A Competition-based Algorithm for Routing Discovery and Repair in Large-scale VANET

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Abstract

Vehicular Ad Hoc Networks (VANET) in the large-scale road section usually have typical characteristics of large number of vehicles and unevenly distribution over geographic spaces. These two inherent characteristics lead to the unsatisfactory performance of VANETs. This poor performance is mainly due to fragile communication link and low dissemination efficiency. We propose a novel routing mechanism to address the issue in the paper, which includes a competition-based routing discovery with priority metrics and a local routing repair strategy. In the routing discovery stage, the algorithm uses adaptive scheme to select a stable route by the priorities of routing metrics, which are the length of each hop, as well as the residual lifetime of each link. Comparisons of different ratios over link length and link stability further show outstanding improvements. In the routing repair process, upstream and downstream nodes also compete for the right to establish repair process and to remain as a member of the active route after repair. Our simulation results confirm the improved performance of the proposed algorithm.

Keywords: Vehicular Ad Hoc Network, Large-scale road section, Routing discovery and repair, Routing metric

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1. Introduction

As a special kind of ad-hoc network designed for transport sector, VANET is a promising road-specific application-oriented solution for various real-time scenarios. Its essence is a highly mobile Ad-hoc network (MANET) in which each moving vehicle works as a wireless node to communicate with its neighbor vehicles or road-side devices without the client and server structure. It is proven to be efficient to deal with the challenge of low communication quality by high-speed mobility, intermittent connectivity and diverse topology[1] [2] [3].

In the past few decades, so many routing protocols in VANET have been proposed for the establishment of stable and robust routing. Most of them are classified as *topology-based routing*, including *reactive routing*, *proactive routing* and *hybrid routing*, and *position-based routing*.In reactive routing, the route to the destination node is established only when required. It broadcasts RREQ packets till the destination sends a RREP packet back to the source node. Typical studies are Dynamic Source Routing (DSR) [4], Ad hoc on-demand distance vector (AODV) [5] and its variation[2] [6] etc. In proactive routing, the nodes in the network are maintaining a routing table. Each node sends regularly a “hello” packet to its neighbors for showing the presence. The nodes receiving the packet update their routing tables for tracking the changing of the network. Examples in the category are Destination-sequenced Distance Vector (DSDV) [7] and Optimized Link State Routing (OLSR) [8].Typical hybrid routing divides the network into two areas: local and global. In order to achieve greater efficiency and scalability, Zone Routing Protocol combines the local active routing protocol with the global reactive routing protocol to minimize routing overhead and delay due to the route discovery process [9]. The current routing path used by the network still needs to be maintained by combining two policies, since it limits the topology change within a given amount of time [3].In position-based routing, each node in the network knows its own position using positioning device, such as GPS, and It floods RREQ packets in a restrict region by priori geographic information. Such examples include Distance Routing Effect Algorithm for Mobility (DREAM) [10]and Location-aided routing (LAR) [11].

As to the route repair process, the traditional AODV provides its typical route repair solution. If the break is not far away from destination node, the upstream node launches local repair for the destination as opposed to source repair [12]. In some circumstances, this achieves the purpose of saving the time for route rediscovery and decreasing routing overhead. Azzuhri et al. define Local Repair Threshold parameter to determine the distance that the breaks occur from the source node along the whole route to help make a choice between source repair and local repair[8] [13]. However, in the local repair process above, the destination is always the same as that of the original route. The reestablishment of the rest route that linked original leads to a waste of network resource and an increase in transmission delay. Furthermore, the literatures [14] [15] above have a single-way route repair from upstream node to downstream node in common. In opposite, the local repair process suggested by Zheng et al. is from downstream node to upstream node. This leaves out the process of broadcasting RREQ from upstream node and contributes to the reduction of route repair delay and network overhead [16] [13]. This is still a single-way repair but in the reverse direction. As the route break can be caused by the movement of upstream node as well as downstream node, using simplex local repair without eliminating intensely-moving node would lead to a fragile link after repair.

The routing discovery and repair process mentioned above provides a rich solution for VANET, and also shows certain performance within a limited network scale. However, recent development shows that more and more VANET studies are including more vehicles and covering wider region [17] [18] [19]. In fact, from the point of view of transportation field, most of traffic flows in urban road networks are naturally large-scale systems with gigantic topologies and enormous devices [20] [21]. Studying such a large-scale VANET in urban environment is necessary due to two of unique performance-related characteristics:

- The real-world urban road network spans over wide geographic regions: the expansion of network scale unavoidably increases the complexity of vehicle network topology and the disordering of vehicle movements, making data links much more frequently fragile [17].
- The network has a large amount of vehicles and road-side devices: more connection nodes in the network leads to the increase of route overhead and setup time. The cost of routing discovery and repair also distinctly goes up [21].
- The type of data service between the vehicles is also undergoing significant changes. It gradually evolves from simple low-byte texts to large-capacity video [22]. Video applications with high user satisfaction are becoming an important part of V2V communications. This change puts forward higher requirements for the routing topology of vehicle communication [23].

In order to reduce the negative impact of the expansion of topology and the increase of moving vehicles, choosing optimal next-hop nodes in a competitive manner for route establishment is clearly a good way [24]. The competition process should be based on new routing metric system. Therefore, we focus our research on a routing algorithm for solving large-scale VANET, called Competition-based Routing Algorithm with new integrated routing metric. To improve link stability, both link length and residual lifetime are considered into routing metric. If the link breaks, the more stable node between upstream and downstream ones would be selected to initialize route repair. The other one is discarded due to high occurrence of another link breakage. It helps alleviate adverse impact of repeated link breaks on the network performance.

The rest of paper is organized as below. Section 2 describes how to design the integrated routing metric to compete next hop in the route establishment process and presents the simulation results. In section 3, the mechanism of competition is applied in the route repair process between upstream and downstream nodes in the route maintenance process. Finally, some concluding remarks are given in Section 4.

2. Routing Discovery Process

In VANET, forwarding area refers to a specific region within its communication range designated by previous node. All nodes within this region enable to forward RREQs, while the others outside have to omit them directly. In **Fig. 1**, the shaded area illustrates the forwarding area of previous node N_s. Intermediate nodes N_{i_1}, N_{i_2} and N_{i_3} are the neighbor nodes of N_s in its communication range. N_d is the destination of data packets. R is the radius of N_s's communication range. N_{i_1} and N_{i_2} are in the forwarding area, which are qualified for forwarding RREQs towards N_d. N_{i_3} is out of the forwarding area, which drops RREQs.

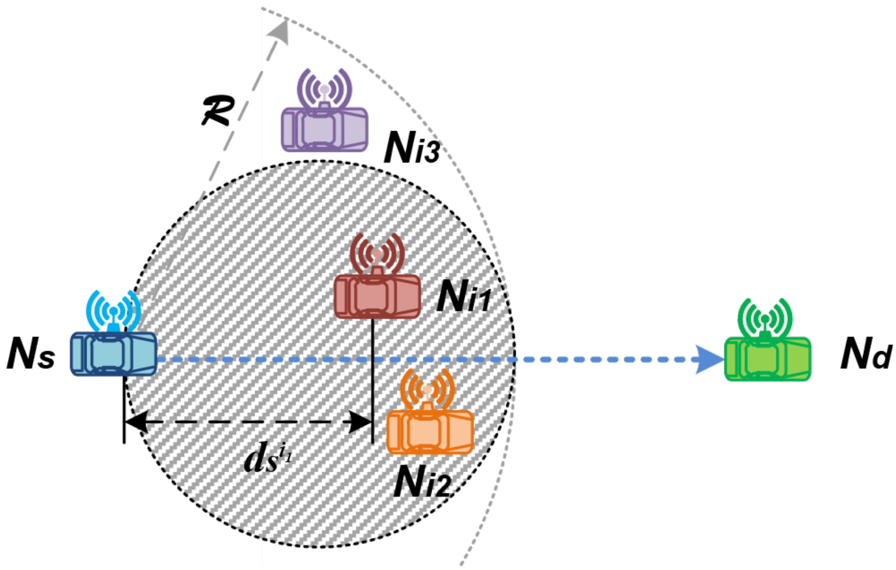


Fig. 1. Forwarding area

The forwarding area in the proposed protocol can be seen as a circular region with the radius of $R/2$. Once a node forwards packets, the others in the forwarding area can overhear and respond. All nodes in the forwarding area must compete to broadcast RREQs based on a competing parameter ω. Each candidate calculates its own forwarding delay t_d by Equation 1.

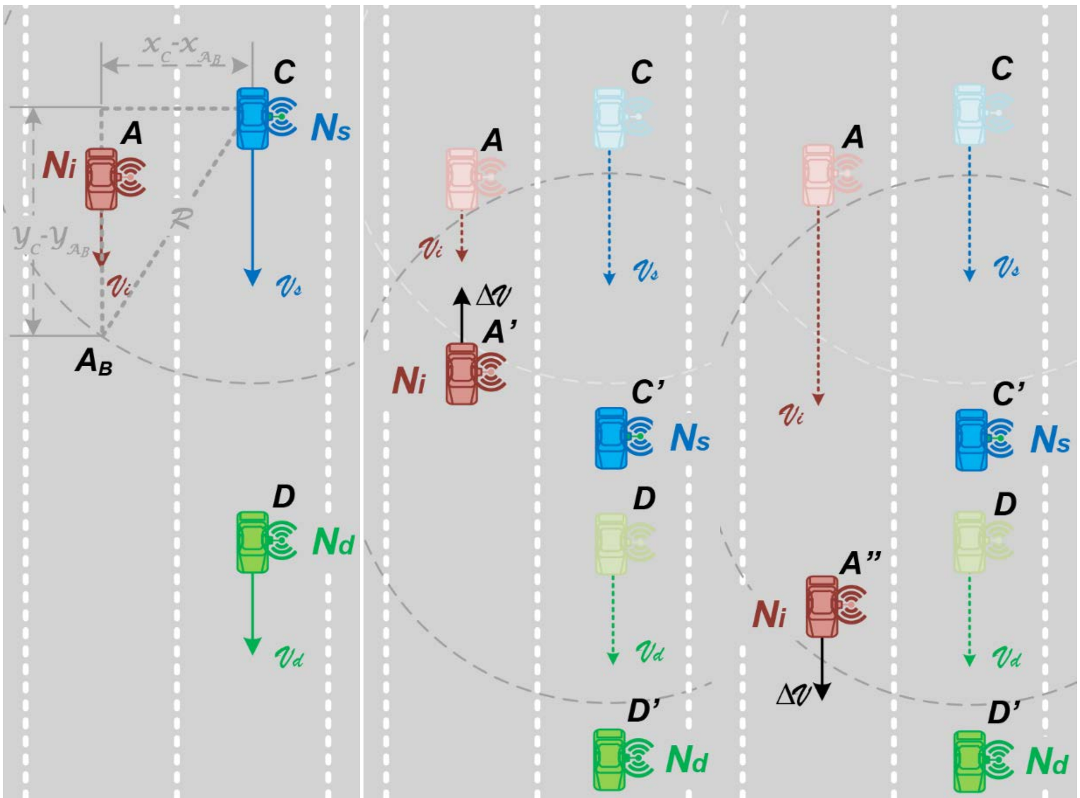
$$t_d = max\_delay \times (1 - \omega) \quad (1)$$

max_delay implies the transmission time of node. It is an estimated value of a packet's one-hop traversal time, including queuing delay, interrupt processing time and propagation time. ω is used to quantify the competitiveness of each node using the routing metric. If the value of ω over one node is maximal among all candidates, the path from N_s to the node is believed to be the most stable and suitable link. The node with the smallest forwarding delay can naturally forward the RREQ first. Once the other nodes in the same forwarding area have overheard the RREQs packet from the first forwarded node, they omit the forwarding request of source node N_s immediately.

2.1 Integrated Routing Metric for Competition

In our proposal, the routing metric can be used to determine the competing parameterω. How to design the routing metric is the key for routing establishment. In large-scale VANET, whether a route is optimal is depended on both link length and link residual lifetime. Hence, we consider the interleaving effect of link residual lifetime and the least number of hops.

We assume that all vehicular nodes have their own geographical information such as location, direction and speed, which may be acquired by GPS. The movement of any node is constant at the current instant. The link residual lifetime can be illustrated in **Fig. 2**. Here N_s is the previous node, N_d is the destination node and N_i is one of the candidates for routing in the forwarding area, which gets RREQs from N_s.



(a) At time t (b) $v_s > v_i$ at $t + \Delta t$ (c) $v_s < v_i$ at $t + \Delta t$

Fig. 2. The calculation of link residual lifetime

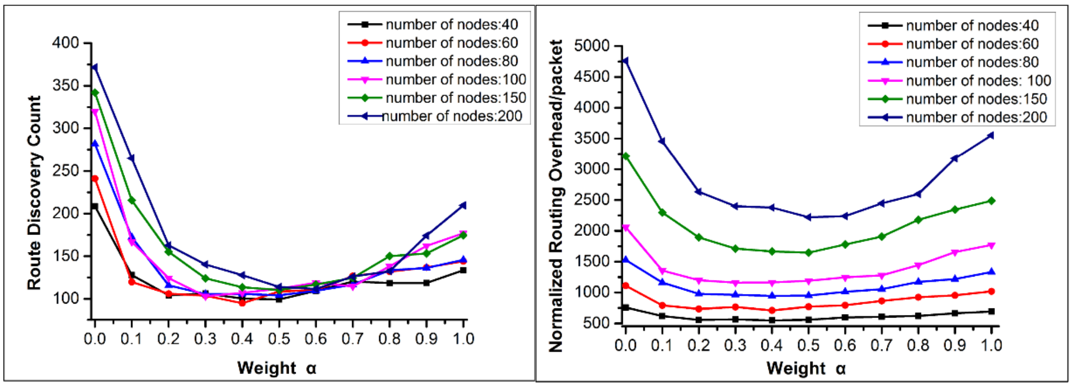
Fig. 2(a) shows that at the initial moment t, N_s is at Point $C(x_C, y_C)$, N_d is at Point $D(x_D, y_D)$ and N_i is at Point $A(x_A, y_A)$, which is located ahead of N_s on the right. After an instant Δt, if N_i keeps a constant speed, then the relative movement of N_i to N_s has two cases. Each case is characterized by different speed conditions. One case is shown in **Fig. 2(b)**. The speed v_s of N_s is faster than v_i of N_i. At the moment $t + \Delta t$, N_s moves from C to C'. N_i moves from A to A', which is on the rear right of N_s. During the moving, N_i first gets closer to N_s, and then goes far away from it.Another case is shown in **Fig. 2(c)**. v_s is slower than v_i. After Δt, N_s moves to C'. N_i gradually moves far away from A to A''. If N_i moves outside N_s's communication area, the established link between these two nodes would break.

Assume A_b is exactly at the boundary of N_s's communication area. The distance between A and A_b, denoted as D_r, is the remainder distance that N_i can move before link breakage. T_r is the link residual lifetime, which is the remainder time left for communicating. Hence we have

$$T_r = \frac{D_r}{|v_s - v_i|} \tag{2}$$

Table 1 shows the values of D_r and T_r under the cases above. Integrating T_r in the cases, we can deduce the general formula of link residual lifetime:

$$T_r = \frac{\sqrt{(v_s - v_i)^2\left[R^2 - \left(x_C - x_{A_b}\right)^2\right]} + (v_s - v_i)(y_A - y_C)}{(v_s - v_i)^2} \tag{3}$$



(a)Route Discovery Count. (b)Normalized Routing Overhead

Fig. 3. Effect of weight α

Table 1. The calculation of D_r and T_r

	D_r	T_r
$v_s > v_i$	$\sqrt{R^2 - \left(x_C - x_{A_b}\right)^2} + (y_A - y_C)$	$\frac{D_r}{v_s - v_i}$
$v_s < v_i$	$\sqrt{R^2 - \left(x_C - x_{A_b}\right)^2} - (y_A - y_C)$	$\frac{D_r}{v_i - v_s}$

Our proposed routing metric also takes route length into account, except link residual lifetime. As shown in **Fig. 1**, $d_s^{i_1}$is the projection distance of N_s to N_{i_1}. It represents the move towards N_s away from N_{i_1}.The node with larger $d_s^{i_1}$ is relatively closer to the destination. Obviously, the route over the nodes with the largest d_s^i has the fewest hops.

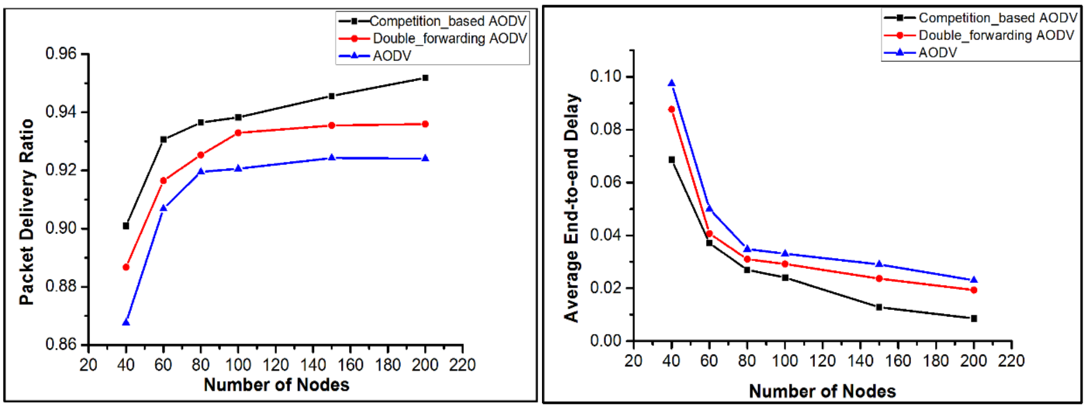
Routing metric is defined to integrate d_s^i and T_r together by competing parameter ω, and the weight α is used to adjust the bias on these two parameters, as shown in Equation 4.

$$\omega = (1-\alpha)\frac{T_r}{T_{max}} + \alpha\frac{d_s^i}{R} \tag{4}$$

where T_{max} is the maximal value of residual lifetime, and $T_r \leq T_{max}$. If α is appropriate, an optimal route with relatively fewer hops and greater stability can be selected. At the time, the competing parameter ω must be the optimal value.

2.2 Scenario Model and Simulation Analysis

Scenario Model Our experiment simulation is from one of typical urban traffic scenarios. When the traffic light turns green, all waiting vehicles start to move forward, and may stop at next intersection if the red light is on. Between the two intersections, all vehicles in different lanes move to the same direction with different speeds and constitute a temporary mobile ad-hoc network. Each vehicle can be seen as the source or the forwarder of data packets. Nodes switch from go-straight state to change-lane state through cycles until they reach the second intersection. When a simulation starts, the sources of five pairs of vehicle nodes generate data packets within 30 seconds. All nodes at the moment move forward and cross the first intersection. They are scattering on the lanes. Once the pair reach the second intersection, the communication between them does stop. When all of 5 pairs reach the second intersection, the simulation ends. Simulation parameters are in **Table 2**. T_{max} is set 80s. According to the simulation, the probability that a link survives till 80s is close to 0. Note that the residual



(a)Packet Delivery Radio. (b)Average End-to-End Delay.

Fig. 4. Performance of Competition-based at $\alpha = 0.5$, D-AODV and AODV

Table 2. Simulation Patameters

Patameters	**Valne**
Simulation area	37.3 m×2000 m
Numbei of lanes	10
Traffic type	40,60,80,100,150,200
Packet rate	Constant Bit Rate(CBR)
Data Packet Size	5 packets/sec
Node speed	10 km/h ~ 80 km/h
Communication range (R)	250 m
T_{max}	80 sec
max_delay	0.04 sec
MAC	802.11b

lifetime is meaningless if its value is larger than 80s.

Effect of Weight α The optimized routing metric includes two parameters, link length d_s^i and link residual lifetime T_r. We investigate their combinations, and deduce the competing parameter ω and its corresponding forwarding delay t_a. Among all candidate nodes, the one with the maximal competing parameter can become a forwarding node with the highest priority. Various α means different bias to two competition parameters. **Fig. 3** shows the effect of weight α changing from 0 to 1 to network performance. Two criterions, route discovery count in **Fig. 3(a)** and routing overhead in **Fig. 3(b)**, are evaluated. The results indicate that both of them decrease at the beginning, and then increase slowly. Their minimal values exist at $\alpha = 0.5$. It implies that residual lifetime and link length effectively work together for achieving a relatively stable route with less rediscovery and lower overhead. We note that if $\alpha = 0$, the node with the maximal link residual lifetime would forward RREQ in every hop. Any change on the speed or direction of node may change ω greatly, causing unstable. If $\alpha = 1$, the further node from N_s has higher priority to forward packets. Small relative movement in any pair may cause link break. The effect of α proves that integrating d_s^i andT_r in route metric greatly contributes to network performance.

Analysis and Comparison We further investigate three performance criterions such as packet delivery rate, average end-to-end delay and normalized routing overhead in our proposed competition-based scheme. It is compared with Double-forwarding AODV (D-AODV) [25] and AODV. Here α is set 0.5 for better performance. Consider the reliability of simulation, all results are statistically obtained by averaging 50 runs. All values in 50 runs with different seeds.

Packet Delivery Ratio: In **Fig. 4(a)**, the packet delivery ratios of AODV, double-forwarding AODV and competition-based AODV protocols gradually increase as the node group expands. It is because the growth of the number of nodes brings in better network connectivity. Further, it indicates that the packet delivery ratio of competition-based AODV is clearly larger than that of double-forwarding AODV in the case of various number of nodes. The result implies that the competition-based AODV is superior when the number of nodes increases. This can be explained by the fact that the prediction of route lifetime in competition-based AODV does eliminate frequent link breaks and improve packet delivery ratio. In fact, the predictive mechanism of route lifetime provides a very efficient and very direct transit node filtering process. Using a routing node with a longer lifetime can reduce unnecessary routing switching overhead.

Average End-to-end Delay: It includes all possible delays such as route discovery latency, queuing time and propagation delay. **Fig. 4(b)** indicates the relationship between average end-to-end delay and the number of nodes. The results show that average end-to-end delay gradually decreases when vehicle density increases. It is explained by the fact that each node has more neighbors to find an optimal route. These results indicate that competition-based scheme has the ability to select further node with longer residual lifetime because it takes both link length and residual lifetime in account, not only link length as in D-AODV. Thus its delay is definitely shorter than those AODVs. It is really worthy in VANET environment with large-scale topology and enormous vehicles.

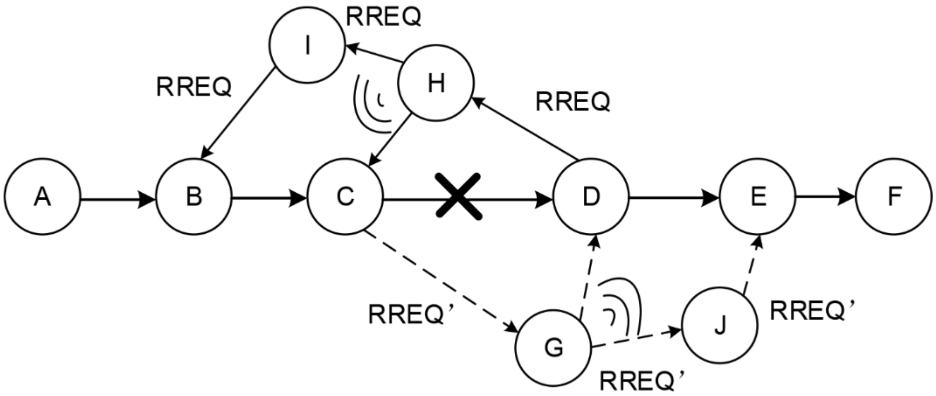
3. Routing Repair Process

In large-scale VANET, using Competition-based route discovery with routing metrics can reduce the negative impact of larger topology and more moving vehicles. However, the kind of “larger” and “more” still cause the fickleness and volatility of the whole VANET. Hence, in practice, repairing the breakage of links as soon as possible is more meaningful. One feasible approach is to limit route repair to occur around the surrounding area of breakage, which may shorten route discovery process. We therefore define to launch local repair at only upstream node, as N_{up}, or downstream node, as N_{down}. In the strategy, N_{up} and N_{down} compete the right of route repair according to their own stability indexes. The more stable node initiates a route repair and another is not allowed to involve in this route repair.

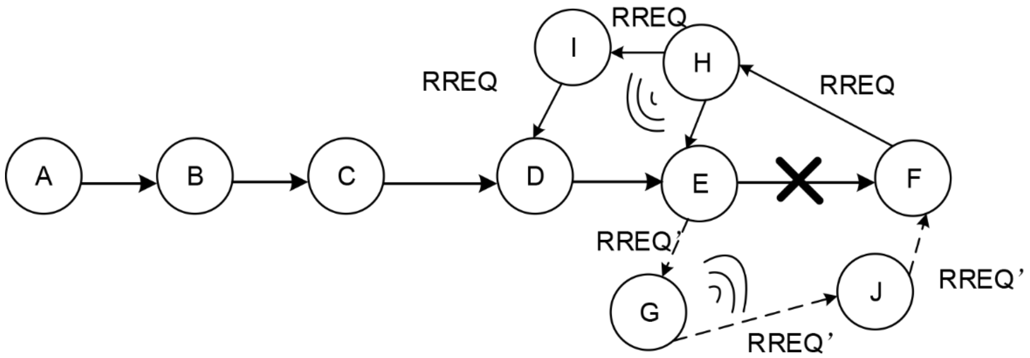
3.1 Competition between Upstream and Downstream Nodes

In the route discovery, the link residual lifetime is used as one parameter for link stability. However, it is obvious that the data acquired for computing residual life is outdated and inaccurate. Therefore, using the stability index β to evaluate the stability of upstream and downstream nodes is a feasible solution.A stability index, denoted as β, is to evaluate the stability of N_{up} or N_{down}.

Now we define a set of nodes:$S_{N_j}^t = \{N_i | N_i \text{ is a neighbor of Node } N_j \text{ at time } t, i = 1,2, \dots\}$.



(a) The break locates at the Middle of the Route



(b) the break locates at the End of the Route

Fig. 5. Route repair in different conditions

At continuous instants t_1 and t_2, we have $S_{N_j}^{t_1}$ and $S_{N_j}^{t_2}$ at N_j. The stability index of N_j is the loss rate of neighbors of N_j from t_1 to t_2 compared to the total number of neighbors at moment t_1.

$$\beta_{N_j} = \left(|S_{N_j}^{t_1}| - |(S_{N_j}^{t_1} \cap S_{N_j}^{t_2})|/|S_{N_j}^{t_1}|\right) \tag{5}$$

The smaller β is, the more stable the node is. Here the update cycle of stability index is 5s. It means each node calculates its stability index β in every five seconds. Then the index is added in the "Hello" packet and broadcasted to its neighbors. So every neighbor receiving copies β to the entry of neighboring node list so that the value of β in the list is updated.

3.2 Local Repair with Competition

When a link breaks, a local repair starts in order to quickly reconnect the route and continue data packets transmission. For instance, in **Fig. 5**, a path of nodes $N_A - N_B - N_C - N_D - N_E - N_F$ is the original route. A link break occurs between N_C and N_D. N_C and N_D first compare their stability index that have been updated before, and then figure out which is more stable. If $\beta_{N_C} < \beta_{N_D}$, that is, the upstream node N_C is more stable than the downstream node N_D, N_C is entitled to launch a route repair. It is called "N_{up} Repair". Otherwise, N_D launches a route repair, which is called "N_{down} Repairs".

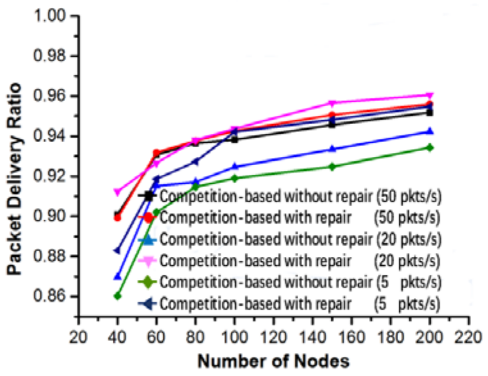
Different from the route discovery process, the destination node here is the next-to-next hop along the route from the fracture. In that case, the unstable one between N_{up} and N_{down} would be kicked out, which can reduce the risk to be broken again and improve the efficiency of route repair. The route is repaired by sending route repair request packets in the broadcasting way from break end within three hops in maximum. Note that a traditional routing table only record the information of adjacent upstream and downstream nodes. It is not enough for our proposed algorithm. The new routing table need to add the "hop after next" entry, and the value of "hop after next" can be obtained at the time of route establishment.

Upstream Node Repair In **Fig. 5(a)**, node C is more stable than node D, node C initiates upstream repair. Node C seeks for the route entry indexed by the address of node F and figures out whether its parameter "hop after next" is valid. If it is valid, node C broadcasts RERREQ (route repair request packet) destined to "hop after next" node E with the maximal 3 hops. Assume that RERREQ packet goes through node G and J and finally reaches node E. Node E looks into the route table. If the path from node E to node F is valid, then node E replies RERREP(route repair reply packet). Both node G and J update their routes to node E as well as to node F. When RERREP reaches node C, the reverse path C - G - J - E establishes and replaces the failed path. If the parameter "hop after next" is invalid, then upstream node C switches to the traditional local repair method and send RERREQ to the original destination node F. When sending RERREQ, node C sets a timer at the same time. If node C cannot receive RERREP in a certain duration, which means local route repair fails, then node C sends route error message to source node A and requires for the source repair. When node C receives data packets during local repair, it first stores the packet and waits to forward it on the fixed route.

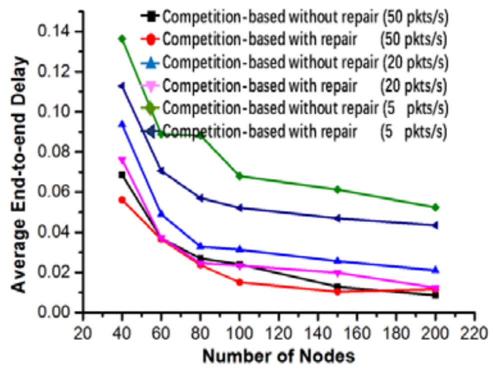
Downstream Node Repair If node D is more stable than node C, node D initiates the downstream repair. The node D uses a similar method in downstream node repair as node C in upstream node repair. Node D broadcasts RERREQ destined to node B. New path B - I - H – D establishes and replaces the failed path. Node G and J update their routes to node E and node F. Note that node C needs to send a one-hop message RERRER to the previous node B. RERRER informs node B that the route is under local repair and node B is the destination of RERREQ. Node B is required to set timer. If node B cannot receive RERREQ in certain duration, node B should report route error message to source node A and request for source repair. When the route is linked again, the data buffered in node B are forwarded via the fixed route.What mentioned above is in the situation that the link break is located at intermediate position of the original path (**Fig. 5(a)**), the destinations of repair request packets from node C and node D are respectively node E and node B. If the break occurs at the end of the link between node E and node F (**Fig. 5(b)**), the destination of repair request packet is not the node after next but the adjacent node F.

3.3 Simulation Analysis

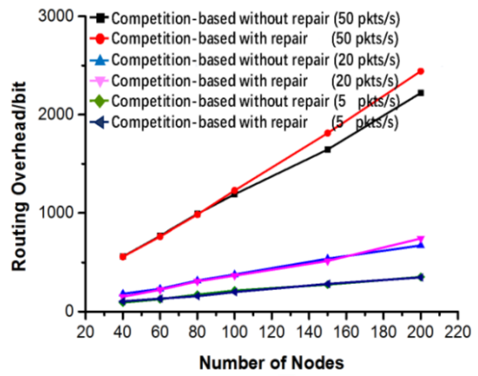
We investigate the effect of our route repair method using four performance criterions, such as packet delivery ratio, average end-to-end delay, normalized routing overhead and route discovery count. A comparison is conducted over Competition-based scheme with and without route repair. The data are obtained when the packet rates of communication nodes are respectively 5, 20 and 50 *packets/s*. The simulation scenario and parameters are the same as the section of simulation model.



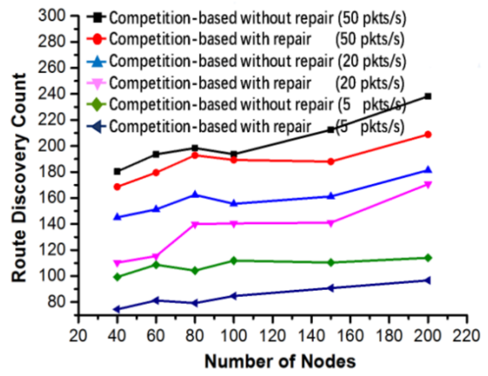
(a)Packet Delivery Radio.



(b)Average End-to-End Delay.



(c)Normalized Routing Overhead..



(d)Route Discovery Count.

Fig. 6. Performance of Competition-based with and without route repair.

Fig. 6(a) shows that route repair increases packet delivery ratios across varying number of nodes. Without route repair, once the route is unavailable in certain duration, the intermediate nodes discard data packets. With route repair, the intermediate nodes save packets. Once link break is fixed, these packets would be resent and pocket loss is reduced. When network scale expands, available substitute nodes increases. At the time, successful rate of repair also increases and packet delivery ratio finally increase greatly. **Fig. 6(b)**, **Fig. 6(c)** and **Fig. 6(d)** shows that route repair gradually decreases average latency of packets delivery, routing overheads and route discovery count across varying number of nodes. With local route repair, it is the intermediate node (N_{up} or N_{down}), not source node, to issue the re-establishment. Due to only 3 hops in local repair, route discovery process is shortened and the repair requests are limited in the surrounding area of breakage. When node density goes up, more intermediate nodes are available to bridge link gaps, hence the latency is largely shortened.

5. Conclusion

In the paper, we focus on routing discovery and repair issues for large-scale VANET, and propose a competition-based route algorithm. With the design of forwarding area and forwarding delay, recipients of RREQ compete for becoming the next-hop node, which effectively reduces the production and diffusion of control messages. Using competition scheme, the optimal node with longer link length and residual lifetime is selected, which reduce the negative impact of the expansion of topology and the increase of moving vehicles. And furthermore, one of the upstream and downstream nodes is also selected competitively according to its own stability to establish a only 3 hop short route to fulfill the quick route repair. The simulation results prove that our competition-based scheme is more suitable for VANET in large-scale urban traffic environment.

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