set of unicast-type repair messages, including

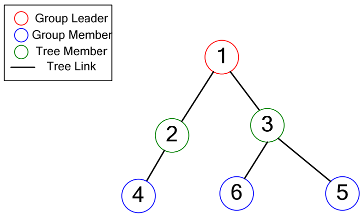
- the Fixed Request message (FREQ),
- the Fixed Reply message (FREP),
- the Fixed Error message (FRERR),
- the Fixed Error message (FRER), and
- the Fixed Update message (FUPDATE),

are adopted to repair broken links automatically when some tree links are broken.

Then, two distributed tables within each mobile node – the multihop neighbor table and the tree node table, are proposed to maintain the information of multiphop neighbor nodes and the tree information, respectively. Based on the proposed messages and the up-to-date routing information of multihop neighbor, the node downstream of a broken link can repair the breaks directly and efficiently. The proposed unicast-based multihop local repair approach is denoted as MHLR and detailed in the following subsections.

A. New tree node table

In MHLR, a tree node table (TNT) is proposed for maintaining the information of tree nodes. As shown in Fig. 1 is an example of multicast tree and tree node table. In TNT, each entry includes DOWNSTREAM_FLAG and HOP_COUNT_TO_LEADER. DOWNSTREAM_FLAG indicates whether it has downstream node or not, where 1 means the node lacks any downstream node and 2 means it has at least one. HOP_COUNT_TO_LEADER is the hop count to leader. For instance, (DOWNSTREAM_FLAG, HOP_COUNT_TO_LEADER) of link (4,2) is (2,2) because node 4 lacks any downstream node and the distance to the group leader is two hops.



Multicast Group IP Address

Down \ Up	1	2	3	4	5	6
1						
2	(1,1)					
3	(1,1)					
4		(2,2)				
5			(2,2)			
6			(2,2)			

(DOWNSTREAM_FLAG , HOP_COUNT_TO_LEADER)

Fig. 1. An example of a multicast tree and the tree node table

B. Extended MACT message

In MAODV, MACT message is only forwarded to the tree node to update the downstream information, but the extended MACT message will be forwarded to the multicast group leader in MHLR. By using the extended MACT message for maintaining or updating the multicast tree structure in TNT when nodes join or leave. Thus, the up-to-date tree structure can be obtained. An example of the extended MACT message forwarded to the multicast group leader is demonstrated in Fig. 2.

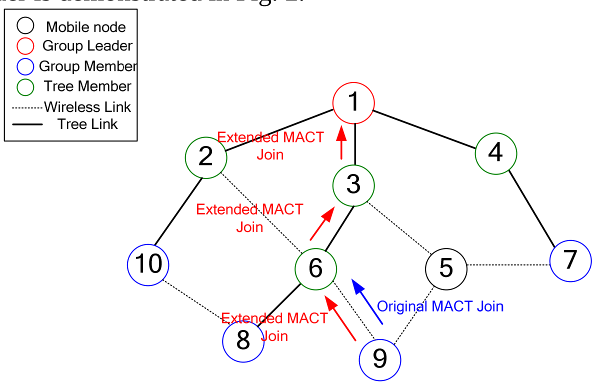


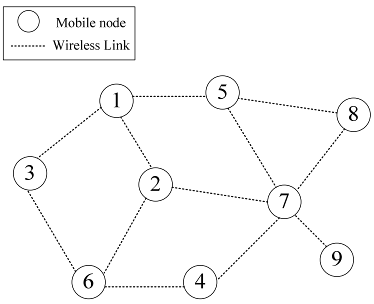
Fig. 2. An example of extended MACT message forwarded to multicast group leader

C. Extended group hello message

In MAODV, the multicast group leader periodically the Group Hello message within an interval timer of *GROUP_HELLO_INTERVAL*, i.e., 5000 ms, as the heartbeat to notify all the tree nodes that the group is still alive. For making the multicast tree structure consistent, the extended Group Hello message, based on Group Hello message in MAODV, is proposed to multicast periodically the up-to-date tree node table to all the tree nodes. After receiving the up-to-date tree information, each node updates its local tree node table for future repair.

D. New multihop neighbor table

For determining an optimal substitute node to replace the broken tree node, a new data structure of the multihop neighbor table (i.e., the neighbor tree structure), is proposed for maintaining the information of multihop neighbor nodes. As Fig. 3 shown is an example of the multihop neighbor table within h-hop, $1 \le h \le H$, where h is the hop index and H is the maximum repair hop. The neighbor set of the h-th hop of node 2 is denoted as $N^h(2)$. For instance, $N^1(2)$ represents the neighbor set of the first hop of node 2, which includes node 1, 6 and 7. Mobile nodes maintain the multihop neighbor table based on the received extended Hello messages from all active neighbor nodes. Consequently, each mobile node can obtain the up-to-date information of multihop neighbor nodes for determining the substitute node to replace the unreachable node.



Mobile node 2

$N^1(i)$	$N^2(i)$	...	$N^H(i)$
1	2,3,5	...	...
6	2,3,4	...	...
7	2,4,5,8,9	...	...

Fig 3. An example of multihop neighbor table of mobile node 2

E. Extended hello message

In MAODV, mobile nodes periodically broadcast the Hello message within an interval timer of *HELLO_INTERVAL*, 1000ms, as the heartbeat to notify neighbor nodes that they are still active. A mobile node can use the received Hello messages from neighbor nodes to sense all connective neighbor nodes. A mobile node sends Hello by using RREP with setting the field of the destination IP address to its IP address and setting TTL to one, i.e., mobile nodes are aware of the neighbor nodes within a single hop. For gathering the information of neighbor nodes within multiple hops, an extended Hello message, which is based on the Hello message in MAODV [6], is proposed to broadcast periodically the multihop neighbor table. Therefore, each mobile node can obtain the up-to-date neighbor information within multiple hops. After receiving the periodical broadcast extended Hello message, each mobile node first updates the multihop neighbor table and checks the multicast routing table to determine whether there are some broken links on the tree link or not. If some broken links can be found on tree link, the node will determine the optimal substitute node as follows.

For reducing the length of the repaired route from the downstream node of the broken link to the tree, two repair orders of different hops and the same hop are considered. First, the order of searching the substitute node (i.e. the node to substitute for the original unreachable node) of different hops is from the first hop neighbor nodes, $N^1(r)$, to the H-th hop neighbor nodes, $N^H(r)$, where r represents the node that initializes the repair procedure as shown in Fig. 4. Second, in the case of the same hop, the order of searching the substitute node on the downstream route is from the destination node to the downstream node of the broken link, which is called the reverse checking-sequence scheme as shown in Fig. 5. The reverse checking-sequence scheme achieve two advantages of reducing the length of repaired route and providing efficient repair, when there are several broken links on the active route.

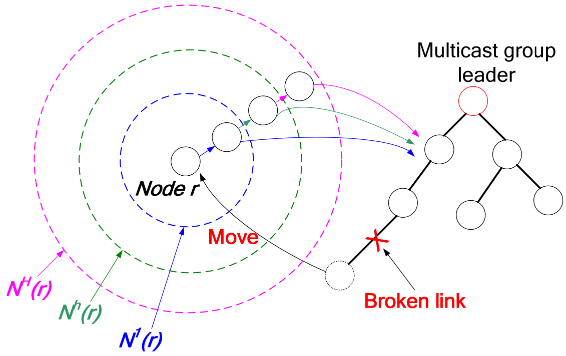


Fig. 4. The repair order of different hops

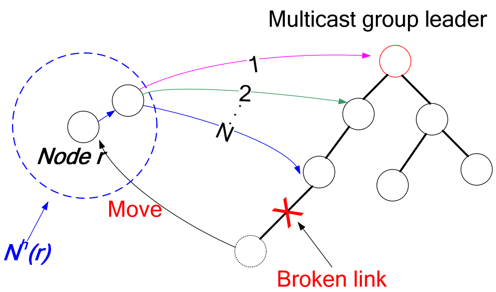


Fig. 5. The repair order of the least hop count first scheme of the same hop

For instance, in Fig. 6 the node 9 receives Hello from neighbors and updates its multihop neighbor table. By comparing the up-to-date multihop neighbor table with the tree node table, the node 9 finds node 6 is unreachable. Node 9 thus initializes the local repair procedure. First, the node 9 searches all substitute nodes from the multihop neighbor table and tree node table. Nodes 5 and 8 are the neighbor of node 9. Node 9 first checks the node 5 that is a tree node; therefore, the node 5 can be chosen as a substitute node. It then checks the node 8, where node 8 can be connected to the tree node 2. Node 8 is thus selected as a substitute node. After determining all possible substitute nodes, nodes 5 and 8, MHLR selects the route with the least hop count to multicast group leader from the repair node as the optimal substitute node. Since the route of (9→8→2→1) has the least hop count as shown in Fig. 7, the node 8 will be chosen the optimal substitute node. Then, the repair node 9 directly sends an unicast-type repair request message (FREQ) to the node 2 via node 8 to initial the repair procedure. The complete repair procedure is described in next subsection.

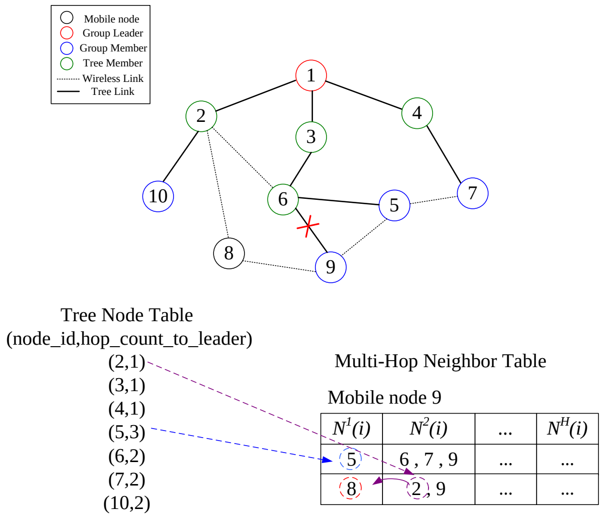


Fig. 6. An example of search the possible substitute node

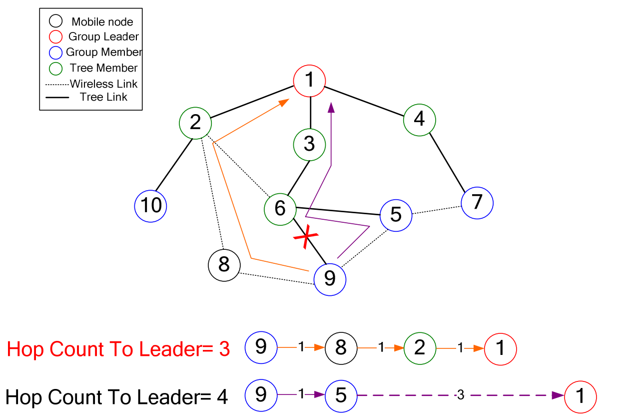


Fig. 7. An example of determining the optimal substitute node

F. The set of unicast-type local repair messages of FREQ, FREP, FRER, and FUPDATE

After determining the optimal substitute node, a set of unicast-type repair messages is proposed instead of broadcast-based messages in MAODV to repair broken links efficiently while reducing large control overhead significantly. The unicast-type multihop repair approach consists of four unicast-type repair messages, including the Fixed Request (FREQ), Fixed Reply (FREP), Fixed Error (FERR) and Fixed Update (FUPDATE) messages. The functions of FREQ, FREP and FERR are similar to the function of RREQ, RREP and RERR in MAODV, respectively, but with different transmission types. FUPDATE is a new message for updating the information of multicast tree structure. The main difference is that FREQ is an unicast message, which reduces large amount of control message overhead and avoids message flooding. The set repair messages are detailed as follows.

Assume that an intermediate node r finds a broken link at an active route tree link and it determines a substitute node t from the first hop neighbor nodes, $N^1(r)$, for repairing. Then it directly sends FREQ to the substitute node t, in which the information of next multihop nodes, previous multihop nodes and destination are stored in FREQ. First of the information, the next multihop nodes, it consists of H nodes including $Next\ hop^1(r)$, $Next\ hop^2(r)$, $\ldots$, and $Next\ hop^H(r)$. Second, the previous multihop nodes are adopted for creating the reverse routing entry back to the source node. Since the substitute node t originally is not on the active route, it does not have the corresponding routing entries of the active route. After receiving FREQ by the substitute node t, it updates the information of next multihop nodes of FREQ by checking whether the received next two-hop node of $Next\ hop^2(r)$ is in its multihop neighbor nodes or not. If $Next\ hop^2(r)$ can be found in its multihop neighbor nodes, the substitute node sets $Next\ hop^2(r)$, $\cdots$, $Next\ hop^H(r)$ and *NULL* to the new next multihop nodes of FREQ, creates a reverse routing entry back to the source node from the received information of previous multihop nodes, and updates the fields of previous multihop nodes of FREQ. Finally, the updated FREQ message is forwarded to the node of $Next\ hop^2(r)$. Otherwise, the substitute node t should reply FERR back to the repair node r. When the repair node r receives FERR or the timeout of FREQ_REPLY_TIMEOUT is expired, it will try another repair based on the repair order of different hops as shown in Fig. 4. Furthermore, Fig. 8 gives an example of sending a FREQ message for repair the broken link between nodes 6 and 9.

Assume that FREQ arrives at a tree node y on the original multicast tree. The repair procedure is done successfully. Then the node y sends a FUPDATE message to the multicast group leader to update the multicast tree structure and replies a FREP message back to the repair node r. Meanwhile, each intermediate node on the repaired route that receives the FREP message will update the corresponding reverse routing entry back to the destination. Finally, when FREP arrives at the repair node r, a FUPDATE message is sent to the previous H hop nodes to update the routing and multicast routing table.

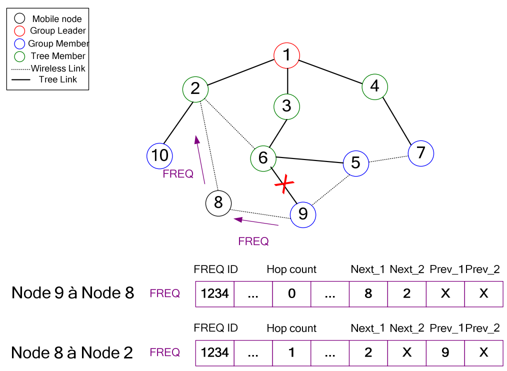


Fig. 8. An example of mutihop repair approach by sending FREQ to the optimal substitute node 8

III. Numerical Result

This section evaluates the proposed unicast-based multihop local repair approach by comparing several performance metrics, including fixed successful rate and the number of control message, with the MAODV protocol of two different TTLs. In MAODV [17], TTL of local repair is referred to *MAODV_TTL*, which is limited to *Last Hop Count* + *TTL_INCREMENT*, where the parameters of *Last Hop Count* (the hop count to group leader) and *TTL_INCREMENT* are set to the same value in [17]. Meanwhile, the unlimited TTL of MAODV, denoted as *MAODV_No_TTL*, is considered as the baseline because *MAODV_No_TTL* has the highest amount of control message overhead. The proposed unicast-based multihop repair approach is denoted as $MHLR\_i$, where i, $1 \le i \le H$, means the hop limit for repairing. In the simulation, the maximum hop limit for repair is set to four. Several useful parameters in the simulation are given as follows.

- The area of simulation is 1000 (meter) $\times$ 1000 (meter).
- The number of mobile nodes (NDS) is from 30 to 100.
- The transmission range of each mobile node is 100 meters.
- The mobility velocity of each mobile node adopts the random-way point mode with ranging from 1 to 25 meters per second (i.e., from 3.6 to 90 kilometers per hour).
- The mobility direction of each mobile node adopts the random-way point mode with ranging from 0 to 360 degree.

In simulations, a multicast session of the CBR traffic arrive at the group leader according to a Poisson distribution with the arrival rate ranging from 6 to 16. The average holding time is exponentially distributed and the mean is normalized to unity. The channel capacity of each node is 11Mbps.

The 95% confidence intervals of the simulation results in the following figures originate from 25 independent runs. For each run, the simulated time is 1000 sec of mean call holding time.

Fig. 9 shows the fixed successful rate among all evaluated approaches under different number of mobile nodes from 30 to 100. In Fig. 9, *MHLR_4* yields the highest result but *MHLR_1* has the lowest fixed successful rate. *MHLR_3* yields very competitive fixed successful rate to that of *MHLR_4* and *MAODV_No_TTL*. Although *MAODV_No_TTL* has better fixed successful rate than that of *MAODV_TTL*, *MAODV_No_TTL* always has worse fixed successful rate than *MHLR_4*. Moreover, the fixed successful rate of all approaches increases as the number of mobile nodes increases. The reason is that when the number of mobile nodes increases, the number of available substitute nodes increases and thus improves the fixed successful rate.

Fig. 10 demonstrates the control message overhead among all approaches under different number of mobile nodes from 30 to 100, and the random-way point mode is adopted as the mobility model. The control message overhead includes all control messages for finding the optimal route and for repairing broken links. In MAODV, the control message overhead includes the total number of RREQs, RREPs and RERRs. In MHLR, the control message overhead includes the total number of RREQs, RREPs, RERRs, FREQs, FREPs, FERRs, MACTs and FUPDATEs. Less the control overhead means less the exhausted energy power and less the bandwidth for control messages. In Fig. 10, the control message overhead increases as the number of mobile nodes increases. Moreover, *MAODV_No_TTL* and *MAODV_TTL* yield obviously high control message overhead, where *MAODV_No_TTL* yields the highest result but *MHLR_1* has the least control message overhead. Meanwhile, all $MHLR\_i$ approaches yield competitive control message overhead.

In summary, MAODV adopts *MAODV_TTL* as the local repair scheme and *MAODV_No_TTL* is selected as baseline for evaluating the performance among all approaches. In the simulation, *MAODV_No_TTL* and *MAODV_TTL* results in much worse control message overhead, in which *MAODV_No_TTL* yields the highest control message overhead significantly. Nevertheless, *MHLR_4* yields the highest fixed successful rate to that of *MAODV_No_TTL*. Meanwhile, *MHLR_3* yields better fixed successful rate than that of *MAODV_TTL*. Consequently, *MHLR_3* outperforms *MAODV_TTL* in all performance metrics. *MHLR_4* surpasses *MAODV_No_TTL* in fixed successful rate and control message overhead.

IV. Conclusions

Since node mobility and limited energy power result in link broken on a multicast tree, this makes ad hoc networks inefficient and unreliable. MAODV provides a simple broadcast-type local repair mechanism to repair the broken links but it brings several disadvantages including large amount of control message overhead and long delay of delivering data. Therefore, in this paper we propose an efficient unicast-based multihop local repair protocol (called MHLR) to recovery the broken links, in which four unicast-type repair messages are proposed to achieve less the amount of control messages while increasing fixed successful rate. Meanwhile, an extended routing table and an extended Hello message are proposed for cooperating with the multihop local repair approach. Numerical results demonstrate that MHLR with the hop limit of three or above outperforms significantly the MAODV protocol in fixed successful rate and control message overhead.

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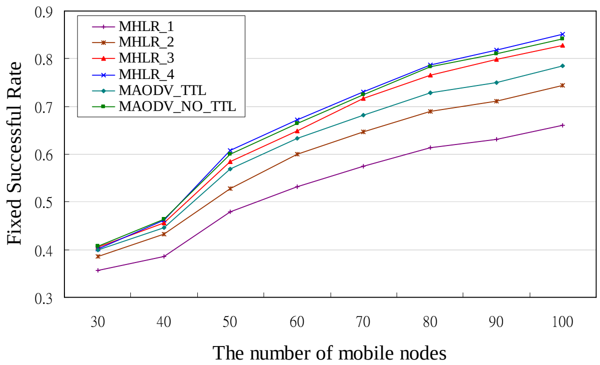

Fig. 9. Fixed successful rate under different number of mobile nodes

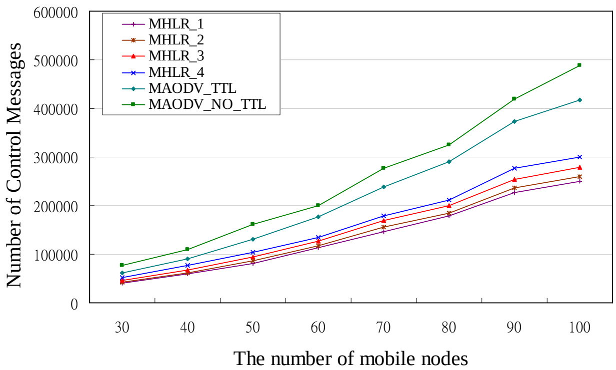

Fig. 10. Number of control messages under different number of mobile nodes