Enhanced Route-Split Routing Tolerant to Multiple Concurrent Link Failure for Mobile Ad Hoc Networks

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Abstract. As the performance of mobile nodes advances, the ad hoc network will work with many mobile nodes. In such network, the route between the source node and the destination node is elongated, and then the route maintenance might become more difficult due to the topology change. Therefore, we have proposed Route-Split Routing (RSR) scheme for large mobile ad hoc network environments. RSR sets up multiple Subroute Management Nodes (SMNs) on the route between the source node and the destination node and divides the route into multiple subroutes. Since the subroute between two adjacent SMNs is locally managed, RSR has less overhead for the route maintenance and achieves the higher performance than AODV. In addition, RSR becomes tolerant to the multiple concurrent link failure because the route is repaired by each SMN on a subroute basis. RSR could provide higher data packet delivery ratio, but has high overhead because the route becomes longer as the subroute can be locally repaired and separately. Therefore, this paper proposes three mechanisms to enhance the performance of RSR for large mobile ad hoc network environment and then evaluates it through simulation environment. As a result, the enhanced RSR with three proposed mechanism can decrease the total control overhead by 50 percent with high data packet delivery ratio.

Keywords: mobile ad hoc networks, ad hoc on-demand distance vector routing.

1 Introduction

A mobile ad hoc network is a kind of autonomous decentralized networks that consist of only mobile nodes without depending on access points and wired links. Many routing protocols such as AODV [1,2] and DSR [3] have been proposed. However, these routing protocols do not work efficiently in the conditions that the hop count between the source node and the destination becomes longer in large mobile ad hoc network environments. Therefore, we have proposed Route-Split Routing (RSR) [4,5] to solve the above issues.

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RSR sets multiple Subroute Management Nodes (SMN) on the route between the source node and the destination node. Since multiple subroutes on the route are maintained by each SMN, each SMN locally repairs the subroute between the SMN and the next SMN toward the destination node even if multiple route breaks occur concurrently. However, there is still room for improving the RSR to achieve the higher data delivery and mitigate the overhead in large mobile ad hoc network environment. In case the hop count between two adjacent SMNs is extended by the topology change due to node movement, the SMN does not manage to locally repair the subroute and the overhead for the route repair is enlarged. In addition, the route can not be locally repaired due to the movement of a SMN. Therefore, this paper proposes three mechanisms to resolve the above issues and enhance the performance of the Route-Split Routing.

The first proposed mechanism is that RSR does not only set SMNs on the route at the route creation phase, but also at the route repair phase. The second proposed mechanism is that RSR repairs the subroute between the SMN and the next SMN but one when RSR does not repair the subroute between the SMN and the next SMN. The third proposed mechanism is that RSR repairs the subroute by the destination node when the hop count between the destination node and the other upstream SMNs except for the adjacent upstream SMN is diminished due to the topology change. This paper demonstrates the effectiveness of the proposed mechanisms using network simulator QualNet ver. 3.9 [6].

The rest of the paper is organized as follows. Section 2 describes the Route-Split Routing (RSR) scheme that we have proposed for large mobile ad hoc networks. Section 3 illustrates the proposed three mechanisms to enhance the RSR. We have conducted simulation experiments to evaluate the enhanced RSR in comparison with the original RSR and AODV. Therefore, Section 4 demonstrates the effectiveness of the enhanced RSR from the simulation results. Finally, we conclude this paper with the future plan in 5.

2 RSR (Route-Split Routing)

2.1 Outline of RSR

RSR is a reactive type routing protocol based on AODV. RSR sets multiple Subroute Management Nodes (SMNs) on the route between the source node and the destination node at the uniform interval as shown in Figure 1. In Figure 1, nodes A (Source node), D, G, J, M (Destination node) behave as a SMN. AODV reconstructs the route between the source node and the destination node in case the route break occurs in the vicinity of the source node so that much overhead might be incurred. In contrast, RSR can repair the subroute locally regardless of a node on the route. Therefore, in case of route repair, each SMN transmits control packets to nodes in a limited area, and then the overhead can be reduced. In addition, RSR can repair each subroute separately by SMNs even if multiple route breaks occur concurrently.

Let the ad hoc network be denoted by an undirected graph $G = (V, E)$. A node $v_i \in V$ represents a mobile node with node ID i and it is simply called node

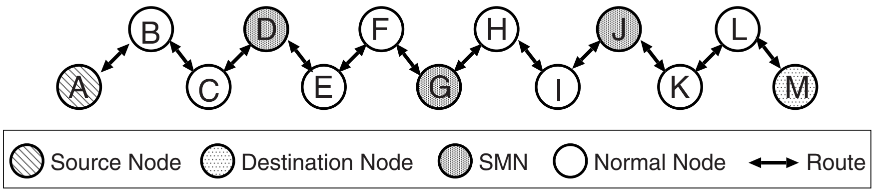

Fig. 1. Outline of RSR

v_i afterwards. An edge $(v_i, v_j) \in E$ represents a wireless link between nodes i and j, and then node v_j is called the neighboring node of node v_i. Consider a source node with node ID s is v_s and a destination node with node ID d is v_d. RSR creates the route between the source node (v_s) and the destination node (v_d), and some nodes on the route behave as a SMN. Let a SMN with node ID g be v_g^{smn}. SMN v_g^{smn} holds an upstream SMN toward the source node $(U\_SMN(v_g^{smn}))$ as the previous SMN and a downstream SMN toward the destination nodes $(D\_SMN(v_g^{smn}))$ as the next SMN. In Figure 1, if v_g^{smn} is node G, $U\_SMN(v_g^{smn})$ and $D\_SMN(v_g^{smn})$ are nodes D and J. SMN v_g^{smn} maintains locally the subroute between v_g^{smn} and $D\_SMN(v_g^{smn})$. Node v_h on the subroute except for SMNs has route entries to the upstream SMN $(U\_SMN(v_h))$, the downstream SMN $(D\_SMN(v_h))$ and the next hop node (v_i) iff $(v_h, v_i) \in E$. In Figure 1, if v_h is node H, $U\_SMN(v_h)$, $D\_SMN(v_h)$, and v_i are nodes G, J, and I.

2.2 Route Creation

RSR uses a RREQ packet, RREP packet, and a RREPAck packet in the route creation phase.

Whenever a data packet is generated, the source node (v_s) checks its own routing table. In case it does not contain the route entry to the destination node (v_d) of the data packet in the routing table, it broadcasts RREQ packets in the network. In this case, the TTL value of RREQ packet is set as follows. In case the source node has already known the hop count between the destination node and itself $(hop_{s,d})$, the TTL is set to $(hop_{s,d} + RSR\_TTL\_INCREMENT)$. Otherwise, the TTL is set to RSR_TTL_START. A node (v_i) that received the RREQ packet checks whether the route entry to the source node (v_s) has been created, and then v_i creates the route entry and forwards the RREQ packet in a way similar to AODV.

In case node v_s can not obtain any response from the destination node (v_d), it increments the TTL of a RREQ packet by $RSR\_TTL\_INCREMENT$ and then rebroadcasts it in the network. However, when the TTL becomes more than $RSR\_TTL\_THRESHOLD$, it is increased up to $RSR\_NET\_DIAMETER$. In case the TTL becomes more than $RSR\_NET\_DIAMETER$ and node v_s can not obtain any response after it broadcasts a RREQ packet three times in the network, node v_s abandons the route create.

When the RREQ packet is delivered to the destination node (v_d), v_d sends a RREP packet back to the source node along the route that is created by RREQ packets. v_i creates the route entry to the destination node (v_d) when v_i receives the RREP packet from the downstream node.

RSR sets a SMN on the route when the RREP packet is forwarded from v_d to v_s as follows. When the destination node (v_d) receives the RREQ packet from the source node (v_s), v_d becomes v_d^{smn}. Then, v_d^{smn} adds its own ID d and $SMN\_hop\_interval$ to the RREQ packet and sends it back to v_s. Here, if $SMN\_hop\_interval = n$, each SMN is set on the route every n hop count. When node v_i receives the RREP packet, it records the downstream SMN (initially, v_d) and the hop count ($hop_{i,d}$) between the current node (v_i) and the downstream SMN (initially, v_d) into the routing table and then forward the RREP packet to the upstream node. In this case, n-th node from the previous SMN (initially, v_d) behaves as a SMN.

However, since each SMN is set when the RREP packet is forwarded, each node on the route does not obtain the ID of SMN toward the source node by the RREP packet. Therefore, after a node became a SMN, the SMN sends a RREPAck packet to the downstream SMN to advertise itself to all nodes on the subroute.

After the above procedures are repeated and the RREP packet is received by the source node, the route creation is completed.

2.3 Route Maintenance

RSR locally repairs the subroute between two adjacent SMNs on the route. RSR invokes the route repair when a data packet is not forwarded from a node to the next node. RSR uses a RERR packet, a RepairREQ packet, and a RepairREP packet for the route maintenance. There are two kinds of phases: route break report phase and route repair phase.

Route Break Report Phase. In case node v_i that tries to transmit a data packet detects the route break, v_i sends a RERR packet to the previous node toward $U\_SMN(v_i)$ to report the route break. Node v_h that receives the RERR packet erases the route entry to v_d, and then forwards it to $U\_SMN(v_h)$. SMN v_g^{smn} receives the RERR packet broadcasts a RepairREQ packet toward the next SMN. However, if it does not obtain any response from the next SMN after it attempts to broadcast a RepairREQ at $RepairREQ\_RETRIES$ times, SMN v_g^{smn} sends a RERR packet to source node v_s. In this case, if the TTL of a RepairREQ packet is more than $MAX\_RepairREQ\_TTL$, a SMN sends a RERR packet to the source node because RSR prevents the subroute from elongating.

Route Repair Phase. SMN v_g^{smn} that receives a RERR packet from node v_i invokes the route repair. SMN v_g^{smn} broadcasts a RepairREQ that includes $U\_SMN(v_g^{smn})$ and $D\_SMN(v_g^{smn})$ to all the neighboring nodes. A node that receives the RepairREQ packet checks its own routing table. If it does not have

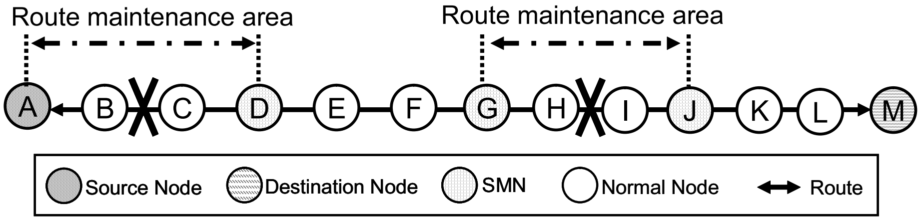

Fig. 2. Example of multiple concurrent link failure

the route entry to the upstream SMN, it creates the route entry and then forwards the RepairREQ packet. The downstream SMN receives the RepairREQ and then sends a RepairREP packet back to the source node of the RepairREQ. The RepairREP packet is forwarded along the subroute that is created by the RepairREQ packet. v_g^{smn} completes the route repair by receiving the RepairREP packet and then restarts forwarding a data packets to the next node.

In this phase, v_g^{smn} sets the TTL of a RepairREQ to $(hop_{v_g,D\_SMN(v_g)} + RSR\_TTL\_INCREMENT\_REPAIR)$. Since RSR can limit the area where the RepairREQ is broadcasted, it can mitigate the explosive increase of control packets due to the route repair. Therefore, the appropriate value of $RSR\_INCREMENT\_REPAIR$ must be chosen according to a variety of network conditions.

2.4 Resiliency to Simultaneous Failure of RSR

RSR divides the route between the source node and the destination node into multiple subroutes and sets a SMN on the subroute for the route maintenance. Therefore, as shown in Figure 2, each SMN invokes the route repair for the subroute separately even if multiple route breaks concurrently occur on some subroutes.

3 Enhanced RSR

RSR can significantly mitigate the amount of control packets in comparison with AODV as mentioned in the previous section. However, the hop count between two adjacent SMNs is extended due to the node movement because SMNs are set up only at the route creation phase. In this case, RSR becomes difficult to perform the local repair and has higher overhead because the subroute is elongated. In addition, the route repair is not completed due to the movement of SMNs. In order to solve the above issues and enhance the RSR, this paper proposes the three following mechanism.

- SMN set-up at the route repair phase (proposal mechanism 1)
- Route repair to the next SMN but one (proposal mechanism 2)
- Response to route repair by the destination node (proposal mechanism 3)

3.1 Proposal Mechanism 1

RSR does not set up SMNs except in the route creation phase so that the subroute might be elongated after the subroute is repaired many times. If the subroute is elongated, the RepairREQ packet is extensively broadcasted and the number of control packets is expanded. In order to solve the above issues, we propose a mechanism that sets up a new SMN on the repaired subroute at the route repair phase. Therefore, the proposed mechanism can locally repair the subroute regardless of the change of the network topology and mitigate the number of control packets.

SMN Set-up Mechanism in Route Repair Phase. Node v_i that detects the route break sends a RERR packet to $U\_SMN(v_i)$. Consider $U\_SMN(v_i)$ is v_g^{smn} to explain the proposed mechanism 1. v_g^{smn} that receives the RERR packet broadcasts a RepairREQ to $D\_SMN(v_g^{smn})$. In case node $v_j(j \neq i)$ except for SMNs that receives the RepairREQ packet does not have the route entry to v_g^{smn}, v_j creates the route entry to v_g^{smn} and then forwards the RepairREQ packet. $D\_SMN(v_g^{smn})$ that receives the RepairREQ packet sends a RepairREP packet back to v_g^{smn}. Node v_j that receives the RepairREP packet stores the route entry to $D\_SMN(v_g^{smn})$ and $hop_{j,D\_SMN(v_g^{smn})}$ in the routing table, and then forwards it to v_g^{smn}. The RepairREP packet includes $SMN\_hop\_interval$. Consider $SMN\_hop\_interval$ is n. In case node v_k that receives the RepairREP packet is n-th hop node from $D\_SMN(v_g^{smn})$, v_k becomes v_k^{smn}. Then, v_k^{smn} exchanges $D\_SMN(v_g^{smn})$ of the RepairREP packet with v_k and then forwards it to v_g^{smn}. In this case, v_k^{smn} notifies the downstream SMN ($v_m(= D\_SMN$ $(v_g^{smn}))$ of having $U\_SMN(v_m)$ changed from v_g^{smn} to v_k^{smn} by forwarding a RREPAck packet to $D\_SMN(v_g^{smn})$. The above procedures are performed until v_g^{smn} receives the RepairREP packet.

3.2 Proposal Mechanism 2

In RSR, each SMN and the next SMN maintain the subroute between two adjacent SMNs. RSR performs the subroute maintenance using a SMN, nonetheless, the source node recreates the route to the destination node and many control packets might be generated whenever a SMN fails to repair the maintaining subroute due to the movement of a SMN. As a result, it is possible that the performance of RSR degrades. Therefore, we propose a mechanism that a SMN repairs the subroute with the next SMN but one in case the SMN fails to repair the subroute with the next SMN due to the movement of the next SMN. Compared with RSR, a RREP packet that is sent from the destination node to the source node in the route creation phase newly includes the next SMN but one to perform the proposal mechanism 2.

Collection of IDs of Next SMN but One. Each SMN obtains the ID of the next SMN but one to repair the subroute with the next SMN but one in the route creation phase. After destination node v_d receives the RREQ packet and v_d becomes SMN v_d^{smn} in the route creation phase, v_d^{smn} sends a RREP

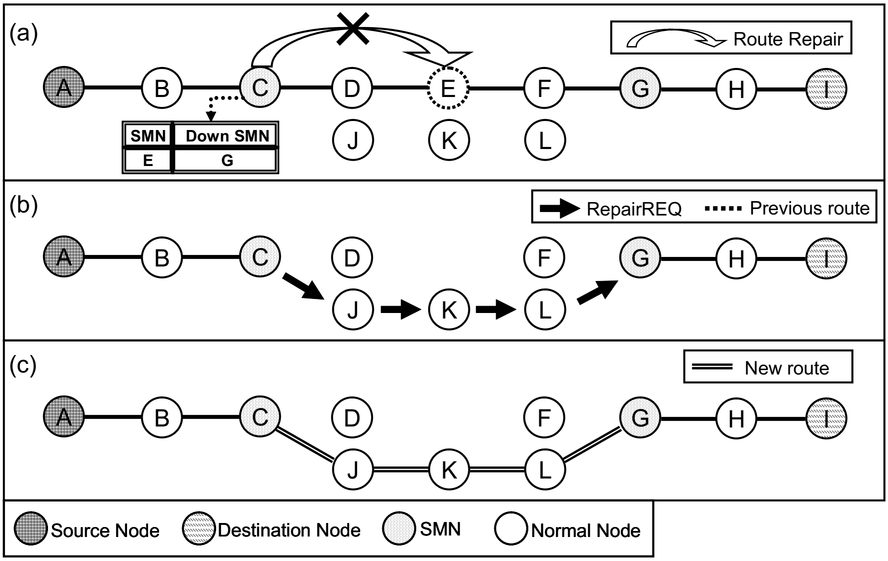

Fig. 3. Example of the route repair between a SMN and the next SMN but one

packet back to the source node and the RREP packets is forwarded from the destination node to the source node similarly to RSR. In this case, each SMN adds the information on the next SMN as well as the next SMN but one to the RREP packet. Therefore, each SMN could obtain the two downstream SMNs and then repair the subroute with the next SMN but one.

Route Repair to Next SMN but One. When a SMN fails to repair the subroute connected with the next SMN, the SMN repairs the subroute with the next SMN but one. The next SMN but one that receives the RepairREQ packet from the SMN sends a RepairREQ packet back to the SMN. However, it is possible that the hop count of the subroute between these two SMNs is elongated more. Therefore, the hop count of the repaired subroute has to become shorter than the value of $SMN\_hop\_interval$ using both proposal mechanisms 1 and 2.

Example of Route Repair to Next SMN but One. In Figure 3, let nodes v_A and v_I are the source node and the destination node. In case of the route break, v_C^{smn} attempts to repair the subroute with the downstream SMN (that is, v_E^{smn}) as shown in Figure 3(a). However, in case it fails to repair the subroute due to the position of migrated v_E^{smn}, v_C^{smn} broadcasts a RepairREQ packet toward v_G^{smn} because v_C^{smn} repairs the subroute with the next SMN but one (that is, v_G^{smn}) as shown in Figure 3(b). SMN v_G^{smn} that receives the RepairREQ packet sends a RepairREP including the next SMN but one of v_G^{smn} (that is, v_I^{smn}) back to v_C^{smn}. When SMN v_C^{smn} receives the RepairREP packet from SMN v_G^{smn}, the subroute between v_C^{smn} and v_G^{smn} is completely repaired (Figure 3(c)). If the

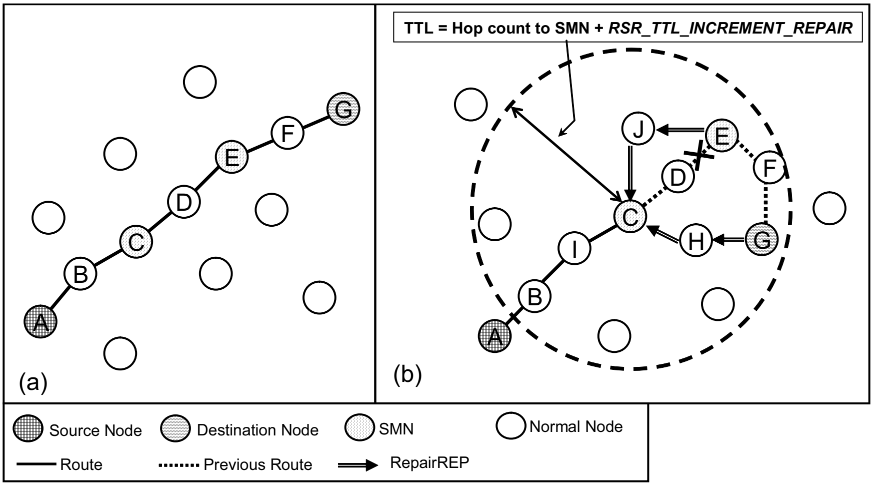

Fig. 4. Example of proposal mechanism 3

proposal mechanism 2 is combined with the proposal mechanism 1, one or more new SMNs are set up on the subroute between SMNs v_C^{smn} and v_G^{smn}.

3.3 Proposal Mechanism 3

In case of mobile ad hoc networks, the network topology is always changing due to the node movement. However, since the route must be maintained during the data transfer, the shorter route should be provided to a maximum extent.

RSR repairs locally the subroute. Whenever a SMN detects a route break, it broadcasts a RepairREQ packet within the specified area. Therefore, it is possible that the destination node receives the RepairREQ packet from the SMN a few times. In such a case, the SMN should repair the subroute with the destination node to reduce the hop count of the route between the source node and the destination node.

We describe the proposal mechanism 3 using Figure 4. Figure 4(a) shows the route between source node v_A and destination node v_G. Nodes v_A, v_C, v_E, and v_G behave as a SMN. In Figure 4(b), the dotted circle represents the nodes that received the RepairREQ packet from v_C^{smn}. Consider the network topology as shown in Figure 4(b) after the network topology was changed due to the node movement. Now, the route repair is invoked by SMN v_C^{smn}. In this case, v_E^{smn} that is the downstream node of v_C^{smn} and v_G^{smn} that is the destination node receive the RepairREQ packet from v_C^{smn}. Even if both of these SMNs send the RepairREP packet back to v_C^{smn}, v_C^{smn} preferentially receives the RepairREQ packet from v_G^{smn}. Finally, the subroute between v_C^{smn} and v_G^{smn} is repaired and the route is totally shortened.

Table 1. Simulation environment

Network simulator	QualNet ver.3.9 [6]
Field size	3500 x 3500 (m^2)
Node number	500
Max. node moving speed	1, 5, 10, 15, 20 (m/sec)
Mobility model	randomway point model [7]
Simulation time	330 (sec)
Number of SD pairs	10
Application	CBR
Data packet size	512 (byte)
Interval of sending data packets	4 (packets/sec)
MAC	802.11
Transmission range	250 (m)
Link capacity	54 (Mbps)

Table 2. Parameters of RSR

RSR_TTL_START	1
RSR_TTL_INCREMENT	2
RSR_TTL_THRESHOLD	10
RSR_NET_DIAMETER	35
RSR_RREQ_RETRIED	7
RSR_RepairREQ_RETRIED	1
RSR_RepairREQ_RETRIED_TO_NNSMN	1
RSR_LIFETIME	3 (sec)

4 Simulation Evaluation

4.1 Simulation Environment

We have conducted simulation experiments to evaluate the effect on the proposed mechanisms. If the proposal mechanisms 2 and 3 are separately introduced on RSR, the subroute between two adjacent SMNs is extended. Therefore, the proposal mechanisms 2 and 3 are introduced with the proposal mechanism 1 in RSR.

Table 1 shows the network environment for simulation experiments. Table 2 shows the parameters that are used for RSR. We have conducted the simulation run 5 times in each case to obtain each result in the following Tables and Figures. Simulation criteria are as follows.

1. Total amount of control packets for the route creation and maintenance
2. Average hop count between the source node and the destination node
3. Data packet delivery ratio
4. Number of route recreations by the source node

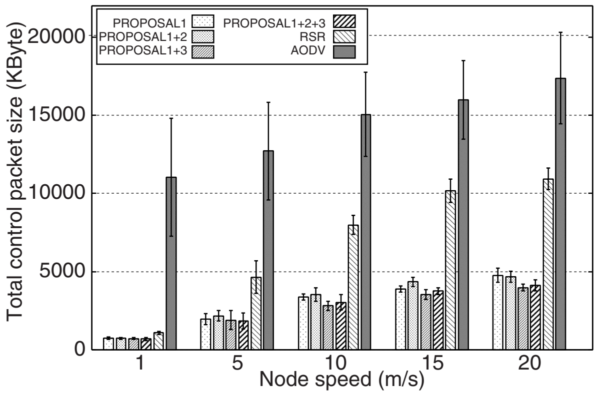

Fig. 5. Total number of control packets in case the SMN hop interval is 1

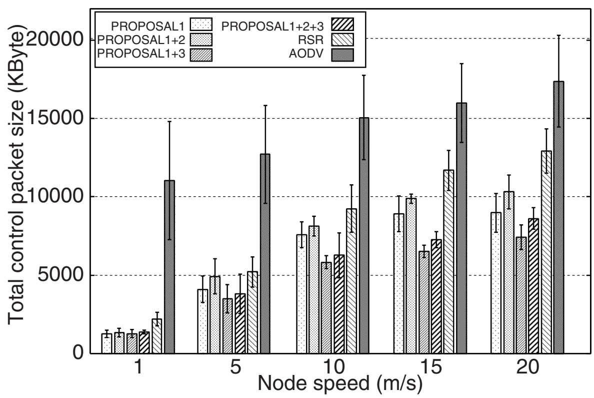

Fig. 6. Total number of control packets in case the SMN hop interval is 3

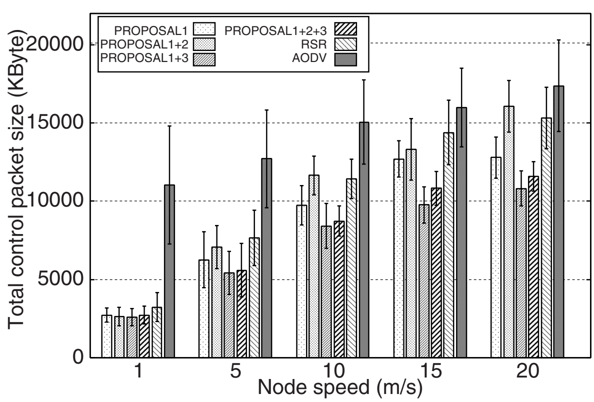

Fig. 7. Total number of control packets in case the SMN hop interval is 5

Table 3. Average hop count between the source node and the destination node in case the SMN hop interval is 1

Node speed	PROPOSAL				RSR	AODV
	1	1+2	1+3	1+2+3		
1	16.72 (8.82)	17.90 (10.08)	16.47 (9.25)	16.77 (9.05)	13.84 (6.87)	9.13 (4.41)
5	18.23 (11.58)	19.93 (12.60)	16.53 (12.05)	17.28 (11.29)	14.64 (8.64)	8.08 (4.17)
10	17.13 (10.72)	17.77 (11.66)	15.50 (11.08)	16.19 (10.46)	14.07 (8.22)	7.75 (3.85)
15	15.91 (10.02)	16.68 (10.63)	14.36 (10.29)	15.25 (9.71)	13.20 (7.48)	7.59 (3.70)
20	14.86 (9.08)	15.78 (9.73)	13.82 (9.27)	14.18 (9.08)	12.91 (7.24)	7.47 (3.78)

Table 4. Average hop count between the source node and the destination node in case the SMN hop interval is 3

Node speed	PROPOSAL				RSR	AODV
	1	1+2	1+3	1+2+3		
1	13.76 (7.23)	14.57 (7.36)	13.57 (6.96)	13.78 (6.96)	11.55 (5.39)	9.13 (4.41)
5	15.67 (9.27)	17.49 (11.50)	13.46 (10.77)	15.70 (8.99)	10.66 (5.55)	8.08 (4.17)
10	15.59 (10.38)	16.41 (10.64)	13.36 (9.87)	14.01 (9.04)	10.46 (5.39)	7.75 (3.85)
15	14.36 (9.35)	15.32 (10.05)	12.25 (9.02)	13.34 (8.05)	10.39 (5.19)	7.59 (3.70)
20	13.08 (8.05)	14.19 (9.07)	11.99 (9.22)	13.36 (7.66)	10.32 (5.07)	7.47 (3.78)

Table 5. Average hop count between the source node and the destination node in case the SMN hop interval is 5

Node speed	PROPOSAL				RSR	AODV
	1	1+2	1+3	1+2+3		
1	12.98 (6.12)	13.82 (6.62)	12.87 (6.31)	13.21 (6.09)	10.92 (5.08)	9.13 (4.41)
5	12.2 (7.12)	14.38 (9.38)	11.6 (7.28)	12.15 (6.45)	9.8 (4.89)	8.08 (4.17)
10	12.17 (7.5)	14.44 (9.23)	11.25 (6.91)	11.4 (6.68)	9.36 (4.59)	7.75 (3.85)
15	12.22 (7.41)	13.05 (8.21)	10.83 (7.1)	11.59 (6.31)	9.33 (4.6)	7.59 (3.7)
20	11.94 (7.31)	13.14 (8.09)	10.66 (7.15)	11.26 (6.4)	9.16 (4.44)	7.47 (3.78)

4.2 Simulation Results and Observations

In all figures and tables, we denote enhanced RSRs with proposal mechanism 1, 2, and 3 as PROPOSAL1, PROPOSAL2, and PROPOSAL3. In addition, we represent the enhanced RSR with proposal mechanisms 1 and 2 as PROPOSAL1+2 by using '+'. We show the simulation results in case of enhanced RSR, RSR, and AODV in all figures and tables.

Total Amount of Control Packets for Route Creation and Maintenance. Figures 5, 6, and 7 show the amount of control packets for route creation and maintenance in case SMN hop interval is 1, 3, and 5.

We observe the simulation results based on Figure 6 because the same observation applies to Figures 5 and 7. PROPOSAL1 becomes less than RSR because the subroutes that are repaired by a SMN are not elongated even if the route breaks often occurred. PROPOSAL1+2 becomes more than PROPOSAL1 because the area where the RepairREQ packet is broadcasted is much wider and the packet size of the RepairREQ packet is enlarged to repair the subroute

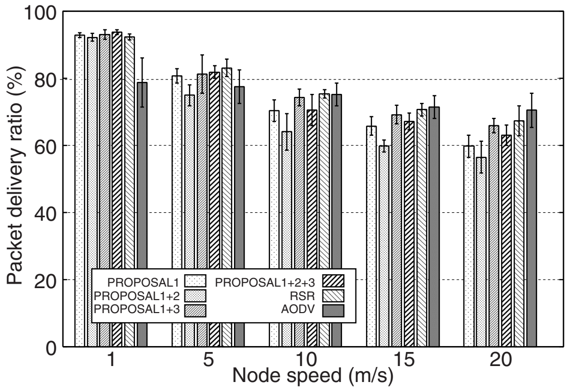

Fig. 8. Data packet delivery ratio in case the SMN hop interval is 1

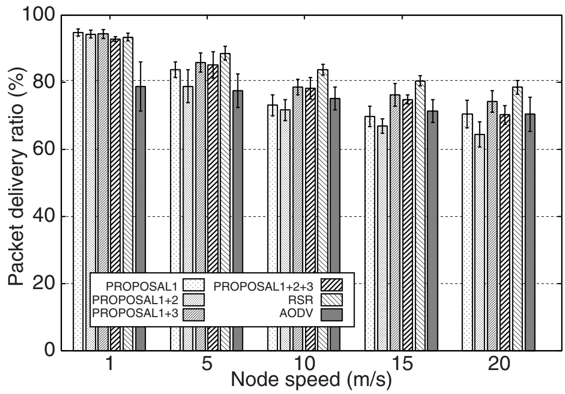

Fig. 9. Data packet delivery ratio in case the SMN hop interval is 3

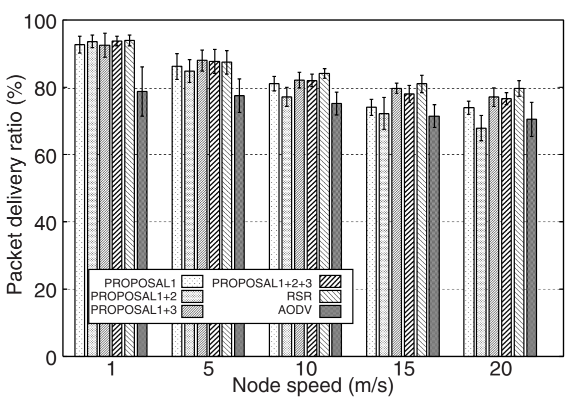

Fig. 10. Data packet delivery ratio in case the SMN hop interval is 5

Table 6. Number of data packet losses during data transfer in case the SMN hop interval is 1

Node speed	PROPOSAL 1	PROPOSAL 1+2	PROPOSAL 1+3	PROPOSAL 1+2+3	RSR	AODV
1	1116.2 (134.82)	1127 (92.89)	993.8 (92.77)	1000.4 (80.66)	884.6 (99.99)	1442.6 (463.32)
5	2499.2 (253.88)	2858.6 (290.93)	2292.6 (431.2)	2336.8 (320.57)	1961 (258.34)	1756. (370.43)
10	3625.4 (223.34)	3952.2 (310.37)	3156.8 (314.68)	3489.4 (356.77)	2858.6 (228.82)	2212.6 (353.99)
15	4206.8 (371.42)	4690.4 (310.25)	3772.6 (355.21)	4019 (455.68)	3309.6 (229.64)	2451 (343.07)
20	4745.4 (406.59)	5045.4 (432.25)	4194.6 (336.08)	4425.8 (406.19)	3738.6 (496.91)	2802.2 (407.94)

Table 7. Number of data packet losses during data transfer in case the SMN hop interval is 3

Node speed	PROPOSAL 1	PROPOSAL 1+2	PROPOSAL 1+3	PROPOSAL 1+2+3	RSR	AODV
1	754 (162.96)	820.6 (138.93)	770.2 (146.28)	838.2 (173.4)	740 (124.98)	1442.6 (463.32)
5	1974.8 (278.75)	2368.4 (371.72)	1643.4 (299.07)	1953.6 (496.99)	1277.6 (193.43)	1756 (370.43)
10	3036 (211.02)	3268 (237.87)	2533.2 (203.64)	2665.6 (393.23)	1929.2 (272.61)	2212.6 (353.99)
15	3448.2 (404.54)	3746.4 (289.09)	2842.6 (296.45)	3231 (328.96)	2328.4 (259.48)	2451 (343.07)
20	3498.6 (300.49)	4104.8 (448.03)	3140 (428.88)	3689 (400.44)	2560.4 (291.46)	2802.2 (407.94)

Table 8. Number of data packet losses during data transfer in case the SMN hop interval is 5

Node speed	PROPOSAL 1	PROPOSAL 1+2	PROPOSAL 1+3	PROPOSAL 1+2+3	RSR	AODV
1	860.2 (107.38)	812 (164.32)	839.2 (158.31)	875.8 (170.59)	707 (166.83)	1442.6 (463.32)
5	1576.2 (308.34)	1955.4 (380.22)	1509.2 (320.52)	1562.6 (410.38)	1342.2 (225.93)	1756 (370.43)
10	2318.2 (315.22)	2795.4 (308.35)	2124.8 (375.96)	2160.4 (266.54)	1769.6 (216.69)	2212.6 (353.99)
15	2950 (238.62)	3200.2 (488.17)	2464.2 (286.4)	2724 (339.98)	2142.2 (284.93)	2451 (343.07)
20	3099.6 (334.03)	3662.6 (378.64)	2811 (335.35)	2911.4 (312.45)	2290.8 (347.34)	2802.2 (407.94)

between a SMN and the next SMN but one. On the contrary, PROPOSAL1+3 is less than PROPOSAL1. PROPOSAL1+3 has shorter route and becomes less subroute repair because a SMN could occasionally repair the subroute with not the downstream but the destination node. Therefore, PROPOSAL1+3 could be reduced in comparison with RSR. Moreover, PROPOSAL1+2+3 becomes more than PROPOSAL1+3 due to the proposal mechanism 2.

Next, we focus on the SMN hop interval. As shown in Figures 5, 6, and 7, the total amount of control packets is enlarged as the SMN interval hop is extended. This is because the SMN interval hop is related with the TTL of a RepairREQ packet that is broadcasted for the route repair.

Average Hop Count. Tables 3, 4, and 5 show the average hop count between the source node and the destination node in case the SMN hop interval is 1, 3, and 5. Figures in parentheses represent the standard deviation. The standard deviation in each result becomes larger because the nodes are randomly deployed in the network.

Table 9. Number of route recreations in case the SMN hop interval is 1

Node speed	PROPOSAL				RSR	AODV
	1	1+2	1+3	1+2+3		
1	6.2 (2.32)	4 (2.19)	5.6 (1.74)	3.2 (1.47)	6.2 (1.6)	655.4 (148.4)
5	28.6 (5.61)	21.8 (6.31)	23.8 (5.98)	18.2 (6.77)	20.8 (6.85)	867.8 (148.96)
10	52.8 (9.04)	42 (5.66)	40.6 (6.28)	34.2 (4.17)	39.2 (5.6)	1079 (156.32)
15	74 (5.55)	63 (7.51)	58.8 (8.68)	49 (6.23)	49 (7.51)	1167.8 (139.81)
20	89.8 (5.95)	74.6 (5.35)	72.8 (10.27)	57.4 (9.39)	62.8 (5.67)	1298.6 (138.88)

Table 10. Number of route recreations in case the SMN hop interval is 3

Node speed	PROPOSAL				RSR	AODV
	1	1+2	1+3	1+2+3		
1	4.6 (2.65)	2.2 (2.99)	4 (3.16)	2.8 (2.04)	6.8 (1.17)	655.4 (148.4)
5	17.6 (5.54)	9.8 (4.17)	12.6 (5.61)	6.6 (2.73)	16.6 (2.73)	867.8 (148.96)
10	35 (3.63)	26 (3.1)	29 (6)	16.4 (3.88)	32.4 (2.87)	1079 (156.32)
15	46.6 (3.01)	34.2 (5.56)	34.6 (6.97)	21.8 (4.87)	41.6 (8.55)	1167.8 (139.81)
20	53.4 (4.59)	44.2 (6.31)	40.4 (9.44)	25.2 (6.08)	47.2 (8.64)	1298.6 (138.88)

Table 11. Number of route recreations in case the SMN hop interval is 5

Node speed	PROPOSAL				RSR	AODV
	1	1+2	1+3	1+2+3		
1	10.4 (5.31)	1.6 (2.06)	7.6 (4.18)	2.4 (2.42)	9.6 (3.07)	655.4 (148.4)
5	21.8 (7.19)	10.4 (4.22)	15.8 (5.46)	8.4 (3.88)	22.4 (9.14)	867.8 (148.96)
10	36.2 (5.81)	20.6 (5.39)	32.2 (9.39)	16.8 (5.08)	38.6 (6.38)	1079 (156.32)
15	49.2 (9.95)	26 (4.69)	39.6 (6.05)	18.8 (3.71)	50.2 (4.26)	1167.8 (139.81)
20	52.8 (10.53)	38.6 (7.12)	39.6 (5.78)	16.4 (2.42)	52.6 (11.02)	1298.6 (138.88)

The hop count becomes shorter as the node moving speed becomes faster. This is because in case of the random mobility model, all nodes tend to move to the center of the network [8].

AODV has the shortest route in any case because it often recreates the route between the source node and the destination node when the route break occurs. RSR is shorter than the enhanced RSR because RSR recreates the route when a RSR fails to repair the subroute to the upstream SMN. PROPOSAL1+2 has the longest route because it introduces the proposal mechanism 2. PROPOSAL3 could reduce the hop count in comparison with the other proposals. It seems that the proposal mechanism is effective for reducing the hop count of the route.

From the results of the total amount of control packets (Figures 5, 6, and 7) and the hop count, in the enhanced RSR, it seems that the total amount of control packets has a connection with the average hop count between the source node and the destination node. This is because the number of route breaks increases in proportion to the hop count. Therefore, it seems that the hop count should be decreased to reduce the number of control packets in case of the enhanced RSR.

Next, we focus on the SMN hop interval. The average hop count is enlarged if the SMN hop interval is short, while the average hop count is shortened if it is not. RSR repairs the subroute between two adjacent SMNs. Therefore, the hop count might be elongated due to the position of migrated SMNs. As the number of SMNs on the route increases, the position of SMNs has the big impact on the repaired route or subroutes. As the SMN hop interval becomes larger, the total amount of control packets increases. Conversely, as the SMN hop interval becomes shorter, the total amount of control packet decreases. Consequently, we can say that there is the trade-off between SMN hop interval, the hop count and the total amount of control packets.

Data Packet Delivery Ratio. Figures 8, 9, and 10 show the data packet delivery ratio in case the SMN hop interval is 1, 3, and 5.

The data packet delivery ratio is correspond to the result of the hop count because the number of data packet losses increases during data transfer if the hop count is large. Tables 6, 7, and 8 show the number of data packet losses during data transfer. In comparison between Tables 3 and 6 in case the SMN hop interval is 1, the number of data packet losses increases as the hop count is elongated. The same applies to the other SMN hop intervals. Moreover, it seems that RSR and PROPOSAL1+3 maintain the same level of the data packet delivery ratio. PROPOSAL1+3 provides longer route than RSR because PROPOSAL1+3 reduces control packets and packet collision.

Number of Route Recreation. Tables 9, 10, and 11 show the number of route recreations between the source node and the destination node.

PROPOSAL1+2+3 has the lowest number of route recreations in any case although PROPOSAL1+2+3 provides longer route than PROPOSAL1+3 as shown in Table 4 and Figure 10. This is because in the route repair phase the downstream SMN as well as the next SMN but one and the destination node respond with the RepirREQ packet that is transmitted by the SMN.

5 Conclusion

This paper presents the Route-Split Routing (RSR) tolerant to multiple concurrent link failure and proposes the three mechanisms to enhance the RSR. We have conducted the simulation experiments to evaluate the enhanced RSR in comparison with the original RSR and AODV, and then shown the effectiveness from the simulation results. The enhanced RSR could decrease the overhead of the route creation and maintenance by 50 percent as well as the number of route recreation by one third in comparison with the original RSR.

In the future work, we are planning to design the retransmission mechanism for data packet loss according to the application such as file transfer and real-time communication in large mobile ad hoc network environment.

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