MORA: a Movement-Based Routing Algorithm for Vehicle Ad Hoc Networks

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***Abstract*— Recent interest in car-to-car communications and networking has lead to the definition of the concept of "Vehicle Ad-hoc NETwork" (VANET) as an infrastructure-free ad-hoc networking solution in the automotive scenario. The requirement for providing reliable and efficient routing schemes in presence of relative movement motivates the proposal of MORA, a movement-based routing algorithm for VANETs. The algorithm is completely distributed, since nodes need to communicate only with direct neighbors within their transmission range, and it exploits a specific metric, which exploits not only the position, but also the direction of movement of vehicles. Extensive simulations evaluating the proposed protocol and results of comparison with state-of-the-art methods demonstrate that MORA provides a promising and robust basis for designing a routing strategy suitable for the automotive scenario.**

***Index Terms*—Vehicle Networking, Routing, Movement-Based Routing, Ad-Hoc Networks.**

I. INTRODUCTION

Ongoing research in the field of ICT for automotive applications is driving the integration of electronic and communication devices providing several added-value services, such as positioning and navigation, automatic toll payments, monitoring of the status of the vehicle, etc. A growing interest within this scenario lies in the possibility of enabling vehicles to access the Internet or other network commodities, or more in general communicating and collaborating. This feature is envisaged to be implemented into two ways: (i) by the deployment of proper communication infrastructure along the roads to act as gateways to the Internet, or (ii) by the implementation of the so-called "Vehicle Ad-hoc NETwork" (VANET). In the last scenario, routing support should be provided by each vehicle belonging to the VANET without the need for specific communication infrastructure. Currently, the Car-2-Car Communication Consortium [1] identified guidelines for providing vehicle-to-vehicle communications as well as a reference protocol architecture, but did not define channel and traffic models, channel usage, and routing algorithms yet. This leaves the floor to further study and proposals, especially in the context of routing.

Indeed, the basic concept of VANETs derives from the well-known model of the mobile ad-hoc networks (MANETs), infrastructure-less networks where wireless hosts communicate with each other in the absence of a fixed infrastructure. Multihop data communication in VANETs is usually provided via location-based ad hoc routing protocols [2], a class of multihop routing for ad hoc networks.

Traditionally, multi-hop routing for MANETs can be classified into proactive and reactive algorithms: in proactive routing algorithms, each node in the mobile ad hoc network maintains a routing table that contains the paths to all possible destinations. If the network topology locally changes, all routing tables throughout the network have to be updated. If the nodes in the network are reasonably mobile, the overhead of control messages to update the routing tables becomes prohibitive. Reactive routing algorithms, on the other hand, find routes only on demand. Routes are designed when they are needed, in order to minimize the communication overhead. A detailed review of routing algorithms in mobile ad hoc networks can be found in [3]-[4], which were lately integrated by many contributions (see for instance [5]-[6]).

In this framework, an interesting approach is represented by position-based routing algorithms, which require information about the physical position of the participating nodes and it is exactly the class of algorithms envisaged to be implemented in VANETs, due to the continuous localization process performed by GPS devices equipped on vehicles. In such schemes (like Distance Routing Effect Algorithm for Mobility (DREAM) [7] and Location Aided Routing (LAR) [8]), the forwarding decision is primarily based on the position of the packet destination and the position of the node's immediate one-hop neighbors. A detailed survey of protocols that do use geographic location in the routing decision is presented in [9]-[12].

One of the most promising routing approaches for VANETs is location based greedy forwarding routing, the example of which is presented in [13]. In Greedy Perimeter Stateless Routing (GPSR) protocol all packets transmitted onto the network are marked by the originator with their destination's locations. As the result, a forwarding node can make a locally optimal routing decision. Specifically, the node assumed to know the exact positions of its neighbors forwards the packet to the neighbor closest to the destination. As the result, the main advantage of greedy forwarding is in its reliance on knowledge of the immediate neighbors of the forwarding node. When a packet reaches the region when greedy

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This work is partially supported by EU in the framework of the SAFESPOT Integrated Project.

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forwarding is not possible due to specifics of the topology, GPSR recovers traversing the topology graph around the perimeter of this region.

However, if only position information is used, it may be possible to lose some good candidates to forward the packet. Moreover, the knowledge of node's position could not be sufficient in a network with frequent topological changes, such as a VANET. In such a situation it is important to guarantee high stability of the links and therefore robustness of the routing protocol.

To provide a solution to the above-mentioned problems, we propose an alternative movement-based routing algorithm (MORA), which exploits not only the position, but also the direction of motion of mobile nodes[1]. Awareness of a node's movement direction implemented in MORA routing represents an attempt to find a solution to this critical problem and to match the requirements of inter-vehicle communication. Current state of the art already includes some proposals for routing in VANETs (see for instance [15]-[17]). However the problem remains under a hot discussion rising a number of open issues needed to be solved.

The structure of the paper is the following: Section II describes the method, while extensive simulations are reported in Section III. Finally, Section IV concludes the paper.

II. THE PROPOSED ALGORITHM

A. *Preliminaries*

In a position-based routing algorithm, each node makes a decision to which neighbor to forward the message based only on the location of itself, its neighboring nodes, and the intended destination. Therefore, the system can be decentralized, more robust and easier to set up and operate. In our approach, considering the specific automotive scenario, this decision is taken considering also which direction neighbors are moving in.

Since VANETs are subject to frequent topology changes, the life time of connections between hosts varies appreciably. Our goal is to exploit information about moving directions of the forwarding nodes in order to route the data over a path resulting from locally optimal routing decision. In literature, there are a lot of different strategies a node can employ to properly select a neighbor for forwarding a given packet [9]. However, none of them takes into consideration that nodes in ad hoc network are moving in directions that can introduce unpredictable changes in the network topology, thus affecting already established routes and network connectivity in general. In the definition of the routing algorithm, we assume that each vehicle is moving along a "regular" route, i.e. its movement pattern remains constant during packet transmission. Moreover, we neglect the impact of errors in the techniques used for position estimation of the vehicles leaving it as an open issue for future investigation.

The metric used in MORA (Movement-Based Routing Algorithm) is a linear combination of the number of hops and a target functional, which can be independently calculated by each node, as described in the following paragraphs.

The functional *F*. The core idea of the approach is to develop a functional which depends on the distance of forwarding car from the line connecting the source and the destination, *sd*, and on the node's movement direction. This functional is required to be implemented in a distributed way allowing any vehicle to calculate it.

The target functional should reach its absolute maxima in the case the node is moving on *sd* and it should decrease as the distance from *sd* increases. Moreover, the more a node moves towards *sd*, the higher should be its value, i.e. for a fixed distance from *sd* the functional should have a maximum if the node is moving perpendicularly to *sd*.

Let d_0 be a reference distance metric, chosen on the basis of the application context. Let $x = d/d_0$ be the adimensional distance of the current node from *sd* and $y = l/d_0$ the adimensional distance from the destination of the intersection point between *sd* and its perpendicular starting from the node's current position (see Fig. 1). The functional F is a function of $x \in [0, \infty]$ and $\alpha \in [-\pi, \pi]$, where α represents an angle between the line of the movement direction and the perpendicular line to *sd* (see Fig. 1).

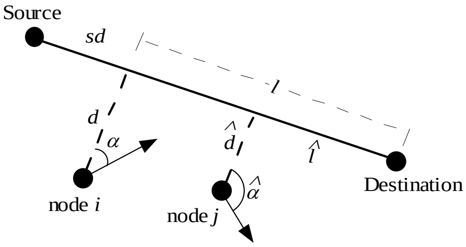

Fig. 1. Graphical representation of parameters used by MORA.

In order to ensure the targeted properties, we choose the functional F as follows:

$$F_{\delta,\gamma}(x,\alpha) = \sin\frac{|\alpha|}{3} e^{-|x|} + \cos\frac{\alpha}{3} e^{-\frac{(x-\delta)^2}{\gamma}} \qquad (1)$$

where δ and γ are two parameters set on the basis of the application, which simply vary the curvature of *F*, adjusting the weight associated with node's movement direction, δ defines the value of x corresponding to the relative maximum along the x axis and γ leads to a smoother or steeper behavior down to zero.

Such a definition of *F* assures more weight to nodes moving on *sd*, and also to nodes moving towards *sd* (see Fig. 2) as required above. In fact

- for $x = 0$ there are 2 absolute maximums, for $\alpha = \pm\pi/2$ respectively;

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[1] The basic concept of this work, in the framework of a generic MANET, was presented in [14].

- for $0 < x < \varepsilon$ (ε arbitrarily small) the trend is the same as above;
- for $x \to \infty$ the function decreases;
- for $x = \delta$ there is a relative maximum corresponding to $\alpha = 0$;
- for $x \in [\delta - a_{\delta,\gamma}, \delta + b_{\delta,\gamma}]$ ($a_{\delta,\gamma}$ and $b_{\delta,\gamma}$ constants defined with the choice of δ and γ) there is a maximum corresponding to $\alpha = 0$.

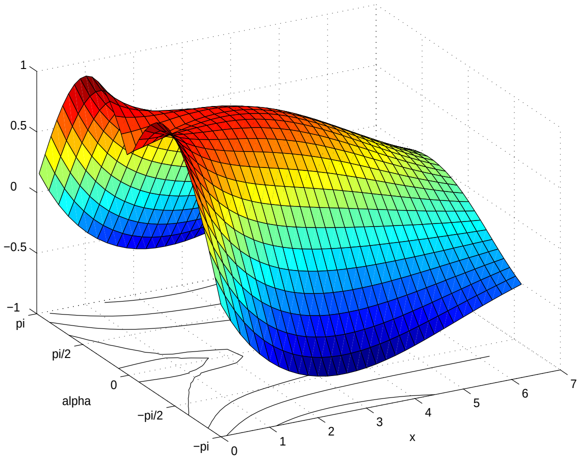

Fig. 2. Plot of the functional *F*.

The functional *F* can be sampled and put into a look up table. In this way, each node does not need to calculate *F* at any iteration, but it can easily obtain the value corresponding to a given combination of *x* and α with a simple and fast table lookup.

The metric m. Another degree of freedom of the metric employed in MORA is the weight assigned to each node, which can be used to represent traffic conditions, application constraints, etc. The goal of the weighting function is to obtain a fair distribution of the available resources through the overall network.

For the purpose of the paper, the function *W*, defined for $y \in [0, y_s]$ where y_s is the *y*-component of the source node, is given by:

$$W(x,y) = \begin{cases} 1 & 0 \le w(x,y) < 0.1 \\ -\log_{10} w(x,y) & 0.1 \le w(x,y) \le 10 \end{cases} \quad (2)$$

where $w(x,y) \in [0,10]$ is the weight of node *i* with coordinates *x*, *y*.

Now the following metric can be defined, for $y \in [0, y_s]$:

$$m_{\delta,\gamma}(x,y,\alpha) = \frac{1}{2}(W(x,y) + F_{\delta,\lambda}(x,\alpha)) \quad (3)$$

where both $W(x,y)$ and $F_{\delta,\gamma}(x,\alpha) \in [-1,1]$, and therefore $m_{\delta,\gamma}(x,y,\alpha) \in [-1,1]$. Due to the fact that *x* and *y* are the coordinates of node *i*, and α depends on the node *i*, in following sections we refer to $m_{\delta,\gamma}(x,y,\alpha)$ and m_i without distinction. The reader should note that, by choosing such metric, the higher the value of m_i the higher the probability node *i* is included into the active route from source to destination.

The presented way of node weighting provides a possibility to include other than location and movement parameters into MORA routing. The weight $w(x,y)$ associated with the node can be calculated based on such parameters like a level of node's congestion, an outgoing date rate, available power resources, etc. For example, in case node *i* is congested and therefore $w(x,y) \to 10$, then $W(x,y) \to -1$.

B. *The MORA routing protocol*

In position-based routing algorithms, usually short probe messages are sent into the network in order to determine the position of the destination node, which is used for route establishment. In more details, the sender floods a route establishment request into the network or its part. The destination replies to the sender with a route reply packet including such information like its location. After a route reply has reached the sender, the data payload can be transmitted using position-based routing algorithms.

MORA routing uses flooding for destination discovery like most of existing routing protocols. The sender includes its location information into the route request flooded into the network. Upon the reception of a route request from the sender, the destination node generates a route reply message which is routed using metric *m* defined in Eq.(3).

On every hop, the current node receiving it polls for information its neighboring nodes, considering only those with the higher values of *y* in order to avoid loops (*y* is related to the distance from the destination as in Section II, *A*). The coordinates of the source node, coordinates of the destination node, position of the node last forwarded the packet, as well as its moving direction, are included into every MORA protocol message. As a result, each node is able to obtain metric *m* for itself as well for its immediate neighbors. The values for *d* and α used in functional *F* calculation presented in Eq.(3) are obtained as follows:

$$d = \frac{y_i - m_{sd}x_i - q_{sd}}{\pm\sqrt{(1+m_{sd})^2}}, \ \alpha = \cos^{-1}\left(\frac{d}{dist}\right) \quad (4)$$

where m_{sd} and q_{sd} are calculated using coordinates of the source and destination nodes (x_s, y_s) and (x_d, y_d), respectively:

$$m_{sd} = \frac{y_d - y_s}{x_d - x_s}, \quad (5)$$

$$q_{sd} = y_s - \frac{y_d - y_s}{x_d - x_s}x_s \quad (6)$$

where *dist* is the distance of the node from *sd* along the direction of movement.

The probe message is then forwarded to the neighbor with the highest value of *m* (see Section II.*A*), attaching path information.

Since all vehicles will probably use GPS technology in the near future, we try to exploit the availability of up-to-dated information about positions and moving directions of the source node, destination node as well as nodes located along the *sd* line and their immediate neighbors. The frequency of the updates is dependant on the particular implementation of the routing protocol. In this paper we consider two possible implementations of MORA routing:

-Standalone. This implementation, referred to as “MORA”, separates the framework of the proposed routing protocol into a standalone routing layer. As a result, location and movement information is carried by only routing protocol messages (such as Route Request and Route Reply). The main drawback of the standalone implementation is that position information is not updated during data packet exchange.

-Link layer integrated. In order to overcome the update limitations of the standalone approach, integration of MORA protocol with the MAC protocol at the link layer is considered as a modification referred to as “MORA+”. In addition to the features of the standalone implementation, MORA+ includes the location and movement information into the ordinary MAC protocol headers, which carry signaling or data payload. This technique enables a dynamic update of such information along the entire data path for every transmitted packet, thus avoiding waste of available communication resources.

III. PERFORMANCE EVALUATION

Performance evaluation of the proposed routing protocol was performed by simulations using GloMoSim 2.0 [18] network simulator. GloMoSim is a scalable simulation environment for wireless mobile networks based on the Parsec parallel discrete-event simulation library. GloMoSim is chosen out of the set of available network simulators to the fact of the availability of physical layer models fairly approximating real-world behavior as well as for extensive support of mobility in ad hoc networks (in terms of movement patterns and routing algorithms).

IEEE 802.11 physical layer standard is chosen for the set of conducted experiments. An additional software module enabling MORA functionality was inserted into a standard Glomosim package. In order to achieve integration between routing plane and link layer protocol required by MORA+, the corresponding modifications were performed for the MAC protocol. The propagation of route request is implemented using flooding model. However, after coordinates of a destination are discovered, the route reply message as well as data payload packets are routed using MORA techniques. In case a node can not find the route to destination (which is probably caused by wrong/changed coordinates of the destination), it sends a route error message to source.

A. General simulation scenario

Simulations are performed for five routing protocols: AODV, DSR, LAR, MORA, and MORA+. The results are obtained for variable number of nodes, their moving speed as well as transmission range. The nodes are uniformly placed onto a two-dimensional terrain of 1000 x 1000 square meters. The number of network nodes is chosen to be 30 in order to achieve a satisfactory connectivity.

Simulations use transmission range values equal to 200, 300, 400, and 500 meters. As a result, data communication between any pair of nodes can occupy from 1 to 7 hops. The sender and the destination nodes are chosen randomly.

Standard FTP client operating over TCP protocol was chosen as a traffic source application. For evaluation of routing overhead, the FTP client was configured to produce bulks of 10 packets in large (0.5 second) intervals of time. After each bulk transmission, the routing table as well as the table with neighbor nodes is cleared for all the nodes. This requires initiation of route discovery for every generated bulk of packets. In other scenarios, FTP application performs uninterrupted data transfer for up to the end of simulation which lasts for 1000 seconds.

The random waypoint mobility model (with pause time equal to zero) is used: each node performs several moves during the simulation time without remaining static between moves. The nodes move with an average speed of 15 and 25 meters-per-second or 54 and 90 km/h. Our simulation results are averaged over 20 runs with different seeds of the random generator. The results where the communication between randomly chosen sender and receiver nodes was not possible due to disconnected topology (which happened rarely) are excluded.

B. Routing Overhead

In this section, MORA routing overhead is compared against other available routing techniques. The overhead is defined as the number of routing packets (requests, replies, route failures) sent over the entire network within a single burst transmission. Forwarding of routing control packet is considered as a separate transmission.

Figure 3 underlines that MORA implementation behaves similar to flooding routing algorithms (for average speeds of 15 and 25 meters, respectively). This is motivated by the fact that destination discovery is performed using route request flooding into the network. A slight enhancement over the flooding curve comes from the difference in the route reply propagation, which is routed using node movement information. Routing overhead becomes considerably lower when LAR is used limiting the region of the network the route request is flooded.

However, we recall the fact that the MORA protocol does not limit the technique used for destination discovery to flooding. Indeed, MORA operation starts from the point when the position of the source node and the destination nodes are available, which happens when the route request message reaches the destination node. It allows an implementation of any existing route request propagation scheme, thus leading to the corresponding advantages.

C. Performance vs Range

The throughput performance versus transmission range for different mobility levels is illustrated in Fig. 4. FTP source always achieves lowest throughput in case DSR routing is used. DSR fixes the routes for route reply propagation as well as for subsequent data communication on the end-to-end basis. As a result, any changes in connectivity between any neighboring nodes create a route failure, which can only be resolved by generation of a new route discovery initiated at the source node.

AODV protocol demonstrates better throughput performance if compared with DSR. A per-hop based routing appears to be more stable than the one fixed on the end-to-end routes. The routes determined by MORA protocol are more stable in presence of mobility. However, the fact that coordinates of destination are determined only during the route request phase limits the performance of MORA in case the destination moves relatively far from its initial position (determined during the route discovery).

This problem is solved in MORA+ version of the protocol, which is an example of close integration between routing plane and the MAC protocol layer. The location of the destination as well as intermediate nodes is dynamically updated with every data or control packet transmission. As a result, MORA+ is almost insensitive to mobility in the presence of continuous data exchange along the route.

The difference in performance of evaluated protocols is better shown for low values of transmission range, while for high transmission ranges communication between nodes can be achieved through a lower number of hops, thus limiting performance to similar throughput values.

Figure 5 presents the performance of evaluated routing protocol versus node’s mobility. DSR appears to be the most sensitive to mobility. The performance of MORA+ is consistently stable for low as well as for high nodes’ moving speeds.

D. *Highway Scenario*

The results presented above show good performance of the proposed protocol in a generic ad-hoc network scenario. However, in order to ensure its performance gain in VANETs, we performed evaluation in a highway simulation scenario presented in Fig. 6. It consists of three cars R1, R2 and R3 moving on the right lane and *n* cars on the left lane moving in the opposite direction. The parameter *n* is chosen to be large enough to ensure there is always a left-lane car within the transmission range of R1, R2, and R3. The distance between every pair of cars driving the same lane is chosen to be 50 meters, while the transmission range is fixed to 70 meters. All the simulated cars are moving with a predefined speed ranging from 0 to 20 m/s (72 km/h). The duration of each experiment is limited by 1 min during which the cars driving at 72 km/h cover the distance of 1.2 km.

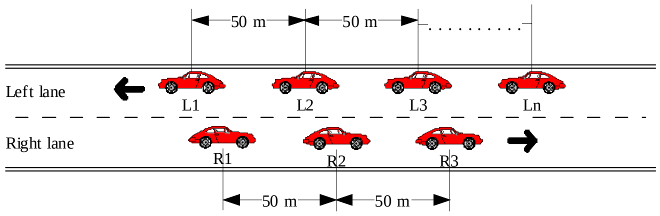

Fig. 6. Simulated highway scenario.

In the first set of experiments, the R1 car running an FTP source communicates with the R3 car. This implies a two-hop communication performed between cars moving in the same direction. The obtained performance results (Fig. 7) show that all evaluated protocols achieve similar level of the throughput. This is mainly an outcome of a high stability of the route R1 – R2 – R3 where the communication is performed.

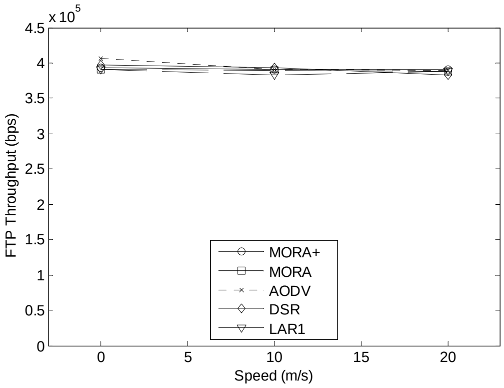

Fig. 7. FTP transfer between cars moving in the same direction.

Indeed, even in case a left-lane node will be included into the route during discovery the communication will break shortly as soon as the left-lane node will move out of the transmission range. Then, eventually the route will be established through the R2 node and will be maintained till the end of the experiment.

In order to evaluate the performance of MORA in the presence of non-stable routes we specified the scenario where the communication is performed between cars moving in opposite directions. In this way, the R2 car runs an FTP source producing the data destined to the L1 car. Initially R1 and L1 are located with a two-hop distance. As soon as the cars move away of each other the route breaks requiring rediscovery. Consequently, the achieved throughput highly depends of the speed the cars move away of each other. The results presented in Fig. 8 show that AODV, DSR, LAR1 and MORA achieve similar throughput. MORA+ protocol demonstrates slight improvement due to a better update of routing metrics.

The reason for dramatic throughput degradation with the car speed increase lies in frequent route failures due to not stable network topology. In case the route failure is detected all the above mentioned protocols perform route discovery flooding the network with route requests. As it is evidenced for the trace files, most of the frames transmitted over the network are RREQ and RREP.

In order to increase the performance of the routing protocol in highway scenario we performed a minor modification of MORA+ protocol which performs route discovery only once in order to determine the coordinates and movement speed of the destination node. Then, in case of a route breakage, instead of flooding the network with route requests, it forwards the packet to the node located closer to the destination assuming the coordinates of the destination did not change greatly from the last packet delivery. The route discovery is being triggered only in case the destination node moved out from its previous location such that a forwarding node located within the transmission range of the destination coordinates can not successfully deliver a packet. As a result, this modification, referred as MORA+ no RTS in Fig. 8, demonstrates a considerable throughput enhancement over other evaluated protocols.

Based on the obtained experimental results we conclude that in such an unstable by network topology but deterministic by movement patterns scenario as cars of a highway traditional routing protocols designed for generic ad-hoc networks do not perform well. However, their performance can be considerably improved fighting the roots of the problem like the reduction of network flooding based on the prediction of the car location.

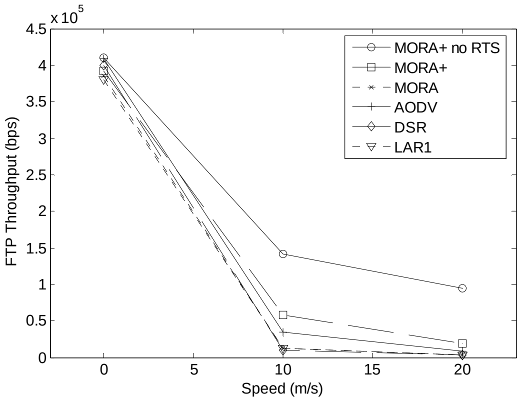

Fig. 8. FTP transfer between cars moving in the opposite directions.

IV. CONCLUSIONS

In this paper, a motion-based routing algorithm for vehicle ad hoc networks, MORA, is proposed. The algorithm is completely distributed, since nodes need to communicate with only direct neighbors located within their transmission range. Main feature of MORA is the use of a routing metric which enables to exploit not only positioning information but also the direction the vehicles move: MORA explicitly considers dynamic changes in the network in addition to available topological information.

Extensive evaluation outlines the advantages of MORA, especially in case of high mobility of vehicles and frequent topology changes. In particular, a link layer integrated implementation of the protocol achieves good performances in highway scenario with non-stable routes.

For future work we consider an application of movement based routing metrics introduced in this paper to the set of greedy routing protocols like GPSR [13]. We believe these protocols are probably the most promising from the performance benefits point of view in dynamic and highly unstable VANET topologies. Along with movement awareness we consider developing techniques which will exploit the peculiar properties of different VANET scenarios (like the highway or the city grid).

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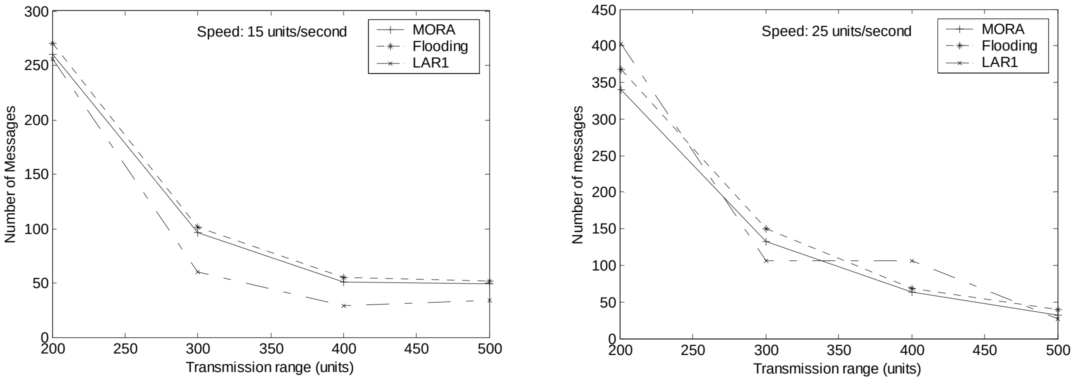

Fig. 3. Comparison among MORA, flooding and LAR in terms of routing overhead (nº. of messages) against transmission range, for different values of the node speed.

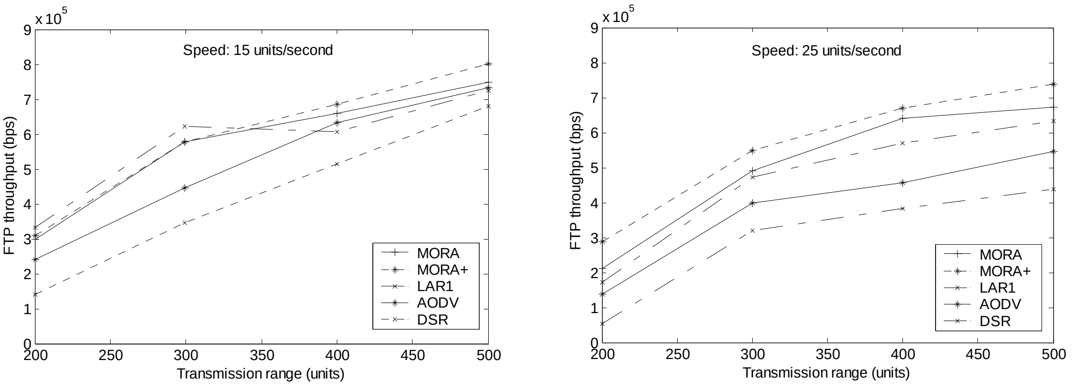

Fig. 4. MORA throughput comparison for different values of transmission range.

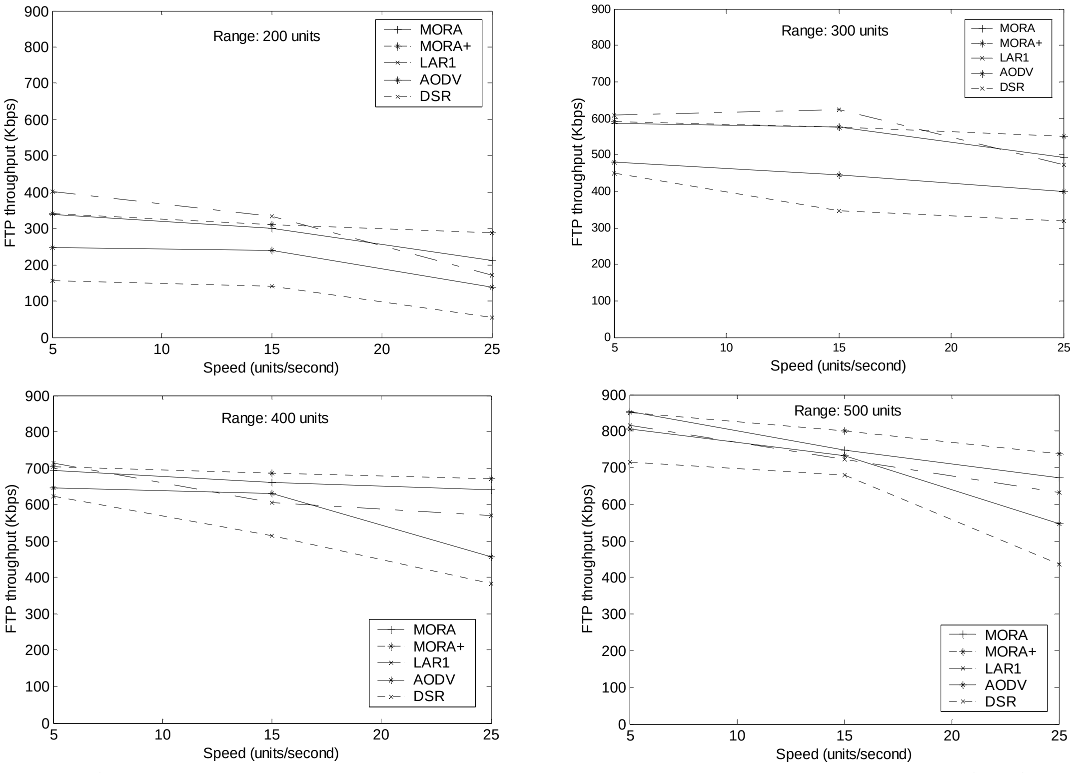

Fig. 5. Performance comparison between MORA, MORA+ and competing schemes in terms of performance against mobility, for different transmission ranges.