A Stable Routing Protocol to Support ITS Services in VANET Networks

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***Abstract*—There are numerous research challenges that need to be addressed until a wide deployment of vehicular *ad hoc* networks (VANETs) becomes possible. One of the critical issues consists of the design of scalable routing algorithms that are robust to frequent path disruptions caused by vehicles' mobility. This paper argues the use of information on vehicles' movement information (e.g., position, direction, speed, and digital mapping of roads) to predict a possible link-breakage event prior to its occurrence. Vehicles are grouped according to their velocity vectors. This kind of grouping ensures that vehicles, belonging to the same group, are more likely to establish stable single and multihop paths as they are moving together. Setting up routes that involve only vehicles from the same group guarantees a high level of stable communication in VANETs. The scheme presented in this paper also reduces the overall traffic in highly mobile VANET networks. The frequency of flood requests is reduced by elongating the link duration of the selected paths. To prevent broadcast storms that may be intrigued during path discovery operation, another scheme is also introduced. The basic concept behind the proposed scheme is to broadcast only specific and well-defined packets, referred to as "best packets" in this paper. The performance of the scheme is evaluated through computer simulations. Simulation results indicate the benefits of the proposed routing strategy in terms of increasing link duration, reducing the number of link-breakage events and increasing the end-to-end throughput.**

***Index Terms*—Intervehicular communications (IVC), road–vehicle communications (RVC), stable routing, vehicular *ad hoc* network (VANET).**

I. INTRODUCTION

RECENT advances in wireless technologies and dedicated short-range communications technologies have made intervehicular communications (IVC) and road–vehicle communications (RVC) possible in mobile *ad hoc* networks (MANETs). This has given birth to a new type of MANET network known as the vehicular *ad hoc* network (VANET). Internetworking over VANETs has been gaining a great deal of momentum over the past few years. Its increasing importance has been recognized by major car manufacturers, governmental organizations, and the academic community. The Federal Communications Commission has allocated spectrum for IVC and similar applications (e.g., wireless access in vehicle environment). Governments and prominent industrial corporations, such as Toyota, BMW, and Daimler–Chrysler, have launched important projects for IVC communications. Advanced Driver Assistance Systems (ADASE2) [1], Crash Avoidance Metrics Partnership (CAMP) [2], Chauffeur in EU [3], CarTALK2000 [4], FleetNet [5], California Partners for Advanced Transit and Highways (California PATH) [6], and DEMO 2000 by Japan Automobile Research Institute (JSK) are few notable examples. These projects are a major step toward the realization of intelligent transport services.

VANET networks are a special case of MANETs. They resemble to MANET networks in their rapidly and dynamically changing network topologies due to the fast motion of vehicles. However, unlike MANETs, the mobility of vehicles in VANETs is, in general, constrained by predefined roads. Vehicle velocities are also restricted according to speed limits, level of congestion in roads, and traffic control mechanisms (e.g., stop signs and traffic lights). In addition, given the fact that future vehicles can be equipped with devices with potentially longer transmission ranges, rechargeable source of energy, and extensive onboard storage capacities, processing power and storage efficiency are not an issue in VANETs as they are in MANETs. From these features, VANETs are considered as an extremely flexible and relatively "easy-to-manage" network pattern of MANETs.

Along with the recent developments in the VANET field, a number of attractive applications, which are unique for the vehicular setting, have emerged. VANET applications include onboard active safety systems that are used to assist drivers in avoiding collisions and to coordinate among them at critical points such as intersections and highway entries. Safety systems may intelligently disseminate road information, such as incidents, real-time traffic congestion, high-speed tolling, or surface condition to vehicles in the vicinity of the subjected sites. This helps to avoid platoon vehicles and to accordingly improve road capacity. With such active safety systems, the number of car accidents and associated damage are expected to be largely reduced. In addition to the aforementioned safety applications, IVC communications can also be used to provide comfort applications. The latter may include weather information, gas station or restaurant locations, mobile e-commerce, infotainment applications, and interactive communications such as Internet access, music downloads, and content delivery. In this paper, our focus is more on the provision of such entertaining applications.

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The design of effective vehicular communications poses a series of technical challenges. Guaranteeing a stable and reliable routing mechanism over VANETs is an important step toward the realization of effective vehicular communications. Existing routing protocols, which are traditionally designed for MANET, do not make use of the unique characteristics of VANETs and are not suitable for vehicle-to-vehicle communications over VANETs. Indeed, the control messages in reactive protocols and route update timers in proactive protocols are not used to anticipate link breakage. They solely indicate presence or absence of a route to a given node. Consequently, the route maintenance process in both protocol types is initiated only after a link-breakage event takes place. When a path breaks, not only portions of data packets are lost, but also in many cases, there is a significant delay in establishing a new path. This delay depends on whether another valid path already exists (in the case of multipath routing protocols) or whether a new route-discovery process needs to take place. The latter scenario introduces yet another problem. In addition to the delay in discovering new paths, flooding required for path discovery would greatly degrade the throughput of the network as it introduces a large amount of network traffic, especially if the flooding is not locally directed, as in the case of location-aided routing (LAR) protocols [7]. However, if the locations of destination nodes are unknown, omnidirectional flooding is inevitably the only option. In a highly mobile system such as VANET, where link breakage is frequent, flooding requests would largely degrade the system performance due to the introduction of additional network traffic into the system and interruption in data transmission.

In this paper, we consider a general scenario where both IVC and RVC coexist. We consider a VANET network made of a number of hot spots dispersed over a geographical area. Vehicles can have a direct access to these hot spots or via other vehicles. A set of schemes tailored to such VANET networks is proposed. The proposed schemes aim at increasing path duration, reducing control overhead, and increasing throughput. In general, control message overhead increases when nodes are highly mobile, due to the higher rate of link breakage. These overhead messages consist of route-request (RREQ) messages generated during the route-discovery process and of route-error (RERR) packets caused by abrupt link failures. The total amount of control messages in a MANET network can be reduced by the following four fundamental strategies: 1) multipath routing; 2) rebroadcast minimization; 3) increasing path duration; and 4) route discovery prior to path expiration.

The first two scenarios have extensively been dealt with in recent literature. In this paper, we introduce more suitable schemes to deliver more efficient results in highly mobile VANETs. For the third strategy, vehicles are grouped according to their moving directions, as in [8]. Communication paths are maintained between vehicles belonging to the same group. Along the connection path, if an intermediate routing node changes its direction and belongs to a different group, a link rupture may likely happen during the transmission time. Throughput may then degrade if a new route was established without taking stability and quality of network links into account. To avoid link ruptures and to establish reliable routes, the routing algorithm dynamically searches for the most stable route that includes only vehicles from the same group. Furthermore, since control messages are only forwarded within the same group, the scheme prevents flooding of control packets throughout the entire network. Hence, the achieved throughput of the network will be more evident than in the case of traditional algorithms that do not take into account mobility, as will be demonstrated later in the simulations. In the proposed protocol, due to the selection of stable and more durable paths, there will be fewer path breaks and handoffs. This consequently not only reduces the delay between new route establishments but also causes fewer route discoveries, hence effectively reducing traffic flooding in VANET networks.

The remainder of this paper is structured as follows. Section II showcases the variety of research being conducted in VANETs and surveys the state-of-the-art in the field of increasing link durations in MANET networks. Section III introduces the proposed schemes of this paper and the routing protocol. Section IV simulates the proposed scheme, followed by results and discussions. This paper is concluded in Section V.

II. RELATED WORK

This section highlights major attempts in applying MANET routing protocols to VANET networks. First is a description of important MANET routing protocols.

A. MANET Routing Protocols

A large number of routing protocols have recently been proposed within the framework of the Internet Engineering Task Force for the execution of routing in MANET networks. They can all be classified as either proactive, reactive, or hybrid. Proactive routing protocols maintain and update information on routing between all nodes of a given network at all times. Route updates are periodically performed regardless of network load, bandwidth constraints, and network size. Routing information are stored in a variety of tables and are based on received control traffic. Generation of control messages and route calculation are driven by the routing tables. The main characteristic of proactive protocols is that nodes maintain a constantly updated understanding of the network topology. Consequently, a route to any node in the network is always available regardless of whether it is needed or not. While periodic updates of routing tables result in substantial signaling overhead, immediate retrieval of routes overcomes the issue of the initial route establishment delay in case of reactive protocols. Some of the protocols that have achieved prominence in the proactive category include optimized link state routing [9], hazy-sighted link state routing [10], topology broadcast based on reverse path forwarding [11], and destination-sequenced distance vector [12].

In reactive routing protocols (RRPs), which are the flip-side of proactive protocols, route determination is invoked on a demand or need basis. Thus, if a node wishes to initiate communication with another host to which it has no route, a global-search procedure is employed. This route-search operation is based on classical flooding search algorithms. Indeed, an RREQ message is generated and flooded, sometimes in a limited way, to other nodes. When the RREQ message reaches either the destination or an intermediate node with a valid route entry to the destination, a route-reply (RREP) message is sent back to the originator of the RREQ. A route is then set up between the source and the destination. Reactive protocols then remain passive until the established route becomes invalid or lost. Link breakage is reported to the source via a Route Error (RERR) message. Several protocols fall in this category. Notable examples are *ad hoc* on-demand distance vector (AODV) [13] and dynamic source routing (DSR) [14].

Hybrid routing protocols combine both the proactive and reactive approaches. Zone routing protocol (ZRP) is a notable example [15]. ZRP divides the network topology into different zones. Routing within zones, "intrazone routing," is performed by a proactive protocol. This yields no initial delay for routing among nodes from the same zone. On the other hand, to increase system scalability, routing between zones, "interzone routing," is done by a reactive protocol. While the hybrid approaches present an efficient and scalable routing strategy for large-scale environments, a number of key issues remain unsolved, and their implementation has not accordingly gained that much popularity within the researchers' community.

Compared to reactive approaches, proactive protocols are easier to implement and exhibit relative stability. However, by applying them to a highly mobile environment such as VANETs, a storm of control messages is required to maintain an accurate view of the network topology. This intuitively results in heavy traffic contention, collisions of packets due to mass flooding broadcasts between neighboring nodes, and, consequently, a significant waste of the scarce wireless bandwidth. They can be used only for environments where mobility is relatively static. Reactive protocols are thus preferred for dynamically changing environments where nodes have a few number of active routes (e.g., VANET) [16]. For a qualitative comparison between reactive and proactive schemes, the interested reader is referred to [17].

B. Reactive Protocols in VANET

Traditionally, reactive protocols do not take into account mobility parameters during route discovery, resulting in paths which often break in highly mobile scenarios such as VANETs, causing excessive broadcasting and flooding the entire network in order for new routes to be discovered. Furthermore, the additional initial latency introduced by the route-discovery procedure poses serious challenges for reactive protocols. For this reason, reactive protocols, in their current format, are seen as inappropriate for time-critical applications such as cooperative collision avoidance (CCA), which is an important application type for vehicular communications.

To cope with flooding, LAR [7], like other broadcast/flood reducing mechanisms [18], [19], directs broadcasting toward the estimated destination node. In [20], broadcast flood is limited only by forwarding consecutive RREQ packets which have a path hop accumulation smaller than the previous identical or duplicate RREQ packet. Otherwise, the newly arrived RREQ packet is dropped and hence not forwarded. Although these methods are quite satisfactory in providing efficient rebroadcasting with regard to coverage, integrating this broadcast minimizing schemes in routing does not consider path stability during the rebroadcasting procedure. Hence, we need a scheme that takes these issues into consideration, while reducing broadcast overhead.

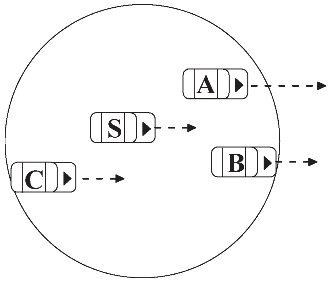

Fig. 1. ABR does not work in this scenario.

Attempts at predicting and selecting stable links have been proposed in [21]–[23]. However, they all depend on statistical analysis and probabilistic models of link duration. A routing algorithm that considers stability in the routing criterion is the associativity-based routing (ABR) [24]. ABR uses associativity "ticks" messages (TICKs), which are periodically broadcasted in order to estimate the lifetime of links. If a node has high associativity ticks with its neighbor node, then the degree of stability (and hence link duration) is high. The destination node chooses nodes which have a high degree of associativity.

If we consider ABR in a highly mobile pseudolinear mobile environment with no pause time, such as a VANET network or an aeronautical *ad hoc* network as introduced in [25], all nodes within a time range would receive equal associativity ticks regardless of their speed and direction. In this case, high associativity means that the neighbor node has been within range for a considerable period of time. It does not ensure that the mobile node will continue to remain within range, as the mobile node may already be close to the edge of the communication boundary. A better node which provides a more stable link may have just come into the range of the target node and would consequently have a lower associativity value. Thus, ABR would not be suitable for the considered mobility model. Fig. 1 shows this idea. Let vehicles A and B have higher associativities with S than they do with C. Applying ABR to such a scenario will lead to the selection of either vehicle A or B for communication. This obviously yields a poor performance of the entire network as vehicles A and B will soon disappear from the range of vehicle S. For this reason, we introduce a scheme which takes into account the relative velocity and relative distances of vehicles during route discovery in order to find the most stable paths.

C. Routing in VANET Networks

Based from the aforementioned routing concepts, a set of routing protocols has been proposed for vehicular communications. While it is all but impossible to come up with a routing approach that can be suitable for all VANET applications and can efficiently handle all their inherent characteristics, attempts have been made to develop some routing protocols specifically designed for particular applications. For safety applications, a broadcast-oriented packet forwarding mechanism with implicit acknowledgment is proposed for intraplatoon CCA [26]. In [27], a swarming protocol based on gossip messages is proposed for content delivery in future vehicular networks. For the provision of comfort applications, a segment-oriented data abstraction and dissemination (SODAD) is proposed in [28]. SODAD is used to create a scalable decentralized information system by local distribution of the information in vehicular networks. CarNet proposes a scalable routing system that uses geographic forwarding and a scalable distributed location service to route packets from vehicle to vehicle without flooding the network [29]. To avoid link rupture during data transmission, a movement-prediction-based routing (MOPR) is proposed in [30]. MOPR predicts future positions of vehicles and estimates the time needed for the transmission of data to decide whether a route is likely to be broken or not during the transmission time. The performance of the scheme largely depends on the prediction accuracy and the estimate of the transmission time that depends, in turn, on several factors such as network congestion status, driver's behavior, and the used transmission protocols. In [31], a distributed movement-based routing algorithm is proposed for VANETs. This algorithm exploits the position and direction of movement of vehicles. The metric used in this protocol is a linear combination of the number of hops and a target functional, which can independently be calculated by each node. This function depends on the distance of the forwarding car from the line connecting the source and destination and on the vehicle's movement direction. Each vehicle needs to implement this in a distributed manner.

III. PROPOSED ROUTING PROTOCOL FOR VANET NETWORKS

This section describes the working of the proposed scheme. The key idea behind the scheme is to group vehicles according to their velocity headings. This kind of grouping ensures that vehicles that belong to the same group are generally moving together. Routes involving vehicles from the same group thus exhibit high level of stability. Among these possible routes, communication is set up on the most stable route using the receive on most stable group-path (ROMSGP) scheme. Decision of the most stable link is made based on the computation of the link expiration time (LET) of each path. Obviously, the path with the longest LET is considered as the most stable link. Details on the key design and distinct features that are incorporated in each element of the proposed routing scheme are described below.

A. Grouping of Vehicles

To demonstrate the advantage of grouping vehicles, we formulate the problem via the following simple example. Fig. 2 shows the scenario of five vehicles at an intersection where vehicle B is turning onto a new street and the other four vehicles are continuing straight on the same road. A connection is established between vehicles A and F. Communication is possible on two routes: one via vehicle B (route A–B–D–F) and the other via vehicle C (route A–C–D–F). As vehicle B is turning left and vehicle A is continuing straight, the former route is more likely to be ruptured after a certain time. Consequently, the selection of the latter router is a more appropriate choice and has a tendency to add more stability and reliability to the communication path between the two vehicles (A and F). In the remainder of this section, we explain how such a selection can be possible using information on the velocity vector of vehicles.

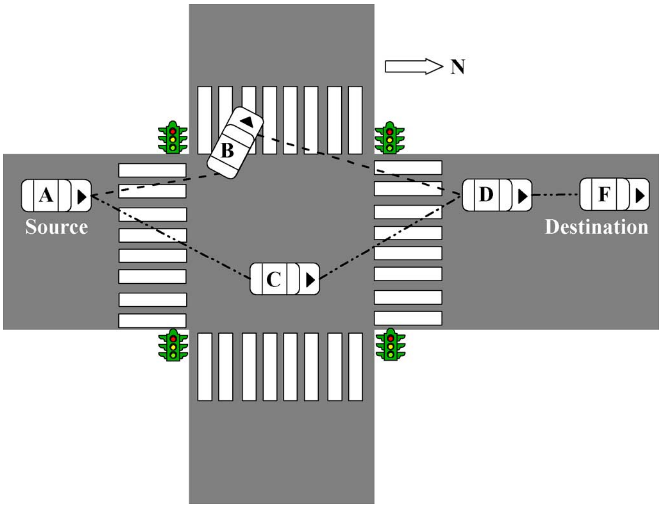

Fig. 2. Link rupture event is more likely to occur between vehicles A, B, and D.

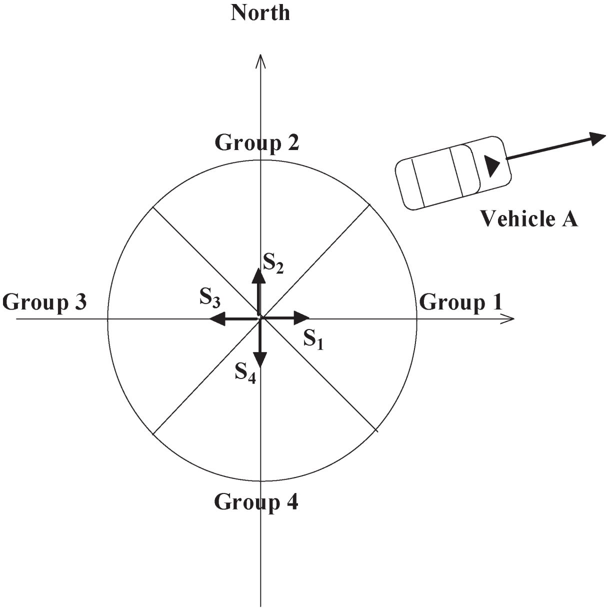

Fig. 3. Velocity-vector-based grouping of vehicles.

In the proposed routing scheme, vehicles are grouped into four different groups based on their velocity vectors. In a Cartesian space, each group is characterized by one of the unit vectors [$S_1 = (1, 0)$, $S_2 = (0, 1)$, $S_3 = (-1, 0)$, and $S_4 = (0, -1)$], as shown in Fig. 3. Vehicles are assumed to be equipped with Global Positioning System (GPS) devices to detect their geographical location. Location detection is performed every 1 s time interval. Let $V_A = (v_x, v_y)$ denote the Cartesian coordinates of the velocity vector of a given vehicle A. By using the velocity and unit vectors, the group of vehicle A can be decided as follows. Vehicle A belongs to group N if the dot product of its velocity vector and the unit vector S_N $[(V_A \cdot S_N)]$ takes the maximum value (Fig. 2; $N = 1$).

In the proposed routing scheme, information on groups is included in the control messages. When a vehicle X receives a control message from another vehicle Y, it compares its group ID with that of the originating vehicle (vehicle Y). If the two vehicles belong to two different groups, the link between the two vehicles is judged to be unstable. A penalty is then added to the routing metric between the two vehicles, and routes are updated. In such a manner, added penalties can reflect the information of groups on the routing procedure. If the two vehicles belong to the same group, routing metrics are not modified. To better explain the basic idea behind the use of metric penalties, we consider the same scenario in Fig. 2. Let β (AB), β (BD), β (AC), and β (CD) denote the routing metrics of the links between vehicles A and B, B and D, A and C, and C and D, respectively. In case of no routing metric penalties, all routing metrics are equal to one. In such case, both routes ABD and ACD can be chosen for communication. However, if a penalty α is added to the routing metrics β (AB) and β (BD) $\{\beta(\text{AB}) = \beta(\text{BD}) = 1 + \alpha\}$, the route ACD will be chosen. In this way, the proposed scheme guarantees stable routes for communication. It should be admitted that, in case of curved roads (e.g., mountainous areas), the vehicle grouping approach may be insufficient in its presented format. The limitation of the proposed approach in such scenario can be overcome by adopting a context-aware solution. Indeed, with the use of topological information on the current location (via GPS), users can tell whether they are driving on curved roads. If they do, grouping can be made among vehicles that are on the same curved roads regardless of their moving directions.

B. *Receive on Most Stable Group-Path (ROMSGP)*

The ROMSGP algorithm is an integration of the receive on most stable path (ROMSP) [32], with the grouping of nodes according to their velocity vectors, as previously demonstrated, with certain modifications to suit it to the VANET scenario. For example, the non-disjoint nature of ROMSP is not considered due to the strict mobility pattern of VANET networks. It is believed that ROMSGP would further enhance stability and further reduce network flooding and control overhead in VANET networks. The mechanism of ROMSGP algorithm is as follows.

1) The requesting vehicle broadcasts an RREQ to all vehicles within range.
2) The receiving vehicle first checks whether the current RREQ is not a duplicate packet. If it is, it will drop it. It will then check if the RREQ is from the same group by checking the group ID of the RREQ. If it is, it will then check whether it can provide the requested data or whether it has knowledge of a path that can provide this requested data. If it does, it will produce an RREP, else it will add its own address to the request packet and rebroadcast the packet.

CNA	Required Data	Required Time	Lifetime	Group ID

Fig. 4. Request packet format.

CNA	Required Data	Mobility Information	Bottleneck LET

Fig. 5. RREP packet format.

3) The RREP is reached at the source (requesting) vehicle, where the most suitable path is chosen to obtain the data from it.
4) A new route discovery is always initiated prior to the link being expired. This happens at a time "*t*" before the estimated LET. In addition to the group ID, the lifetime of the packet ensures that rebroadcasting of packets ceases after either certain number of rebroadcasts by different vehicles (hop count) or when the lifetime of a packet is reached (packet expiration).

C. *Packet Format*

The request packet format is shown in Fig. 4. When the lifetime of a packet is up, it is dropped. The cached node addresses (CNAs) are where the addresses of the forwarding vehicles are stored. Before a vehicle forwards the packet, it will add its own address to the CNA. The Required Data field defines the requested data. The Required Time field defines the time needed for the data to be transmitted. The Lifetime field will determine the expiration parameters for the request packet so that it is not indefinitely rebroadcasted over the entire network. The Group ID field identifies the group to which the requesting vehicle belongs. Vehicles which receive RREQs from other groups (with a different group IDs) will ignore (drop) the RREQs. Hence, this mechanism avoids rebroadcasting the RREQ packet over vehicles which may usually provide unstable links (as they belong to different velocity groups) and also reduces the flooding of control messages in the network.

When a vehicle can provide the data defined by the Required Data field, it will produce an RREP packet, copying the CNA field onto this new packet and forwarding it back to the source vehicle. The RREP packet format is shown in Fig. 5. The Required Data field is the same as the Required Data field in the RREQ packet. The Bottleneck LET field is updated as the RREP is forwarded back to the source vehicle. It represents the shortest lived link on the path defined by CNA. The LET is calculated using the information given in the Mobility Information field of the RREP packet, which can include the position and velocity information using GPS or other means, as outlined in [32]. The Mobility Information field is updated at each intermediate node as the RREP packet traverses toward the requesting node, with each node inputting its mobility information into this field, before forwarding the RREP packet. Each receiving intermediate node can then use the information in the RREP's Mobility Information field (representing the previous node's mobility information) together with its own local mobility information to calculate the LET of the link,

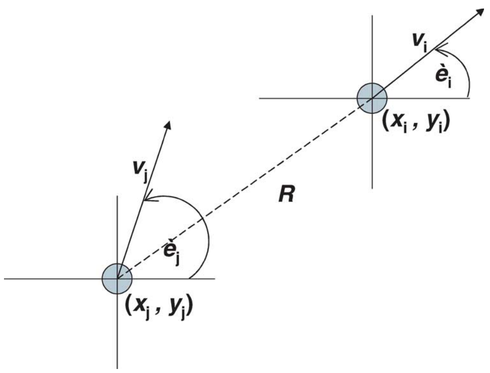

Fig. 6. Parameters used in calculating the LET.

which is then used to update the Bottleneck LET field. At the source vehicle, depending on the size of the data, the source vehicle will choose the path which can provide the requested data, and its Bottleneck LET is at least long enough to be able to successfully transmit the requested data. The source vehicle can estimate the time required by knowing the average bandwidth of the path and the size of the data. Hence, the estimated time required is the size of the data divided by the bottleneck bandwidth of the path.

D. Calculation of LET

Some of the GPSs which will be used in current and future vehicles can be used to determine the distance between vehicles. From [33], if we consider two vehicles i and j with a transmission or line-of-sight range of r, speeds v_i and v_j, coordinates (x_i, y_i) and (x_j, y_j), and velocity angles θ_i and θ_j (Fig. 6), respectively, the predicted LET is

$$\mathrm{LET} = \frac{-(ab+cd)+\sqrt{(a^2+c^2)r^2-(ad-bc)^2}}{a^2+c^2} \tag{1}$$

where

$$\begin{aligned} a &= v_i \cos\theta_i - v_j \cos\theta_j \\ b &= x_i - x_j \\ c &= v_i \sin\theta_i - v_j \sin\theta_j \\ d &= y_i - y_j. \end{aligned}$$

It is worth noting that, in the absence (or inefficiency) of the GPS technology (e.g., deterioration of GPS reception due to specific environmental conditions or signal cutoff due to particular obstacles), the aforementioned GPS-based LET metric can simply be substituted by the Doppler value, as demonstrated in some of the authors' previous research work [32]. It should be also stressed out that, in this paper, the path with the maximum LET is considered to be the most stable. However, it should be admitted that there is no need to establish a highly durable path for short-time applications. Information on the data transmission time (e.g., data size) or the type of application (e.g., VANET safety applications require short delay paths rather than durable ones) should somehow be taken into account in the decision of the most stable link.

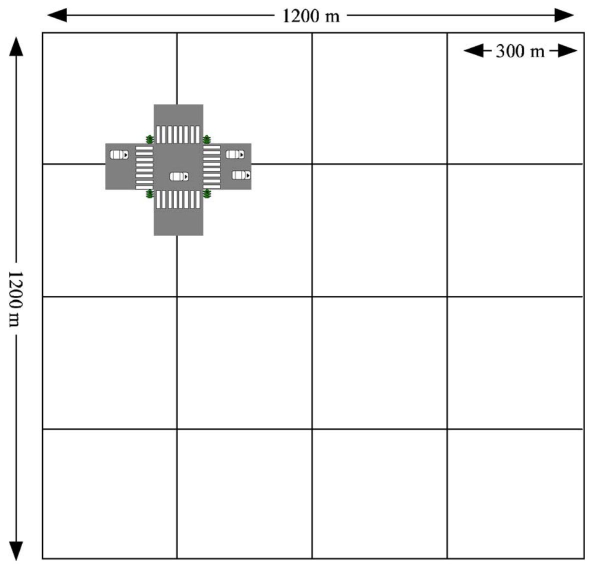

Fig. 7. Network topology.

E. Link Breakage

When the primary path used for routing breaks, the vehicle that first notices this break sends a RERR packet back to the source vehicle. The source vehicle then selects the next best path that does not contain the link that was broken. The routing table is then updated by removing (purging) all paths that contain the broken link.

When a link breaks, a local repair procedure takes place, which is similar to ABR. However, as soon as the link is repaired, the vehicle which is responsible for the repair will send a RERR.

If there is a sudden broken link, one of the two following scenarios can be envisioned.

1) If there is an alternative path at the vehicle which realizes the link break, the alternative path is chosen, and a RERR packet containing the broken link information is sent back to the source vehicle. The data packets that are already on their way are sent via the new link (i.e., the packets are salvaged, which is adapted from DSR packet salvaging [34]), where the original route cache in packet is replaced by the new alternative route cache and then forwarded. Hence, the packet is not lost.
2) If there is no alternative path, a local recovery procedure, which is similar to ABR, is performed. If the broken link is less than h hops from the source, a RERR message with the details of the broken link is sent to the source vehicle. The source vehicle then initiates a route discovery. Otherwise, a local route-recovery procedure takes place where the vehicle detecting the broken link will broadcast a two-hop recovery request that is similar to that of [19]. Once the vehicle in charge discovers a new route to the destination, it will send a route recovery (RREC) message showing the broken link and the new link back to the source. The source will then update its routing table,

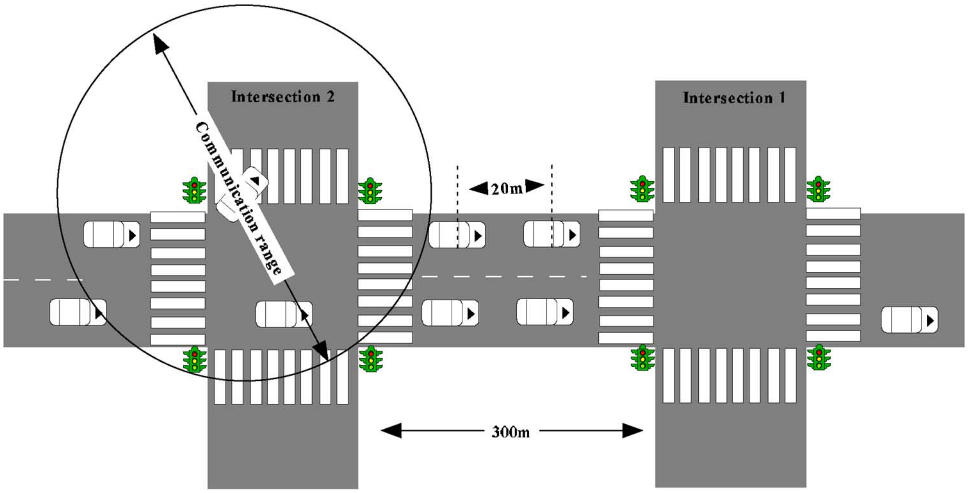

Fig. 8. Example of two adjacent intersections in the simulation layout.

purging and updating the paths in the table. However, since the process resembles source routing, the source needs to know the local repair so that, if the vehicle that is responsible for the local repair fails, the source vehicle or the vehicles on the upstream of the failed vehicle can handle the broken link.

Our scheme also reduces RERR packets by selecting/choosing new paths before the path (link) expires. Thus, it prevents the path to be broken and RREPs being sent. RREP packets are hence only produced due to unexpected link failures. This effectively reduces the total number of control messages.

Furthermore, disruption in communication is minimized by finding a new path prior to the current path's expiration. Indeed, at a time t before the primary link's estimated expiry, a new route discovery takes place, and the routing table at the source is updated. At the time of the link's estimate expiry, the newly found route is selected. This is done so that the delay between the actual link breakage, notification, and path reestablishment are avoided. The alternate paths are only there to supplement unexpected link breakage. We note that, in most cases, the primary path usually has the longest link duration. Hence, being close to the expiry of this primary path, the alternate paths have already been exhausted and most likely purged from the table. Effectively, they are not suitable, and hence, a new route discovery must take place.

IV. PERFORMANCE EVALUATION

In this section, we evaluate the performance of the proposed routing scheme against that of DSR, a traditional RRP, and ABR which more closely resembles the nature of our algorithm (being stability-driven). Figs. 7 and 8 show the simulation environment and an example of two adjacent intersections, respectively. Vehicles move along the roads until they reach intersections. Their probabilities of continuing straight, turning right, or turning left are set to 0.5, 0.25, and 0.25, respectively. At T-junctions, vehicles turn right or left at equivalent probabilities. Table I shows the simulation parameters and the range of values. The chosen parameters should resemble that of heavily dense urban areas. Max hop count is the maximum hops for a path. In the simulations, h is set to ten hops in order to encourage source-initiated routing upon link breakage due to the high unpredictability of a VANET scenario. The entry for "% of vehicles with requested data" reflects the percentage of vehicles which can provide the data requested in the RREQ packet, i.e., these nodes will produce an RREP packet.

TABLE I
SIMULATION PARAMETERS AND RANGE OF VALUES

Factor	Range of values
Simulation area	1.2 × 1.2 km^2
Distance between intersections	300 m
Inter-vehicles distance	20 m
No. of vehicles	600
Communication range	100 – 400 m
Vehicles speed	10 – 90 km/h
Simulation time	60 min
Max hop count of vehicles	10
% of vehicles with requested data	20 %

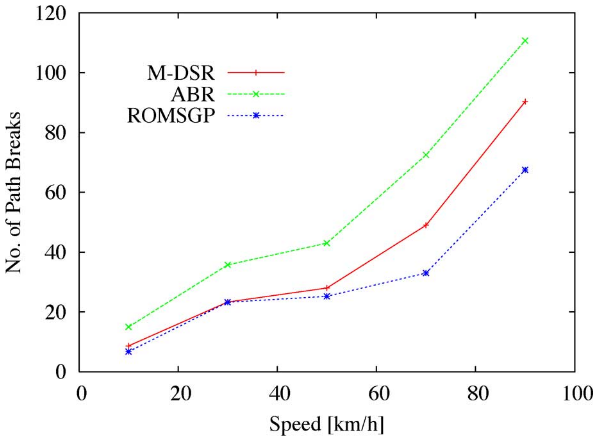

Fig. 9. Number of path breaks when varying the speed of the vehicles (communication range = 400 m).

In this simulation, vehicles are already grouped according to their velocity vectors. Dynamic routing takes place between vehicles of the same group. Figs. 9 and 10 show the stability with respect to varying speed and range, respectively. The two figures show the higher stability of ROMSGP compared to that of ABR and a modified version of DSR (M-DSR)

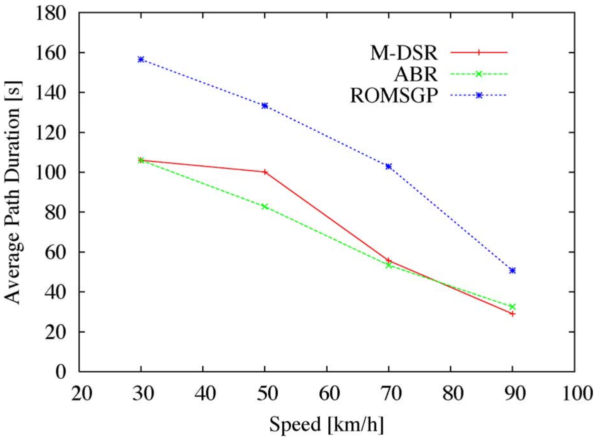

Fig. 10. Average path duration for different speed values (communication range = 400 m).

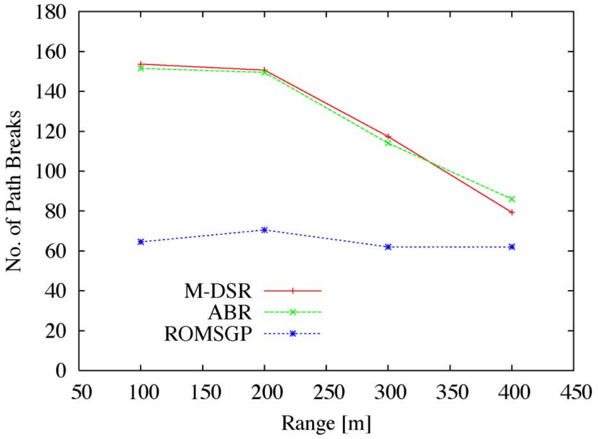

Fig. 11. Number of path breaks when varying the communication range (vehicle speed = 70 km/h).

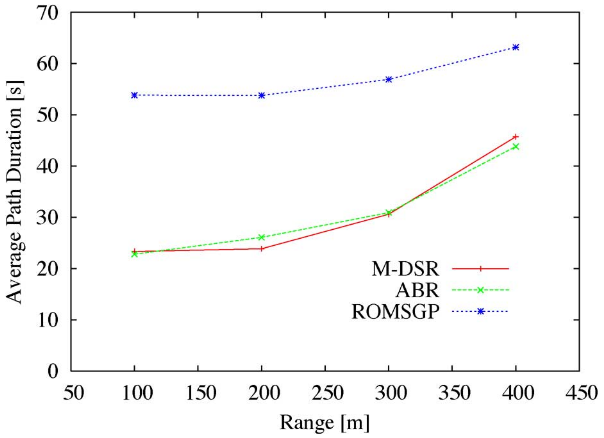

Fig. 12. Average path duration when varying the range (vehicle speed = 70 km/h).

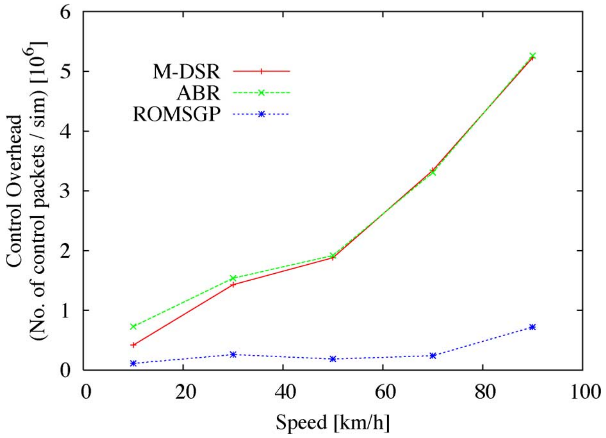

Fig. 13. Control overhead when varying the speed (communication range = 400 m).

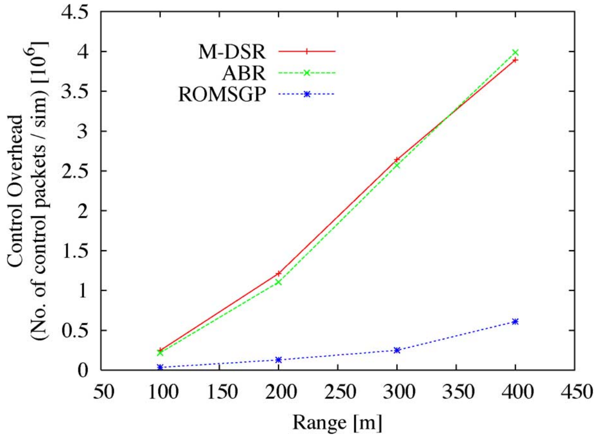

Fig. 14. Control overhead when varying the range (vehicle speed = 70 km/h).

which adapts the data retrieval concept of finding nodes that can provide the requested data and uses path distance as a cost metric to find the best path (other similar reactive protocols which do not take mobility into consideration such as AODV would yield similar results to DSR) for path selection. Furthermore, in Fig. 9, it is shown that, as the speeds of the vehicles are increased, the stability of the paths (characterized by "No. of Path Breaks") deteriorates (i.e., higher rate of path breakage occurs). Fig. 10 shows the average path duration in case of the three schemes when varying speeds. In Fig. 11, it is shown that, as the communication range between vehicles is increased, the stability of the paths increases in DSR and ABR, but this does not have a significant effect on ROMSGP. Fig. 12 shows the average path duration for different values of the communication range.

Figs. 13 and 14 show the control overhead when speed and communication range are varied. In these two figures, it can be seen that the use of ROMSGP results in fewer broadcasts and, hence, the reduction in control overhead compared to that of DSR and ABR. Fig. 13 shows that the control overhead progressively increases as the speed is increased for both DSR and ABR, whereas there is no significant increase in ROMSGP. Likewise, control overhead increases with an increasing range, as shown in Fig. 14. However, an increasing transmission range has a more significant effect on ABR and DSR than it does on ROMSGP.

Fig. 15 shows the cumulative frequency distribution (CFD) function of the path duration for the three protocols. The figure shows the higher path duration for ROMSGP compared to that of ABR and DSR with regard to high frequency of longer duration paths.

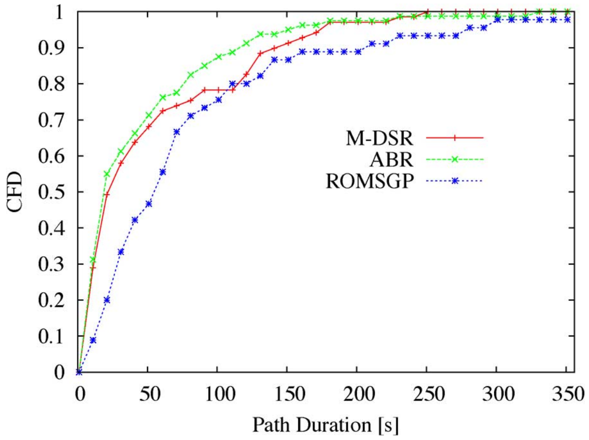

Fig. 15. CFD of the path duration (communication range = 400 m and vehicle speed = 70 km/h).

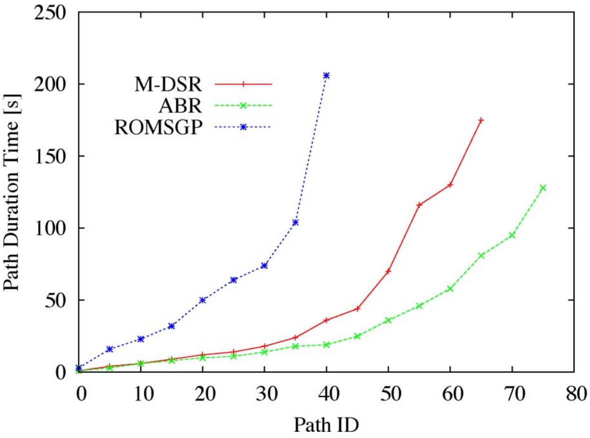

Fig. 16. Path duration times (communication range = 400 m and vehicle speed = 70 km/h).

Fig. 16 shows the path duration times when using a speed of 70 km/h. The path IDs are from the ones that are selected during the simulation by each protocol, and lifetimes of each is shown. There are fewer paths in ROMSGP as there are fewer path breaks. The paths for ROMSGP have much longer duration than those selected by DSR and ABR. Fig. 17 shows the total amount of data transmitted by a vehicle during the entire course of the simulation in case of the three protocols. The figure shows the results obtained when the data transmission rate of the vehicle is set to 1 Mb/s. ROMSGP reduces the number of path breaks and control overhead. It increases stability as the duration of the paths is longer. This good performance is also reflected in the higher throughput that is shown in Fig. 17 when varying the speed of the vehicles. As for delay, since the time required for the establishment of new paths is smaller in ROMSGP, then ROMSGP will be able to ensure also shorter delays for communications. Indeed, since identical mechanisms are performed for actual routing, the delay for path establishment would effectively be constant for all schemes. The total accumulated delay in establishing new paths is thus reflected on the number of path breaks. By considering a constant path establishment delay K, then the total delay (i.e., caused by the time expended on establishing new paths) during the simulation would be $(K \cdot n)$, where n denotes the number of path breaks.

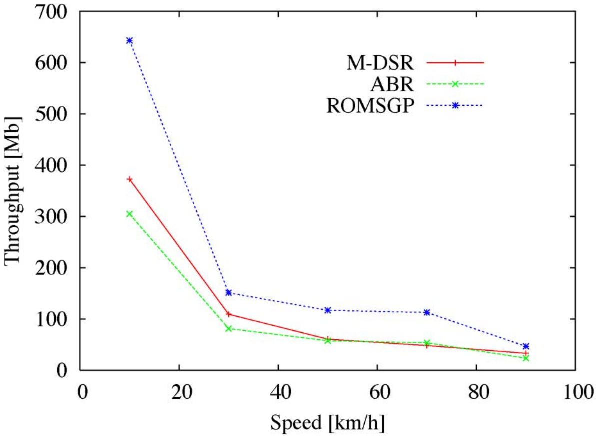

Fig. 17. Throughput when varying the speed (communication range = 400 m).

V. CONCLUSION

In this paper, we introduced a scheme which enhances the stability of IVC and RVC communications in VANET networks. The key idea behind the proposed scheme is to group vehicles according to their moving directions. Communication stability is ensured by choosing the most stable route using the ROMSGP scheme. Decision of the most stable link is made based on the computation of the LET of each path. The path with the longest LET is considered as the most stable. The performance of the scheme is evaluated through computer simulations. Simulation results show the protocol's effectiveness in terms of high stability, reduced control overhead, and high throughput compared to DSR and ABR. It is believed that the proposed protocol should be able to provide good stability and maintain high throughput in IVC and RVC scenarios.

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