Improving Proactive Routing in VANETs with the MOPR Movement Prediction Framework

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***Abstract*—Wireless vehicular communications are attracting more and more interests for applied research in industries. Most of the efforts are spent in deploying Vehicular Mobile Ad-Hoc Networks (VANETs) for applications such as active safety and Internet services. This paper addresses routing problem in VANETs for applications related to comfort and infotainment for users where an unicast routing protocol optimized for fast topology changes is needed. In previous research work, we have proposed a new movement prediction-based routing concept for VANETs called MOPR which we have already applied to the reactive routing protocol AODV in order to improve its performances by exploiting vehicules movements patterns. In this work, we first propose a new design of this concept, then we apply it to the OLSR routing protocol by optimizing the procedure of selecting the MPR (MultiPoint Relay) sets as well as that of determining the optimal path from each pair of vehicles. Basically, the connected MPR graph is composed of the most stable wireless links in the VANETs. We conduct several simulation scenarios to investigate the performance of the modified OLSR (OLSR-MOPR) by studying several metrics including the end-to-end average delay, the routing overhead, the packet delivery ratio, and the routing overhead ratio. The simulation results of the modified OLSR for various VANETs scenarios show great improvements comparing to the basic OLSR.**

Keywords: VANETs, OLSR, movement prediction, link and path stability.

I. Introduction

Vehicular Ad-hoc Networks (VANETs) are a specific case of the traditional Mobile Ad hoc Networks (MANETs), with the main difference that nodes are the vehicles themselves. This paves way for more storage and power resources on each node, so wider transmission ranges and longer communication lifetimes are possible [1]. The applications for VANETs can be roughly divided into two main categories: the ones related to active safety on the roads[1], and the applications dedicated to improve the comfort of drivers and/or passengers (imagine for example a road-side unit wanting to contact a vehicle for downloading a previously requested set of data).

An interesting functionality that can be easily integrated in vehicles is is the fact of having a continuous knowledge about their location and movement information which may be provided by a positioning system like GPS or GALILEO, or from other on-board devices. An inherent characteristic of vehicles is their non-random mobility because they have to follow the roads which may be mapped and digitally available. Furthermore, driving rules can be electronically represented. The main problems related to vehicular networks are the potential high speed of moving nodes, which causes fast and frequent network topology changes and further instability of the transmission wireless channel. Consequently, some of the challenges that researchers on working medium access and routing protocols for VANETs is to deal with available bandwidth estimation, medium access control, hidden and exposed nodes problem, high mobility, support of heterogeneous vehicles, node movement, fast speed, obstacles and fast handover. The existing MANET reactive and proactive routing protocols are not suitable (as they are) for wireless vehicular communications [2], [3].

In this paper we focus on VANETs entertainment and comfort applications. For this category of applications an unicast routing protocol is required in order to deliver relatively large data to a particular destination in real time over multi-hop paths. On the contrary, for active safety applications, information (generally small) should be provided to all surrounding vehicles in most cases, so a broadcast forwarding protocol is needed.

In [4] and [5], respectively we proposed the MOvement Prediction based Routing (MOPR) and we optimized the MOPR implementation into the context of of reactive routing (AODV [6]) in VANETs. MOPR tries to predict the future vehicles' positions in order to avoid link ruptures during vehicular communications, so that frame loss rate is reduced while improving the network efficiency.

In this work, we present a new design of the MOPR concept, which is more adapted to vehicular networks conditions. We consider that each vehicle in the network is supposed to have locally available all its neighbour's movement information (position, speed, and direction). Hence, we integrate this new concept of MOPR in the proactive routing protocol Optimized Link State Routing (OLSR) [7].

The organisation of the rest of this paper is as follows. Section II overviews the MOPR concept. Section III presents how the new MOPR concept is integrated into the proactive routing protocol OLSR. Some preliminary simulation results

[1]active because trying to inform the drivers and/or to act on the vehicle in order to avoid accidents instead of alleviating their consequences like airbags.

are provided in Section IV. Section V concludes this paper and outlines some future works.

II. The MOPR Movement Prediction-based Framework

In vehicular networks a routing route between a source and a destination vehicles is seen like a multi hop wireless communication through several intermediate vehicles. Thus, a route is composed of several communication links (pair of vehicles) connected to each other from the source to the destination. Therefore, the stability of any route in terms of communication lifetime depends directly to the stability of each communication link in that route.

The following assumptions and arguments are important to understand the rest of this paper.

1) Each vehicle has a bidirectional communication link with any other neighbour vehicle. And two vehicles are considered as neighbours, if and only if they are within a distance less than or equal to R meters from one another.
2) Each vehicle in the network moves with a constant velocity V meters/second during the calculation time, but initially randomly chosen.
3) $PS\left[i,j\right] \in [0,1]$: is the Path Stability to the path from i to j.
4) $LS\left[i,j\right] \in [0,1]$: is th Link Stability to the communication link between i and j.

Now, supposing we have a simple vehicular network as showed in Figure 1 with a source vehicle s, a destination vehicle d, and intermediate vehicles: $1, 2, \cdots, i, j, \cdots n$. So, $PS[s,d]$ depends to the stability of the intermediate links $[i,j]$, and it is represented as follow

$$\begin{aligned} PS\left[s,d\right] &= \min\left(LS\left[s,1\right], LS\left[1,2\right], ..., LS\left[i,j\right],\right. \\ &\quad \left. ..., LS\left[n-1,n\right], LS\left[n,d\right]\right) \end{aligned} \tag{1}$$

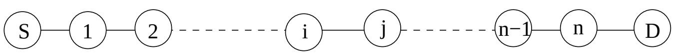

Fig. 1. An example for explaining paths stability in terms of communication lifetime

The main goal of MOPR is to increase the routing performances by increasing the routing routes stability in terms of lifetime. And that, not by increasing the link stability of each intermediate links ($LS\left[i,j\right]$) which is fixed, but by choosing the best available intermediate links (to the highest LS) for our route. Of course, in Figure 1 we have only one available routing route from s to d, but in a real vehicular network, many different routes can exist.

Supposing that the routing protocol is capable to provide several unicast routes to a destination, one of those routes can result to be more stable with respect to the others in terms of its lifetime. A stable route can, for example, increase the probability that link failures will be avoided during the whole communication. In vehicular communications, using the shortest route (in terms of number of hops) is not always the best choice. Because of the high movement of vehicles, the shortest route may become invalid during the transmission, while another route, longer, but more stable, would exist.

The objective of MOPR is to select the routing route which is the most stable by considering the movement characteristics (positions, speeds and directions) of intermediate vehicles with respect to the source and the destination vehicles. The intermediate vehicles can be other moving or stationary vehicles, or static gateways along the roads.

By knowing the movement information of vehicles involved in the routes (including source and destination), MOPR can roughly predict their positions in the near future in order to predict the lifetime of the link between each pair of vehicles in the path.

This approach should help as well in minimizing the risk of broken links and in reducing data loss and link-layer and transport retransmissions.

In the following we present the MOPR process more in detail. We suppose that we have a source node s and a destination node d. And to reach d from s we have two different paths: $path_1 = (s\cdots, i_1, j_1, \cdots d)$ and $path_2 = (s\cdots, i_2, j_2, \cdots d)$

First, MOPR estimates the path stability for both $Path_1$ and $Path_2$, respectively $PS\left[s\cdots, i_1, j_1, \cdots d\right]$ and $PS\left[s\cdots, i_2, j_2, \cdots d\right]$, and then, it selects the most stable path, i.e. the path to the biggest PS. Suppose that

$$\begin{aligned} \min\left(LS\left[s,m\right], .., LS\left[i_1,j_1\right], .., LS\left[n_1,d\right]\right) &= LS\left[i_1,j_1\right] \\ \min\left(LS\left[s,n\right], .., LS\left[i_2,j_2\right], .., LS\left[n_2,d\right]\right) &= LS\left[i_2,j_2\right] \end{aligned} \tag{2}$$

Then

$$\begin{cases} PS\left[s\cdots, i_1, j_1, \cdots d\right] = LS\left[i_1,j_1\right] \\ PS\left[s\cdots, i_2, j_2, \cdots d\right] = LS\left[i_2,j_2\right] \end{cases} \tag{3}$$

Now, let us calculate $LS\left[i_1,j_1\right]$ and $LS\left[i_2,j_2\right]$.
We have

$$\begin{cases} LS\left[i_1,j_1\right] = \frac{LifeTime[i_1,j_1]}{MaxLifeTim} \\ LS\left[i_2,j_2\right] = \frac{LifeTime[i_2,j_2]}{MaxLifeTim} \end{cases} \tag{4}$$

With $MaxLifeTime$ being a constant parameter that depends on the used routing protocol. Basically it may correspond to the validity period of time of the routing table or even it can be configured dynamically using another heuristic which out of the scope of this work.

And $LifeTime\left[i,j\right]$ is the duration time that vehicles i and j spend to go out of the communication range of each other. It means, the time needed, in seconds, to have the distance between i and j bigger than $R = 250m$.

Figure 2 shows how $LifeTime\left[i,j\right]$ is estimated. We have two neighbour vehicles i and j moving on a stationary Cartesian coordinate system with orthogonal unit vectors $\hat{x}$ and $\hat{y}$ along the X and Y axes respectively, which lets the velocity of vehicle i be $\overrightarrow{v_i} = vx_i\hat{x} + vy_i\hat{y}$ and the velocity of the vehicle j be $\overrightarrow{v_j} = vx_j\hat{x} + vy_j\hat{y}$.

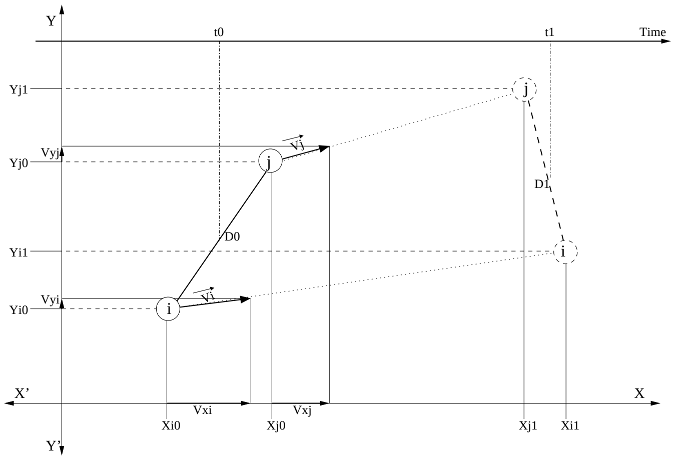

Fig. 2. Link lifetime estimation.

$LifeTime\,[i,j] = t_1 - t_0 = \Delta t$ with t_1 the time when $D_1 = R$.

$$\begin{aligned} D_1^2 &= \|X_i1 - X_j1\|^2 + \|Y_i1 - Y_j1\|^2 \\ &= \|(X_i0 + Vx_i\Delta t) - (X_j0 + Vx_j\Delta t)\|^2 \\ &+ \|(Y_i0 + Vy_i\Delta t) - (Y_j0 + Vy_j\Delta t)\|^2 \\ &= A\Delta t^2 + B\Delta t + C \end{aligned} \tag{5}$$

$D_1^2 = A\Delta t^2 + B\Delta t + C$

With:

$$\begin{cases} A = (Vx_i - Vx_j)^2 + (Vy_i - Vy_j)^2 \\ B = 2\left[(X_i0 - X_j0)(Vx_i - Vx_j) + \right. \\ \quad \left. + (X_i0 - Y_j0)(Vy_i - Vy_j)\right] \\ C = (X_i0 - X_j0)^2 + (Y_i0 - Y_j0)^2 \end{cases} \tag{6}$$

So, $LifeTime\,[i,j] = \Delta t$ when $D_1^2 = R^2$.

Then, to find $LifeTime\,[i,j]$ we have just to solve the equation $A\Delta t^2 + B\Delta t + C - R^2 = 0$

Finally, MOPR selects the path to the highest PS value, thus to the highest LS among $LS\,[i_2, j_2]$ and $LS\,[i_1, j_1]$ which are computed as explained above.

A. MOPR new concept implementation

In its basic process as described in [4], MOPR makes each vehicle communicate its movement informations to all neighbours through the routing control packets. This way makes MOPR increase the routing overhead in the network and what we want is to reduce that in order to make MOPR improve more the routing performances.

Nowadays, different research projects, like the CAR 2 CAR Communication Consortium (C2C-CC) [10], are strongly active to solve the vehicular networks' problems and to find a new communication technology or/and to adapt the existing ones. In C2C-CC, researchers are looking for standardising the vehicular communications in Europe. And it seems that one common point of view in that project, is to have some flooding protocol, like Multi-hop vehicular broadcast (MHVB)[11], working in a low layer and providing to each vehicle some useful informations about its neighbour vehicles. Position is one of these informations, and that is our main interest in this paper.

In the rest of this paper we assume our vehicular network equipped with some low layer providing periodically to each vehicle in the network the position information of all its neighbour vehicles. By having a history of the neighbour's position information during the few last seconds, it is easy to estimate their velocities. Therefore, each vehicle in the network is supposed to have locally saved and periodically updated the movement information of all nodes in its neighborhood.

III. Enhancements of proactive routing with the MOPR concept

We have chosen OLSR as the proactive routing protocol for our MOPR implementation. First of all, we give a short overview about how OLSR works and then we explain how MOPR is integrated to it.

OLSR is a proactive routing protocol for mobile ad-hoc networks. The main feature of OLSR is the building of a sub-graph connecting all nodes in the network in order to reduce the overhead of broadcast control message while reaching all nodes in the network. The route discovery is done through the exchanging of control messages called Topology Control (TC) messages, that allows each node in the network to have a global view on the whole network topology, then to build its routing table.

Mainly, OLSR works in two steps: MultiPoint Relay (MPR) nodes selection and routing routes construction. In the first step, each node in the network selects as MPRs the shortest set of one-hop neighbours that covers all its two-hop neighbours. These MPR nodes are used for flooding the network with control messages. In the second step, each node communicates through the TC messages the list of its one-hop neighbour nodes. By receiving TC messages from different nodes in the network, a global topology information can be built locally, from which a routing table is computed providing one route to each node in the network.

The enhancements of OLSR routing protocol using the MOPR concept have been conducted during its two main operation steps; mainly, the MPR selection and the route determination phases. In the following sub-sections, we explain in detail how these two phases have been improved, thanks to the movement information of vehicles.

A. MOPR-based MPRs selection

As specified in the IETF RFC 3626, in the classical OLSR, a node in a one-hop neighborhood will be first selected as MPR if it covers more neighbors in the two-hops neighborhood. This basic heuristic allows to reduce the number of nodes in the multipoint relay sets used for flooding the entire network, so that to enhance the overhead of the protocol. However, as the mobility of a node with the regard to the mobility of nodes in its MPR set is not taken into account, the latter heuristic may lead to non-stable links in the MPR graph using for the broadcasting of control messages.

In our proposal, the neighbor node having a better stability to us is first selected as MPR even if it covers less neighbors in the two-hops neighborhood than another potential MPR nodes. We have proposed two ways for the MOPR-based MPRs selection: (1) MPRs are selected based on one-hop LS information, (2) MPRs are selected based on both one-hop and two-hop LS information. In the following we explain more in detail how these two different MOPR-based MPR selection ways.

1) MOPR one-hop-based MPRs selection: Suppose we have a small vehicular network, with i one of vehicles in that network. We have:

- $NB1hop(i)$: a set of all vehicles within the one-hop neighborhood of the vehicle i.
- $r(i)$: number of vehicles in $NB1hop(i)$.
- $GLS(i,j) \rightarrow [0,1]$: global stability to the link $[i,j]$. And it is the main criteria which MOPR is based on in its MPRs selection.

In our MOPR concept, during the MPRs selection process, the vehicle i first calculates for each neighbour j the global link stability $GLS(i,j)$, with $j \in NB1hop(i)$ as follow:

$$GLS(i,j) = LS(i,j)\frac{r(j)}{\sum_k r(k)} \tag{7}$$

with $k \in NB1hop(i)$

Then, it selects as first MPR the neighbor j corresponding to the biggest $GLS(i,j)$.

2) MOPR two-hops-based MPRs selection: Suppose we have the same vehicular network as above, with i one of vehicles in that network. We have:

- $NB1hop(i)$: a set of all vehicles within the one-hop neighborhood of the vehicle i.
- $NB2hop(i)$: a set of all vehicles within the two-hop neighborhood of the vehicle i.
- $GlobLS(i,j) \rightarrow [0,1]$: global stability to the link (i,j). And it is the main criteria which MOPR is based on in its MPRs selection.

In that implementation, not only the the one-hop links' LS are taken into account, but the two-hop links' LS as well. Now, to select its MPRs, the vehicle i first calculates for each neighbour j the $GLS(i,j)$ as follows:

$$GLS(i,j) = LS(i,j)\frac{\sum_k LS(jk)}{\sum_{l,m} LS(lm)} \tag{8}$$

with

$$\begin{cases} k \in NB1hop(i) \\ l \in NB1hop(i) \\ m \in NB1hop(l) \end{cases} \tag{9}$$

Then, it selects as first MPR the neighbor j corresponding to the biggest $GLS(i,j)$.

As a result, in both MOPR-based MPRs selection ways, the transmission links to the selected MPRs should be more stable and guarantee a long connection lifetime, even with the two-hop neighbours.

B. MOPR-based routing route construction

The objective of this phase is to select the most stable route in terms of transmission lifetime.

In the basic OLSR process, a TC message sent by the vehicle i in the network, contains a list of all one-hop neighbours' IDs. In MOPR, we propose that each vehicle in the network adds to each entry (neighbour's ID) in the TC message the corresponding GLS, which is calculated as showed in the above subsections III-A1 and III-A2, then sends the message. When receiving TC messages, a vehicle is able to build a global network topology information, with a GLS information corresponding to each topology link (entry). Having this information, a routing table is computed with selecting the most stable routes in terms of communication lifetime based on the topology links' GLS information.

In Figure 3 a simple example is showing how MOPR-based routing route selection is done. We have 10 vehicles (0 to 9). Suppose that all vehicles in two-hop distance regarding to vehicle 0 have already a route to reach 0. Now, the vehicle 8 for example, has three choices to reach the vehicle 0: through 4, through 5, or through 6. MOPR will select for 8 the most stable route to reach 0 among these three different possibilities. As you can see, vehicles 4, 5, and 6, have different routes to reach 0 with respectively the different path stabilities: $PS\,[4,0] = 0.9$, $PS\,[5,0] = 0.7$, and $PS\,[6,0] = 0.6$. Vehicles 8 has different GLSs regarding to its neighbours 4, 5, and 6, respectively $GLS\,[8,4] = 1$, $GLS\,[8,5] = 0.9$, and $GLS\,[8,6] = 1$. Therefor, the best route that MOPR selects for 8 to reach 0 is the route trough 4 with the biggest path stability: $PS\,[8,0] = 0.9$.

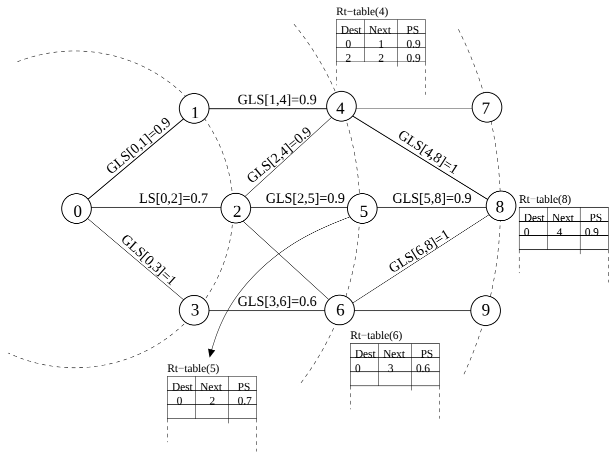

Fig. 3. MOPR-based routing routes selection example.

As a result, MOPR-based route construction guarantees a more stable routing tables in terms of lifetime.

IV. Performance evaluation and scenario description

A. Simulation environment and scenario description

To evaluate the performance of our MOPR proposal, we have implemented under the NS2.28 network simulator [9] the MOPR-based OLSR (named MOPR-OLSR). The MOPR-OLSR has been implemented on the OLSR implementation of the University of Murcia (UM-OLSR). In MOPR-OLSR, we have coupled both MOPR two-hop-based MPRs selection and MOPR-based routing route selection.

We have 5000 meters length highway like scenario, with 200 vehicles moving on it. As shown in Figure 4, in each direction we have three lanes with different speed ranges, respectively: (lane1: 50-80Kmh, lane2: 70-100Kmh, lane3: 100-130Kmh). In each direction we have a density of 5 vehicles every 150 m.

We used the classical 802.11 Medium Access Control (MAC) functionalities, i.e. Distributed Coordination Function (DCF), Carrier Sense Multiple Access with acknowledgments (CSMA/CA with ACK) and Request-To-Send Clear-To-Send (RTS/CTS), and fragmentation, even if we suppose the messages are enough small. Traffic type was CBR, and the two transmitting source and destination couple were selected randomly along the lane with the speed range (70-100kmh).

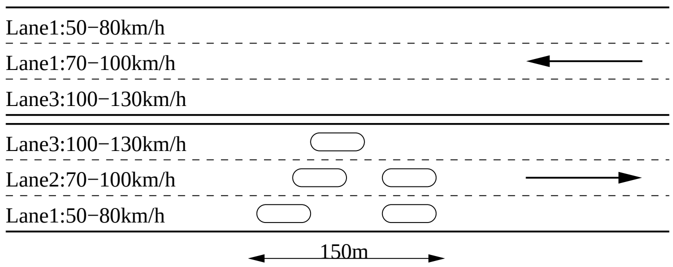

Fig. 4. the highway scenario used for our ns2 simulations.

B. Results and analysis

Some preliminary simulation results are presented in this section. The metrics we have studied are the follows:

- **packet delivery ratio:** defined as the number of correctly received packets at the destination vehicle over the number of packets sent by the source vehicle.
- **delay:** defined as the average time in seconds, that a data packet take to travel from the source till the destination vehicle.
- **routing overhead:** defined as the number of bytes injected in the network by the routing protocol.
- **routing overhead ratio:** defined as the routing overhead caused by the routing protocol over the size of correctly received packets at the destination vehicle.

All graphs shown in this section show our simulation results as a function of the maximum CBR packet size.

The MOPR-OLSR performances are compared to those of OLSR. In Figure 5, we see that MOPR-OLSR improves OLSR in terms of packet delivery ratio till the maximum CBR packet size reaches 1536 bytes, and that with keeping almost the same delay as shown in Figure 6. After that 1536 bytes of maximum CBR packet size, it seems that MOPR-OLSR suffers little bit vs OLSR in terms of delay, while guaranteeing almost the same packet delivery ratio.

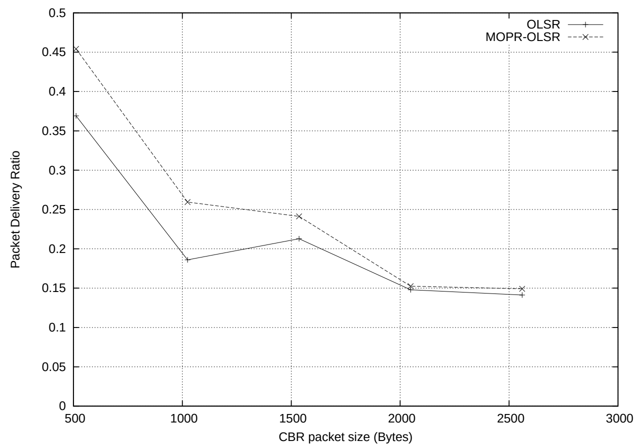

Fig. 5. MOPR-OLSR vs OLSR in terms of packet delivery ratio.

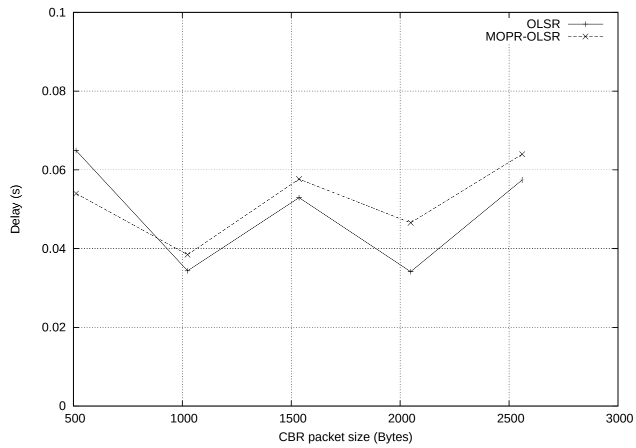

Fig. 6. MOPR-OLSR vs OLSR in terms of delay.

In Figure 7 we see that MOPR-OLSR increases a little bit the routing overhead compared to OLSR, which is logical since the the size of the TC messages is larger within MOPR-OLSR. But that is not bad since the routing overhead ratio, as shown in Figure8, is almost the same for both MOPR-OLSR and OLSR.

V. Conclusions and future works

Because of the fast moving characteristics of vehicles and the difficulty to predict the traffic variations, it is very hard to efficiently cope with these problems while deploying methods for data routing in vehicular networks.

In some previous works, we presented MOPR which is an algorithm that, based on node movement informations, can

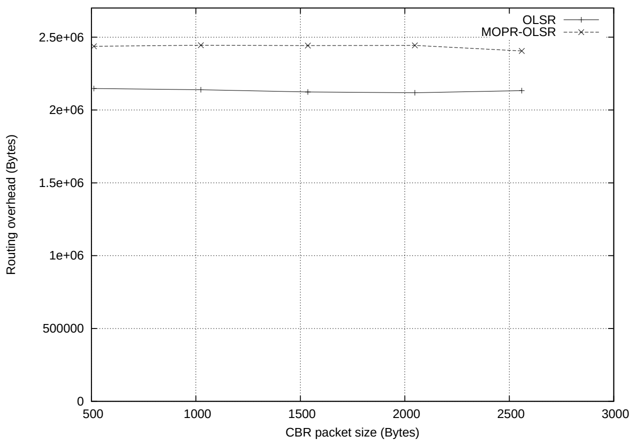

Fig. 7. MOPR-OLSR vs OLSR in terms of routing overhead.

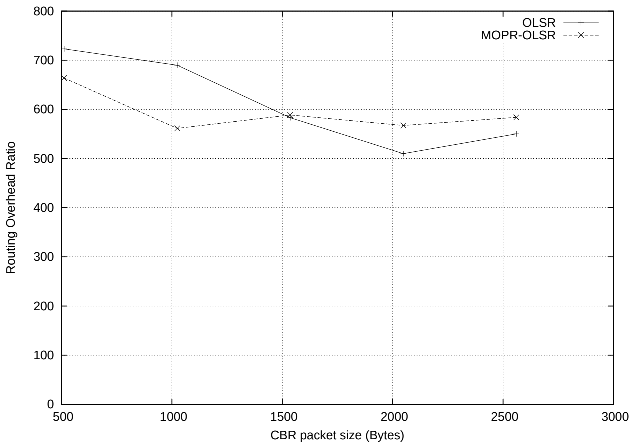

Fig. 8. MOPR-OLSR vs OLSR in terms of routing overhead ratio.

improve the routing process in MANETs, and specially in case of high node speed like in VANETs. After having shown the performance of MOPR over reactive routing protocols in the previous works, in this paper we presented a new implementation concept of MOPR, specially designed for vehicular networks, which we implemented on top-of the proactive routing protocol OLSR .

We presented some promising ns2 simulation results, that show that MOPR improves the routing performances, mainly in terms of packet delivery ratio.

As a future work, we would like to see the reaction of MOPR on some geo-routing protocols by applying MOPR on Greedy Perimeter Stateless Routing (GPSR) [12] for example, and then make some comparisons between MOPR-based proactive/reactive unicast routing, the MOPR-based geo-routing implementation, and another movement-based geo-routing protocol (MORA) [13] which has been proposed as a modified version of GPSR.

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