

A New Local Repair Scheme for Mobile Ad Hoc Networks

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Abstract—A new route repair scheme based on link breaks is proposed to improve route repair efficiency for realistic ad hoc networks. Its design idea is as follows. Change of downstream node status is regarded as the basis of choosing route repair schemes by the repairing node. Causes of link breaks would be analyzed according to the change of node status. And different nodes are selected as the destinations for RREQ. RREQ with multiple destinations would be broadcasted by the repairing node. Causes for link breaks are classified as 3 types, i.e. mobility between nodes, node failure and node power-off. Mathematical analysis and simulation are carried out to evaluate network performance. Under different node failure circumstances with the proposed scheme, on average, route setup time is reduced by 13% and control overhead ratio is lowered by 18%. The proposed mechanism is shown to have better ability to adapt to real networks.

Keywords—MANET; routing protocol; AODV; link break; local repair

I. INTRODUCTION

MANET (Mobile Ad hoc Network) is a mobile multi-hop, wireless self-organized distributed network [1]. The existing routing protocols may be categorized into proactive ones and reactive ones [2]. AODV [3] is a representative of reactive routing protocols of MANET. Local repair procedure of AODV could help to reduce route repair time and control overhead by enabling the node upstream of break repair the route locally. The local repair techniques are necessary to be employed in reactive protocols to make them suitable for large ad hoc networks [4].

The rest of the paper is organized as follows. Research efforts and technical limitations on AODV local repair are discussed in Section II. The essential idea of the local repair scheme based on link breaks is described in Section III. Section IV elaborates the new local repair scheme through giving a typical example. The performance evaluation is detailed in Section V. In Section VI, the concluding remarks are outlined.

II. DISCUSSION ON LOCAL REPAIR

Some solutions have been proposed to make routing protocols more robust against link breakages. On the one hand, researchers use cross-layer mechanisms, backup routes

or prediction of link breakages to enhance route reliability [5], [6]. A cross-layer approach is proposed in [5], which allows fast detection of and recovery from link error at the MAC layer. Cross-layer interactions present opportunities for optimizations of routing protocol, while routing algorithms have been more complicated. A cache bypass and local recovery based route reconstruction scheme is proposed in [6]. The nodes listen in all frames including data packets and routing control packet to maintain local route cache. Then fast route discovery and local recovery would be achieved by local route cache when a broken link occurs. The drawback of the scheme in [6] is that nodes maintain backup routes would consume additional energy. In addition, not all wireless devices support this type of operation of listening in all packets for security considerations.

On the other hand, the researchers focus more attention on route repair solutions provided by typical routing protocols (e.g. AODV local repair). Some schemes have been proposed to improve the performance of routing protocol by optimizing the algorithm on the routing layer [7], [8]. Generally, when the link breaks between the node and the next hop node, the next one-hop node or next two-hop node still has an active route to the destination. And the next one-hop or two-hop node is closer to the repairing node than the destination node. By broadcasting RREQ on a small scale, we can establish a route from the repairing node to its next one-hop or two-hop node. This is equal to the successful route setup from the repairing node to the destination node. So the improvements could reduce route setup time and control overhead.

In local repair of [7], a link repair packet is broadcasted from a downstream node where the link breaks to an upstream node. This leaves out the process of the upstream node broadcasting RREQ and achieves the purposes of reducing time for route setup and reducing control overhead. The local repair scheme of [8] is based on keeping the next two-hop node. When the node discovers a link breakage in an active route, it established the route by broadcasting RREQ with the next two-hop node as its route destination and by-passing the next hop node. This reduces the route setup time and the overhead of control packets to some extent.

III. LOCAL REPAIR BASED ON LINK BREAKS

In this paper, we make an effort to optimize the local repair mechanism on the routing layer. A new local repair scheme based on link breaks has been proposed. Its design idea could be outlined as follows.

A. Classification of Link Breaks

The classification of link breaks aims to provide the basis for the new improved local repair scheme. When the link breaks, the repairing node analyses the possible causes of breakage and chooses different repair methods for different link breaks. With the change of node status in the network in consideration, this paper sums up 3 types of causes for link breaks, which result in 3 corresponding types of link breaks.

1) Link Break Type 1

Relative mobility of neighboring nodes may result in link break between them, eventually causing related routes to be invalid. The new local repair scheme regards the breakage resulting from mobility of nodes as the 1st type of link breaks.

2) Link Break Type 2

In real ad hoc networks, nodes are very likely to stop working properly as a result of failures (i.e. software and hardware failures of node). When the software or hardware failure of node occurs, the links between this node and its neighboring nodes would break simultaneously. The link breaks caused by failures of node are defined as the 2nd type of link breaks in the new local repair scheme.

3) Link Break Type 3

It is normal to see the power-off of node produced by intentional behavior or exhaustion for energy in real ad hoc networks. When a node powers off, links between itself and its neighboring nodes would break at the same time. In the new local repair scheme, link breakages produced by power-off of node are considered the 3rd type of link breaks.

B. Improved RREQ Packet

The traditional RREQ has only one destination address. The new scheme proposed in this paper adopts the improved RREQ which includes not only the address of downstream node but also the destination address of data packets. By broadcasting the improved RREQ, the repairing node not only establishes the route to the downstream node but also to discovers the route to the destination node of data packets.

C. Failure Indication Packet

When node is about to power off, it should look up the routing table and get addresses of the next hop and destination from each route entry. Then it broadcast Failure Indication Packet contains couples of node addresses to its neighboring nodes. The neighboring node receives the packet and considers the link between itself and the sending node would break soon. And Link Break Type 3 should be recorded. The neighboring node looks up its routing table based on the sending node of the packet and each destination node contained in the packet. And the next-two hop node of the corresponding route entry should be set as the next hop element contained in the packet.

The new local repair scheme falls into two phases. In the first phase, the repairing node initiates the first local repair. For the 3rd type of link breaks, the next two-hop node and the destination node are taken as the multiple destinations for route discovery. For the other two types of link breaks, the next one-hop node and the destination node are taken as the multiple destinations for route discovery. For the first local repair, the small-scale broadcast of RREQ is adopted. If the first local repair is successful, the repairing node updates the routing table and sends the buffered data packets. If the first local repair fails, the node attempts the second local repair which is the same as AODV local repair.

IV. TYPICAL EXAMPLES

As shown in Fig. 1, there is a route (ABFCEHJ). Three types of link break occur in the network respectively. The relative mobility of node C and node E result in Link (CE) Breaks Type 1. For Link Break Type 2, the node E fails abnormally due to software or hardware failure, resulting in breakages of links (CE), (EH) and (DE). For Link Break Type 3, when node E is about to power off, E broadcast failure indication packet. After receiving failure indication packet, node C could determine the exact cause of break of link (CE). And node C would set the route leading to node J as invalid.

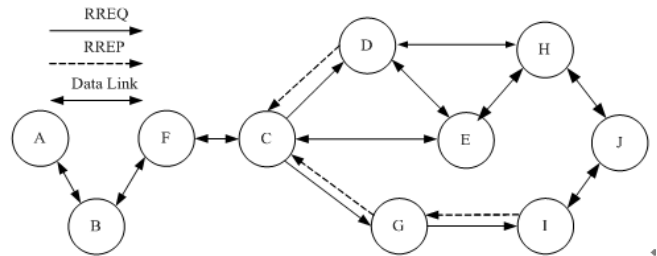


Figure 1. Example of the New Local Repair Scheme

- (1) Node C receives the data packet whose destination node is J. At the time the route has become invalid, and C carries out local repair procedure.
- (2) During the first local repair process, the route discovery destinations are the next two-hop node H and the destination node J of data packets for Link Break Type 3. For the other Link Break Types, the destinations for route discovery are the next one-hop node E and the destination node J.
- (3) When node J or node I which has an active route to J receives RREQ, node will return RREP.
- (4) If node D receives RREQ and has a route to node J, it will return RREP. Otherwise, if it has an effective link to node E (Link Break Type 1 or 2) or H (Link Break Type 3), D also returns RREP and establishes a route entry in its routing table with J as its destination node and E or H as its next one-hop node.
- (5) Node C receives RREP and updates the routing table, the local repair process is completed.
- (6) In case the first local repair fails, node C initiates the second local repair process. The destination node for route discovery is only node J.

- (7) If the 2nd local repair fails, node C broadcasts RERR to inform other nodes that the link (CE) has already broken.

V. PERFORMANCE EVALUATION

The mathematic method and simulation analysis used in the follows aim to demonstrate that the local repair scheme based on link breaks is superior in performance than the traditional local repair scheme on several performance metrics for ad hoc networks.

A. Route Setup Time

Suppose P_i stands for the probability of the i kind of link breaks, $i = 1, 2, 3$; $\sum_{i=1}^3 P_i = 1$;

Suppose Q_i stands for the probability of successful repair of the i kind of link breaks in the first local repair process, T_i stands for the corresponding time for repairing route;

Suppose T_a stands for the average time needed for successful route repair in the second local repair after the first repair fails;

Suppose T_w stands for the maximal time for the repairing node waiting RREP in the first local repair process;

The local repair scheme based on link breaks includes two local repair processes. When the first repair process fails, the second one would be initiated. When the i kind of link break occurs, the average time needed for successful route setup in local repair should be:

$$T_i' = Q_i \cdot T_i + (1 - Q_i) \cdot (T_a + T_w). \quad (1)$$

Therefore, when the link breaks, the average time needed for successful route setup in local repair should be:

$$T_{lr++} = \sum_{i=1}^3 (T_i' \cdot P_i) = \sum_{i=1}^3 [Q_i \cdot T_i + (1 - Q_i) \cdot (T_a + T_w)] \cdot P_i. \quad (2)$$

The AODV local repair process is the same as the second local repair process of the local repair scheme based on link breaks. So the average time needed for successful route setup in the AODV local repair should be: $T_{lr} = T_a$; What we need to prove is: $T_{lr} \geq T_{lr++}$ (i.e. $T_{lr} - T_{lr++} \geq 0$).

$$\begin{aligned} T_{lr} - T_{lr++} &= T_a - T_{lr++} = T_a - \sum_{i=1}^3 (T_i' \cdot P_i) \\ &= T_a - \sum_{i=1}^3 [Q_i \cdot T_i + (1 - Q_i) \cdot (T_a + T_w)] \cdot P_i \\ &= T_a - \sum_{i=1}^3 (1 - Q_i) T_a \cdot P_i - \sum_{i=1}^3 [Q_i \cdot T_i + (1 - Q_i) \cdot T_w] \cdot P_i \\ &= T_a \left[1 - \sum_{i=1}^3 (P_i - Q_i \cdot P_i) \right] - \sum_{i=1}^3 Q_i \cdot T_i \cdot P_i - T_w \left[\sum_{i=1}^3 (1 - Q_i) \cdot P_i \right] \end{aligned}$$

$$= T_a \sum_{i=1}^3 Q_i \cdot P_i - \sum_{i=1}^3 Q_i \cdot T_i \cdot P_i - T_w \left(1 - \sum_{i=1}^3 Q_i \cdot P_i \right) \quad (3)$$

To make (3) ≥ 0 , we have the following inference:

$$\begin{aligned} T_a \sum_{i=1}^3 Q_i \cdot P_i - \sum_{i=1}^3 Q_i \cdot T_i \cdot P_i - T_w \left(1 - \sum_{i=1}^3 Q_i \cdot P_i \right) &\geq 0 \Rightarrow \\ T_w \left(1 - \sum_{i=1}^3 Q_i \cdot P_i \right) &\leq T_a \sum_{i=1}^3 Q_i \cdot P_i - \sum_{i=1}^3 Q_i \cdot T_i \cdot P_i \quad (4) \end{aligned}$$

Because $Q_i < 1$ and $\sum_{i=1}^3 P_i = 1$, so we have the following

$$\text{inference: } \sum_{i=1}^3 Q_i \cdot P_i < 1 \Rightarrow 1 - \sum_{i=1}^3 Q_i \cdot P_i > 0. \quad (5)$$

After we use (5) in (4), we could get

$$T_w \leq \frac{T_a \sum_{i=1}^3 Q_i \cdot P_i - \sum_{i=1}^3 Q_i \cdot T_i \cdot P_i}{1 - \sum_{i=1}^3 Q_i \cdot P_i} = T \quad (6)$$

Generally, the next one-hop node and two-hop node are closer to the repairing node than the destination node, so $T_a > T_i$. Therefore, through further analysis for (6), we could get $T > 0$. Consequently, as long as T_w satisfies (6), we would have $T_{lr} \geq T_{lr++}$ and the proof is successful. Further analysis indicates that, the longer the next one-hop node and two-hop node are from the destination node, the bigger is the value of $T_a - T_i$, the bigger is the value of the numerator of (6). The bigger the probability of successful route setup in the first local repair, the smaller is the denominator of (6), so the value of T becomes greater and the sampling scope of T_w would be bigger, thus more likely to satisfy the condition of $T_{lr} > T_{lr++}$. Therefore, the time needed by the improved local repair scheme for route setup would be shorter than that needed by AODV for the same purpose. What's more, the longer the next one-hop and two-hop nodes are from the destination node, the greater is the probability of successful repair in the first local repair, the more obvious is the result of optimization.

Similarly, it can be proved that the improved local repair scheme is smaller than the traditional one in the demand for control overhead. The farther the next one-hop node and two-hop node from the destination node, the more likely it is for the first local repair to be successful, the more obvious the optimization effect is.

B. Simulation Analysis

NS-2 simulator is adopted in this paper to evaluate the performance of the improved local repair scheme. In the network, we choose 50 nodes in random distribution in an area $1500m \times 300m$. The Random Way point motion

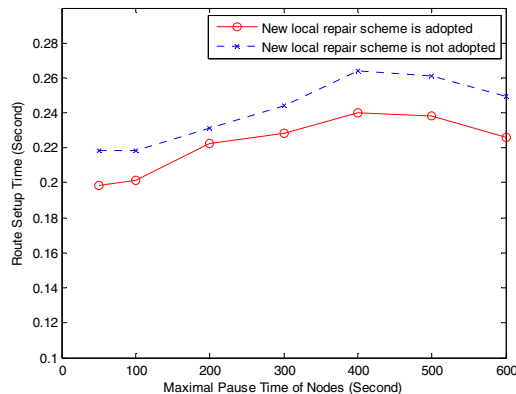
pattern [9] is adopted. The nodes in the area randomly choose a destination and move there with velocity of maximal 10m/s. The maximal number of connections is 20. We use CBR traffic and 4 data packets are produced per second, each packet having 512 bytes. IEEE 802.11b protocol is used for wireless transmission, with a transmission rate of 2Mb/s and a transmission radius of 250 meters. Every simulation produces 5 different scenarios, the average value of performance metric is taken and each simulation takes 600 seconds.

In order to simulate the status change of nodes in the ad hoc network more realistically, nodes randomly change their status with a certain probability in simulation. The status changes include the nodes' power-on, power-off and unusual failures. The unusual failures of nodes result in the 2nd type of link breaks; their power-off causes the 3rd type of link breaks and the 1st type of link breaks result from the mobility between nodes. The node failure ratio refers to the proportion of unusual failures and usually power-off nodes in the total number of nodes during the simulation.

Simulation is conducted on both the improved and unimproved local repair schemes. Data packet delivery ratio, route setup time and control packet overhead would be recorded. The data packet delivery ratio refers to the proportion of the number of data packet successfully received in the total number of data packets that have been sent out. The route setup time refers to the average time used for establishment of all routes. The control overhead ratio refers to the specific value between accumulated overhead of control packets and the data packets successfully delivered.

1) Performance with Varying Node Mobility

In this simulation, we implemented the proposed local repair scheme and unimproved AODV local repair mechanism respectively. The goal of this experiment is to see how the new scheme performs with varying node mobility. The node failure ratio is 20%, of which unusual node failure ratio is 20% and the number of normal power-off node takes up 80%, these values of setting are rough estimations of the situations in the real ad hoc networks. We change mobility rate by setting different values of maximal pause time of nodes as 50, 100, 200, 300, 400, 500, and 600 simulation seconds.



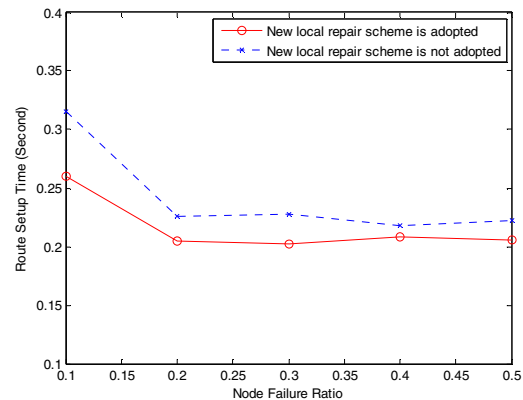
(a) Route Setup Time

As shown in Fig. 2, the proposed local repair scheme performs better than the local repair mechanism of AODV at different node mobility rates. Starting from lower mobility scenario to higher mobility rate, the proposed local repair scheme achieves better optimality than the traditional solution of AODV. Route setup time is reduced by an average value of 8%. Control overhead ratio is lowered by about 20% at each mobility rate. This is due to the fact that direct or indirect route could be set up even through the smaller scale broadcast of improved RREQ, while AODV local repair is simply performed via larger scale RREQ flooding which consumes a substantial amount of bandwidth. The average value of data packet delivery ratio is promoted by about 3%. This is because the proposed local repair scheme takes advantage of explicit power-off communication by the interested node.

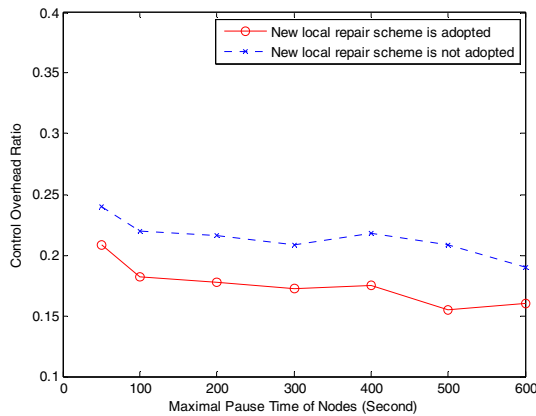
2) Performance with Varying Node Failure Ratio

The proposed local repair scheme and traditional AODV local repair mechanism are implemented respectively in this simulation. We do this experiment to observe how the two schemes perform differently with varying node failure ratio. Maximal pause time of the node is set to be 50s. We reflect the situation of link breaks in the network by using varying values of node failure ratio as 10%, 20%, 30%, 40%, and 50%.

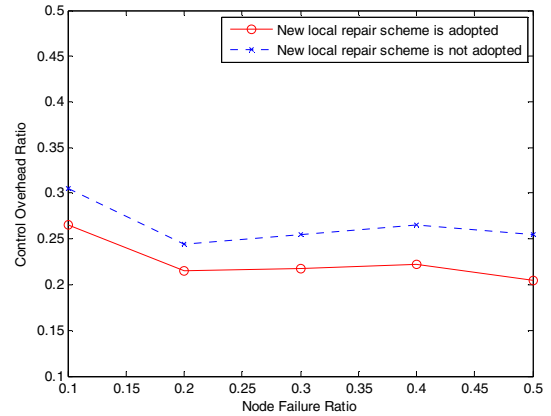
Fig. 3 shows that the new local repair scheme performs better than that of AODV in different scenarios. For each node failure ratio, there is not much difference on the performance metrics of route setup time and control overhead ratio. Route setup time is reduced by about 13% on an average. Control overhead ratio lowers by an average value of 18%. As the node failure ratio increases, the data packet delivery ratio of legacy local repair mechanism drops faster than that of the new scheme. This is because the new local repair scheme uses method to judge the link status in advance of link breaks. At this time, the repairing node would buffer data packets and initiate local repair instead of sending data packets through links which would break soon. Data packet delivery ratio is obviously optimized when the node failure ratio is relatively big. It is raised by an average value of 10%.



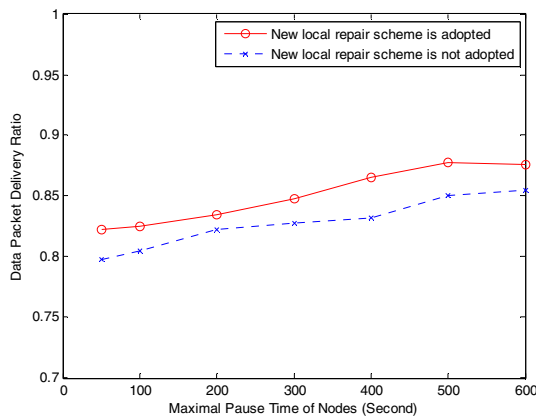
(a) Route Setup Time



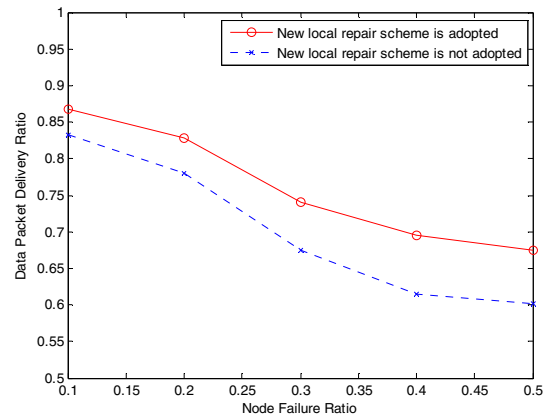
(b) Control Overhead Ratio



(b) Control Overhead Ratio



(c) Data Packet Delivery Ratio



(c) Data Packet Delivery Ratio

Figure 2. Performance with varying maximal pause time of nodes.

Figure 3. Performance with varying node failure ratio.

VI. CONCLUSION

This paper proposes a local repair scheme based on link breaks for ad hoc networks. The node judges the causes of a link break depending on the status change of its neighboring nodes, and then it adopts a corresponding local repair method. The new local repair scheme is more adaption to the real ad hoc networks. Mathematical analysis and simulation results demonstrate that network performance can be significantly improved using the new local repair scheme.

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