A RELIABLE ROUTING FOR VEHICULAR AD HOC NETWORKS USING EVOLVING GRAPH

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Abstract: Vehicular ad hoc networks (VANETs) are a special form of wireless networks made by vehicles communicating among themselves on roads which includes communications among vehicles and between vehicles and road side units. However, due to the high mobility and the frequent changes of the network topology, the communication links are highly vulnerable to disconnection in VANETs. This paper extend the well-known ad hoc on-demand distance vector (AODV) routing protocol with evolving graph theory to propose reliable routing protocol EG-RAODV. Simulation results demonstrate that EG-RAODV significantly outperforms better packet delivery ratio, lowest routing request ratio, less link failures while maintaining a reasonable routing control overhead and lowest average end to end delay.

Keywords AODV, Vehicular ad hoc network (VANET), Vehicular networks.

I. INTRODUCTION

The number of automobiles has been increasing on the road from the past few years. Due to high density of vehicles, the potential threats and road accident is increasing. VANET is one of the influencing areas for the improvement of Intelligent Transportation System (ITS) in order to assists vehicle drivers to communicate and coordinate among themselves in order to avoid any critical situation before they actually face it, which significantly improve driver's safety and comfort. Inter-vehicle communication (IVC) is necessary to realize traffic condition monitoring, dynamic route scheduling, emergency-message dissemination and most importantly, safe driving [1]. It is supposed that each vehicle has a wireless communication equipment to provide ad hoc network connectivity. VANETs are considered as a special class of mobile ad hoc networks (MANETs), yet they have several key features distinguishing them. The most challenging issues in VANET is the high mobility and the frequent changes of the network topology. The topology of vehicular networks could vary when the vehicles change their velocities and/or lanes. These changes depend on the drivers, road situations and traffic status, and are not scheduled in advance. The proposed routing protocols and mechanisms that may be employed in VANETs should adapt to the rapidly changing topology. Besides that, they must be efficient and provide quality of Service (QOS) support to permit different transmission priorities according to the data traffic type. The existing routing protocols as they are designed for MANETs are not suitable for VANETs. In this paper, we propose a new reliability based routing scheme using evolving graph to establish a more reliable route between the source and the destination nodes. The rest of this paper is organized as follows: Vehicular reliability model, VANET oriented evolving graph, EG-RAODV, Simulation results and finally, Conclusion concludes the paper.

II. VEHICULAR RELIABILITY MODEL

A. *Basis of Vehicular Traffic Flow Models*

The traffic dynamics in terms of aggregated macroscopic quantities such as traffic density p(x, t), traffic flow q(x, t), and average velocity v(x, t) as a function of space x and time t corresponding to partial differential equations. These parameters can be related together by their average values using the following relations:

$$d_m = \frac{1000}{\rho_{\text{veh}}} - l_m \tag{1}$$

$$q_m = \frac{1}{\tau_m} = v_m \left(\frac{1}{\frac{1000}{\rho_{\text{veh}}} - l_m} \right) \tag{2}$$

$$\tau_m = \frac{d_m}{v_m} = \frac{1}{v_m} \left(\frac{1000}{\rho_{\text{veh}}} - l_m \right) \tag{3}$$

where d_m is the average distance between vehicles (in meters), ρ_{veh} is the traffic density on the freeway section considered (in vehicles per kilometer), l_m is the average length of vehicles (in meters), τ_m is the average time gap between vehicles (in seconds), v_m is the average velocity of vehicles on the road (in kilometers per hour), and q_m is the average traffic flow (in vehicles per hour). This approach can be used to describe both general traffic flow status and individual vehicles [2].

B. *Link Reliability Model*

Definition: Link reliability is defined as the probability that a direct communication link between two vehicles will stay continuously available over a specified time period. Given a prediction interval Tp for the continuous availability of a specific link l between two vehicles at t, the link reliability value r(l) is defined as follows:

r(l) = P{To continue to be available until
t + T_p | available at t}.

It is assumed that the velocity of vehicles has a normal distribution. Based on this assumption, let g(v) be the probability density function of the velocity of vehicle v and G(v) be the corresponding probability distribution function; then

$$g(v) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(v-\mu)^2}{2\sigma^2}} \tag{4}$$

$$G(v \leq V_0) = \frac{1}{\sigma\sqrt{2\pi}} \int_0^{V_0} e^{-\frac{(v-\mu)^2}{2\sigma^2}} dv \tag{5}$$

where μ and σ^2 denote the average value and the variance of velocity, respectively. The distance d between two vehicles can be calculated using d = Δv × T, where Δv is the relative velocity and T is the time duration. The relative velocity is given by $\Delta v = |v_2 - v_1|$. Let H denote the radio communication range of each vehicle. The maximum distance where a communication between any two vehicles remains possible can be determined as 2H. Let f(T) denote the probability density function of the communication duration T. We can calculate f(T) as follows:

$$f(T) = \frac{4H}{\sigma_{\Delta v}\sqrt{2\pi}} \frac{1}{T^2} e^{-\frac{\left(\frac{2H}{T}-\mu_{\Delta v}\right)^2}{2\sigma^2_{\Delta v}}} \qquad \text{for } T \geq 0 \tag{6}$$

where $\mu_{\Delta v}$ and $\sigma^2_{\Delta v}$ denote the average value and the variance of relative velocity Δv, respectively. We suppose that each vehicle is equipped with a Global Positioning System device to give the location, velocity, and direction information. T_p is defined as the continuous availability of a specific link l between two vehicles i and j. It can be determined as

$$T_p = \frac{H - L_{ij}}{v_{ij}} = \frac{H - \sqrt{(y_i - y_j)^2 + (x_i - x_j)^2}}{|v_i - v_j|} \tag{7}$$

where L_{ij} is the Euclidean distance between vehicles i and j, and v_{ij} is the relative velocity between vehicles i and j.We can integrate f(T) in (6) from t to t + T_p to obtain the probability that, at time t, the link will be available for a duration T_p. Thus, the link reliability value $r_t(l)$ at time t is calculated as follows:

$$r_t(l) = \begin{cases} \int_t^{t+T_p} f(T)dT, & \text{if } T_p > 0 \\ 0, & \text{otherwise.} \end{cases} \tag{8}$$

The integral in (8) can be derived using the Gauss error function Erf. It can be obtained as

$$r_t(l) = \text{Erf}\left[\frac{\left(\frac{2H}{t} - \mu_{\Delta v}\right)}{\sigma_{\Delta v}\sqrt{2}}\right] \tag{9}$$

$$-\text{Erf}\left[\frac{\left(\frac{2H}{t+T_p} - \mu_{\Delta v}\right)}{\sigma_{\Delta v}\sqrt{2}}\right] \qquad \text{when } T_p > 0$$

Where Erf is defined as follows:

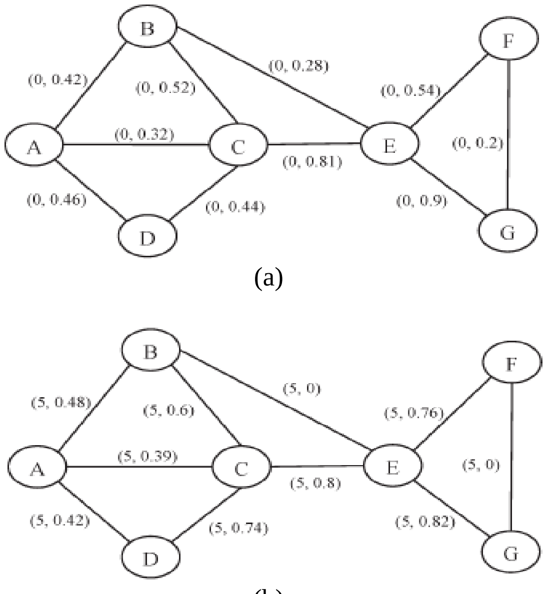
$$\text{Erf}(\tau) = \frac{2}{\sqrt{\pi}} \int_0^{\tau} e^{-t^2} dt, \qquad -\infty < \tau < +\infty. \tag{10}$$

III. VANET-ORIENTED EVOLVING GRAPH (VOEG) MODEL

We propose the VoEG model to address the evolving properties of the VANET communication graph and consider the reliability of communications links among vehicles. We associate the following 2-tuple (t, $r_t(e)$) with each edge, where t denotes the current time, and $r_t(e) = r_t(l)$ denotes the link reliability value at this time *t*, as defined in (8). In the VoEG model, the communication link between two vehicles is not available if its reliability value $r_t(e)$ is equal to zero. Let e = {A,B} be a link in the VoEG, where V_{VoEG} is the set of vertices and E_{VoEG} is the set of links. Let Trav(e) be a function that determines whether this link e can be traversed or not, i.e.,

$$\text{Trav}(e) = \begin{cases} \text{True}, & \text{if } 0 < r_t(e) \leq 1 \\ \text{False}, & r_t(e) = 0. \end{cases} \tag{11}$$

Fig. 2(a) shows the VoEG status and the corresponding reliability values associated to each link at t = 0 s. All links are eligible to be traversed because ∀e ∈ E_{VoEG}, Trav(e) = true.



(a)

(b)

Fig. 1: Proposed VoEG model at (a) *t* = 0 s and (b) *t* = 5 s.

Fig. 2(b) shows the VoEG status at t = 5 s, where the associated links' reliability values change due to the evolution of the VoEG. It can be noticed that edges {B,E} and {F,G} are now not eligible to be traversed, i.e., Trav({B,E}) = Trav({F,G}) = false at t = 5 s, where r_5({B,E}) = r_5({F,G}) = 0.

Our objective is to find the most reliable journey (MRJ) instead of using the conventional approaches of finding the foremost, shortest, or fastest journey. The MRJ has the highest journey reliability value among all possible journeys from the source to the destination. Let k be the number of edges that constitute a valid journey J(u, v) between u and v and let $r_t(e_w)$ be the reliability value of the edge e_w at time t, where J = (Ω,Ω_σ) and w = (1, 2, . . . , k). The journey reliability, which is denoted by R(J(u, v)), is defined as follows:

$$R(J(u,v)) = \prod_{w=1}^{k} r_t(e_w), \qquad \text{where } e_w \in J(u,v) \tag{12}$$

i.e., the journey reliability value is equal to the product of reliability values of all its formed links, where

$$0 \le R(J(u,v)) \le 1. \tag{13}$$

Suppose that there are z potential multiple journeys from u to v. If M J(u, v) = {J1, J2, . . . , J_z} is a set of all those possible journeys, then the MRJ will be chosen based on the following criteria at the destination vehicle:

$$\arg\max_{J \in M\, J(u,v)} R(J) \tag{14}$$

i.e., we will choose the MRJ among all possible journeys from u to v.

IV. EVOLVING GRAPH RELIABLE AD HOC ON-DEMAND DISTANCE VECTOR ROUTING (EG-RAODV) PROTOCOL

A new routing algorithm to find the MRJ is needed first. Then, this algorithm will be applied to design the route discovery process for our proposed EG-RAODV routing protocol. Note that AODV stands for the Ad hoc On-Demand Distance Vector routing protocol [3].

A. Prediction Algorithm

To predict the location of vehicles at time t, we need to apply a mobility model. In this paper, we assume that vehicles travel at a constant velocity v_0 along the same direction α_0. On the highway is given by:

$$\begin{aligned} \Delta x_{i,j} &= v_0 \times \Delta t \times \cos\alpha_0 \\ \Delta y_{i,j} &= v_0 \times \Delta t \times \sin\alpha_0 \end{aligned} \tag{15}$$

Where $\Delta x_{i,j}$ and $\Delta y_{i,j}$ are the travelling distances along the x and y directions during $\Delta t = (t_j - t_i)$.

B. EG-Dijkstra

Finding the most reliable route in the VoEG model is equivalent to finding the MRJ. The normal Dijkstra algorithm [4] cannot be directly applied in this context. We modify it and propose the evolving graph Dijkstra's algorithm (EG-Dijkstra) to find the MRJ based on the journey reliability definitions in (12) and (14). The proposed EG-Dijkstra algorithm maintains an array called the reliable graph (RG) that contains all vehicles and their corresponding MRJ values. EG- Dijkstra starts by initializing the journey reliability value RG (s_r) = 1 for the source vehicle and RG (u) = φ for other vehicles.
A pseudocode for the EG-Dijkstra algorithm is:

```
Input: A VoEG and a source vehicle sr.
Output: Array RG that gives the most reliable routes from $s_r$ to all other vehicles.
Variables: A set Q of unvisited vehicles.
1. Set route reliability RG ($s_r$) = 1 and RG (u) = φ for all other vehicles;
2. Initialize array Q by inserting $s_r$;
3. While Q is not empty do
    (a) x ←the vehicle with highest reliability value in Q;
    (b) Mark x as visited vehicle;
    (c) For each open neighbor v of x do
        i. if Trav (e) is True
            1. Set RG (v) ← $r_t$(e) × RG(x);
            2. Insert v if not visited in Q;
    (e) Close x;
4. Return the array RG;
```

C. Route Discovery Process in EG-RAODV

When a network node needs a connection, it broadcasts a routing request (RREQ) message to the neighboring vehicles. Every node receives this RREQ will record the node it heard from and forward the request to other nodes. This procedure of recording the previous hop is called backward learning. If one of the intermediate nodes has a route to the destination, it replies back to the source node with that route. If more than one reply arrives at the source node, then it uses the route with the least number of hops. If the routing request arrives at the destination node, a routing reply (RREP) message is sent back to the source node using the complete route obtained from the backward learning. When a link breakage occurs, routing error messages (RERR) are generated to repair the existing route or discover a new one.

A pseudocode of the EG-RAODV route discovery process is illustrated.

```
Input: A VoEG and a source vehicle $s_r$ and a destination vehicle $d_e$.
Output: The MRJ from $s_r$ to $d_e$.
1. Get VoEG current status using the prediction algorithm
2. Calculate the reliability value for all links in VoEG based on (8);
3. MRJ ← EG-Dijkstra(VoEG, $s_r$);
4. While the MRJ is not empty
    (a) x ← the first node from the MRJ;
    (b) Record x in the RREQ header as extension;
    (c) Remove x from the MRJ;
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4. Send an RREQ from s_r to d_e along the MRJ;
5. While an RREP is not received, wait;
6. Start sending data;

V. PERFORMANCE EVALUATION SETTINGS

We construct our performance evaluation using the MATLAB simulator. For each simulation experiment, we perform ten runs to obtain its average results.

A. Simulation Environment

We constructed a simulation scenario that uses a 5000-mlong highway with three lanes for vehicles to move. The number of vehicles is 30 (low traffic density). Only one direction for vehicle motion is considered. When vehicles reach the end of the highway, they will exit the simulation area. The average velocity of vehicles for each lane is 40, 60, and 80 km/h, respectively. Two simulation experiments will be performed.

- Experiment A: We change the transmission data rate from 32 to 512 kb/s. The data packet size is 1500 bytes. Here, the average velocity of vehicles will stay constant in the three lanes: 40, 60, and 80 km/h, respectively.
- Experiment B: We change the data packet size from 500 to 3000 bytes. The transmission data rate is 128 kb/s. Here, the average velocity of vehicles will stay constant in the three lanes: 40, 60, and 80 km/h, respectively.

B. Performance Metrics

Four performance metrics will be considered for the simulation experiments.

- Packet delivery ratio (PDR): It represents the average ratio of all successfully received data packets at the destination node over all data packets generated by the application layer at the source node.
- Link failures: It represents the average number of link failures during the routing process. This metric shows the efficiency of the routing protocol in avoiding link failures.
- Routing requests ratio: It expresses the ratio of the total transmitted routing requests to the total successfully received routing packets at the destination vehicle.
- Average end-to-end (E2E) delay: It represents the average time between the sending and receiving times for packets received.

VI. SIMULATION RESULTS

A. Effect of Different Data Rates on the Routing Performance

Fig. 2 shows that our proposed EG-RAODV achieves a higher and stable PDR performance because it chooses the most reliable route by utilizing the extended Evolving graph model. A no routing-requests broadcast is needed in this which saves network bandwidth resource and contribute to higher data delivery ratio.

Fig. 3 shows the average routing requests ratio of EG-RAODV is much smaller because it proactively finds the most reliable route and directs RREQs based on the chosen route. As shown in Fig. 4, the average number of link failures of the EG-RAODV protocol is lower. Note that with all different data transmission rates, EG- RAODV performs the best. As shown in Fig. 5. The average E2E delay performance is much lower. The lowest delay achievement comes from the proactive principle it uses when a new route is sought. As it holds the whole information, can easily predict the current locations of other vehicles and find the most reliable route without broadcasting control messages.

Fig. 2: Experiment A: Average PDR.

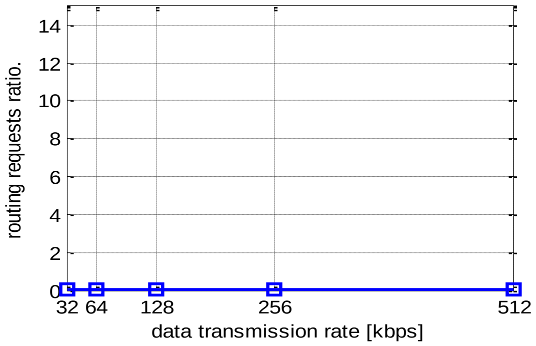

Fig. 3: Experiment A: Average routing requests ratio.

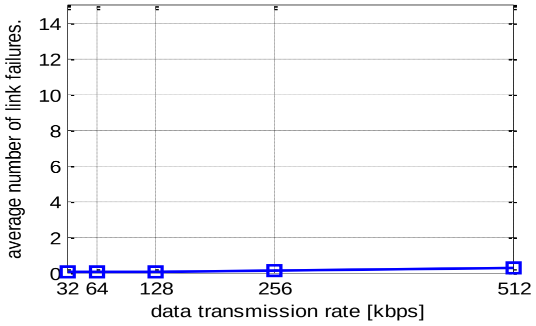

Fig. 4: Experiment A: Average number of link failures.

B. Effect of Different Data Packet Sizes on the Routing Performance

In Fig. 6, EG-RAODV always achieves the highest and stable PDR performance over different data packet sizes. Note that large packets may be fragmented. Any link breakage during the delivery process of a fragment of a packet can cause the failure of the whole data packet delivery. If the delivery fails, then a new route discovery process is needed. In Fig. 7, the average routing requests ratio, as the size of data packets increases, the number of fragments increases. More routing requests are generated for the route discovery processes due to higher delivery failures caused by additional fragments. Fortunately, EG-RAODV is not affected by this issue because the most reliable route is discovered. In Fig. 8, the average number of link failures, EG-RAODV obtains the lowest and stable number of link failures because it chooses the most reliable route.

Fig. 5: Experiment A: Average E2E delay.

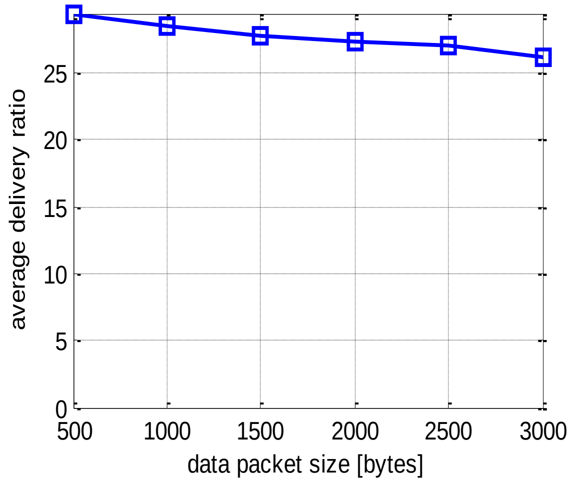

Fig. 6: Experiment B: Average PDR.

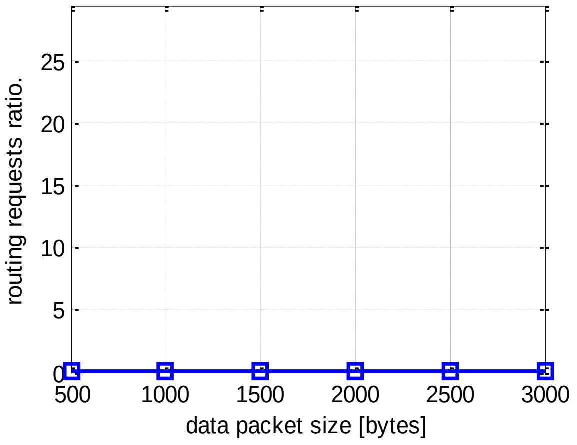

Fig. 7: Experiment B: Average routing requests ratio.

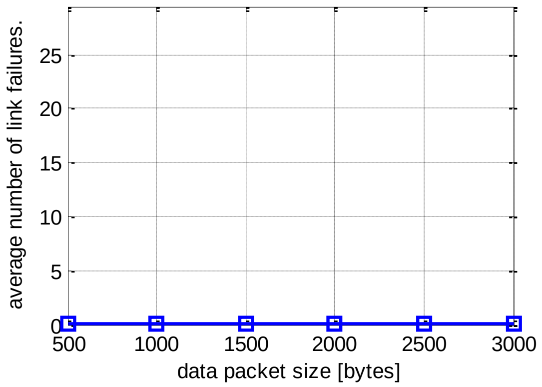

Fig. 8: Experiment B: Average number of link failures

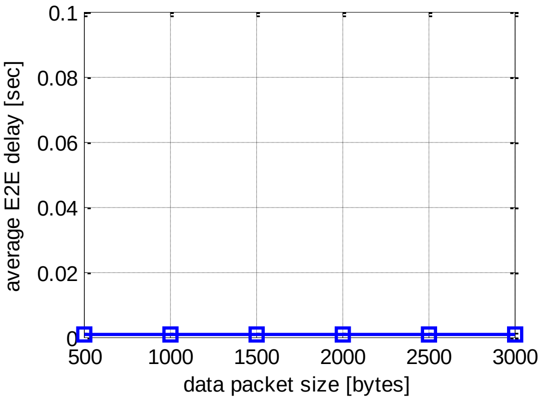

Fig. 9: Experiment B: Average E2E delay

In this experiment, EG-RAODV also achieves a lower average E2E delay value, as shown in Fig. 9. The delay performance is not affected by varying packet size. The slight increase of the delay according to packet size is because of the fact that a larger data packet means more fragments to be delivered.

VII. CONCLUSIONS

In this paper, we have extended the evolving graph theory and proposed our VoEG model. A new EG-Dijkstra algorithm was developed to find the MRJ in the proposed VoEG. We designed and formalized our EG-RAODV routing protocol to provide a reliability-based routing scheme for VANETs. The performance of EG-RAODV has been done using extensive simulations with different transmission data rates, and data packet sizes. The evaluation results reveal that EG-RAODV achieves the highest PDR and it obtains the lowest routing request ratio because the broadcasting technique is not needed in the route discovery process. As it chooses the most reliable route to the destination, it achieves the lowest number of link failures and the lowest average E2E delay values.

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