Performance Comparison of AODV and OLSR in VANETs Urban Environments under Realistic Mobility Patterns

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***Abstract*— A Vehicular Ad Hoc Network (VANET) is an instance of MANETs that establishes wireless connections between cars. In VANETs, routing protocols and other techniques must be adapted to vehicular-specific capabilities and requirements. As many previous works have shown, routing performance is greatly dependent to the availability and stability of wireless links, which makes it a crucial parameter that should not be neglected in order to obtain accurate performance measurements in VANETs. Although routing protocols have already been analyzed and compared in the past, simulations and comparisons have almost always been done considering random motions. But could we assess that those results hold if performed using realistic urban vehicular motion patterns ?**

In this paper, we evaluate AODV and OLSR performance in realistic urban scenarios. We study those protocols under varying metrics such as node mobility and vehicle density, and with varying traffic rates. We show that clustering effects created by cars aggregating at intersections have remarkable impacts on evaluation and performance metrics. Our objective is to provide a qualitative assessment of the applicability of the protocols in different vehicular scenarios.

***Index Terms*— Urban Environment, Realistic Vehicular Mobility Models, OLSR, AODV, Performance.**

I. Introduction

Vehicular Ad-hoc Networks (VANETs) represent a rapidly emerging, particularly challenging class of Mobile Ad Hoc Networks (MANETs). VANETs are distributed, self-organizing communication networks built up by moving vehicles, and are thus characterized by a very high node mobility and limited degrees of freedom in the mobility patterns. Hence, ad hoc routing protocols must adapt continuously to these unreliable conditions, whence the growing effort in the development of communication protocols which are specific to vehicular networks.

One of the critical aspects when evaluating routing protocols for VANETs is the employment of mobility models that reflect as closely as possible the real behavior of vehicular traffic. This notwithstanding, using simple random-pattern, graph-constrained mobility models is a common practice among researchers working on VANETs. There is no need to say that such models cannot describe vehicular mobility in a realistic way, since they ignore the peculiar aspects of vehicular traffic, such as cars acceleration and deceleration in presence of nearby vehicles, queuing at roads intersections, traffic bursts caused by traffic lights, and traffic congestion or traffic jams. All these situations greatly affect the network performance, since they act on network connectivity, and this makes vehicular specific performance evaluations fundamental when studying routing protocols for VANETs. Initial works [1], [2] on performance evaluation considered simple pseudo-random motion patterns and lacked any interaction between cars, generally referred as *micro-mobility*. Following the recent interest in realistic mobility models for VANETs, new studies appeared on performance evaluations of VANETs in urban traffic or highway traffic conditions [3], [4]. However, their models were quite limited, notably the macro-model, which also limited the scope of their results.

In this paper, our objective is to evaluate AODV and OLSR in realistic urban traffic environment. In order to model realistic vehicular motion patterns, we make use of the *Vehicular Mobility Model (VMM)*, which is part on the VanetMobiSim tool we previously developed (see [5]). This model is able to closely reflect spatial and temporal correlations between cars, and between cars and urban obstacles. Notably, the tool illustrates clustering effects obtained at intersection, also is more commonly called *traffic jam*, or drastic speed decays. Accordingly, it becomes possible to more realistically evaluate ad hoc routing performances for vehicular networks. We configure VMM to model urban environment then evaluate the performance of AODV and OLSR in terms of *(i) Packet Delivery Ratio (PDR) (ii) Control Traffic Overhead (RO), (iii) Delay, and (iv) Number of Hops*. We test AODV and OLSR in three different conditions *(i) variable velocity (ii) variable density (iii) variable data traffic rate*. We show first that the clustering effect obtained at intersection has a major effect on the effective average velocity during the simulation. We

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then illustrate how OLSR is able to outperform AODV in any condition and for almost all metrics.

The rest of the paper is organized as follows: In Section II, we shortly provide some related work in the performance evaluation field, while in Section III, we briefly depict OLSR and AODV protocols. Section IV presents the Vehicular Mobility Model (VMM) we used in this paper to model urban motion patterns, while Section V discusses the scenario characteristics and the simulation results. Finally, in Section VI, we draw some conclusion remarks and outline some future works.

II. Related Work

Several studies have been published comparing the performance of routing protocols using different mobility models or performance metrics. One of the first comprehensive studies was done by the Monarch project [1]. This study compared AODV, DSDV, DSR and TORA and introduced some standard metrics that were then used in further studies of wireless routing protocols. A paper by Das et al. [2] compared a larger number of protocols. However, link level details and MAC interference are not modeled.Another study [6] compared the same protocols as the work by Broch et al. [1], yet for specific scenarios as the authors understood that random mobility would not correctly model realistic network behaviors, and consequently the performance of the protocols tested. Globally, all of these papers concluded that reactive routing protocols perform better than proactive routing protocols.

Although that the proactive OLSR protocol has been developed in 2002, very few studies compared it with other ad hoc network protocols. Clausen *et al.* [7] evaluated AODV, DSR and OLSR in varying network conditions (node mobility, network density) and with varying traffic conditions (TCP, UDP). They showed that unlike previous studies, OLSR performs comparatively to the reactive protocols.

Following the developments started with scenarios-based testing, it also became obvious that, as scenarios were able to alter protocol performances, so would realistic node-to-node or node-to-environment correlations. This approach became recently more exciting as VANETs attracted more attention, and a new wave of vehicles-specific models appeared. The most comprehensive studies have been performed by the Fleetnet project [8]. In a first study [3], authors compared AODV, DSR, FSR and TORA on highway scenarios, while [4] compared the same protocols in city traffic scenarios. They found for example that AODV and FSR are the two best suited protocols, and that TORA or DSR are completely unsuitable for VANET. Another study [9] compared a position-based routing protocol (LORA) with the two non-position-based protocols AODV and DSR. Their conclusions are that, although AODV and DSR perform almost equally well under vehicular mobility, the location-based routing schema provides excellent performance. A similar results has been reached by members of the NoW project [10], which was their major justification for the design of Position-based forwarding techniques. However, to the best of our knowledge, no performance evaluation have been conducted between OLSR and other routing protocols under realistic urban traffic configurations.

III. Background

For our performance comparison study, we picked up two ad hoc routing protocols that reached the IETF RFC stage, the on-demand AODV protocol (RFC[3561] [11]), and the table-driven OLSR protocol (RFC[3626] [12]). We shortly address both protocols in the rest of this section. For a more detailed description, the reader is referred to the respective RFCs.

A. AODV (Ad-hoc On-demand Distance Vector)

In AODV, when a source node has data traffic to send to a destination node, it first initiates a route discovery process. In this process, the source node broadcasts a Route Request (RREQ) packet. Neighbor nodes which do not know an active route for the requested destination node forward the packet to their neighbors until an active route is found or the maximum number of hops is reached. When an intermediate node knows an active route to the requested destination node, it sends a Route Reply (RREP) packet back to source node in unicast mode. Eventually, the source node receives the RREP packet and opens the route.

B. OLSR (Optimized Link State Routing)

In OLSR, each node periodically constructs and maintains the set of neighbors that can be reached in 1-hop and 2-hops. Based on this, the dedicated *MPR* algorithm minimizes the number of active relays needed to cover all 2-hops neighbors. Such relays are called *Multi-Point Relays (MPR)*. A node forwards a packet if and only if it has been elected as MPR by the sender node. In order to construct and maintain its routing tables, OLSR periodically transmit link state information over the MPR backbone. Upon convergence, an active route is created at each node to reach any destination node in the network.

IV. Vehicular Mobility Model

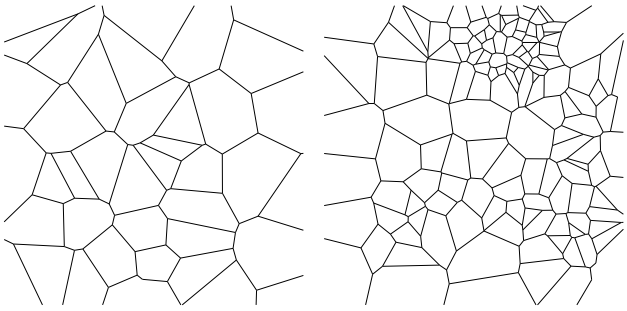
As depicted in [13], a mobility model clearly affects the simulation results. Thus, since simple models like the Random Waypoint mobility model do not consider vehicles' specific motion patterns, they cannot be applied to simulation of vehicular networks. Accordingly, we developed in [5] a new realistic mobility model, called *Vehicular Mobility Model (VMM)*, that is compliant with the principles of the general framework for mobility models generation described in [14], and capable of modeling detailed vehicular movements in different traffic conditions.

Following the general classification proposed by [15], *VMM* contains a **microscopic** and a **macroscopic** component:

A. Macro-Mobility

The macro-model is represented by a graph where vertices and edges represent, respectively, junction and road elements. As proposed by [16], a good solution to randomly generate graphs on a particular simulation area is Voronoi tessellations based on distributed points over the simulation area which

represent obstacles (e.g., buildings). Accordingly, we obtain a planar graph representing a set of urban roads, intersections and obstacles. Then, in order to increase the realism, as dense areas such as city centers have a larger number of obstacles which in turn increase the number of Voronoi domains, the model generates clusters of obstacles with different densities, eventually creating clusters of Voronoi domains. Figure 1(a) presents a random topological map with uniformly spread obstacles, while Figure 1(b) depicts a topological map considering three different types of clusters with different obstacle densities.



(a) Uniform Topology (b) Cluster Topology

Fig. 1. Illustration of the random topology generation

In order to model the typical vehicular motion patterns, the objective is also to create a relationship between the topological map and the traffic generator that could go beyond the simple constrained motions induced by graph-based mobility. Accordingly, the macro-model first offers the possibility to separate single flows roads, as well as to increase the number of lanes per road. Then, as the traffic generator needs to act when reaching an intersection, the urban topology is also enhanced by traffic signs. According to the model's configuration, traffic lights or stop signs may be added, depending on the type of intersection.

B. Micro-Mobility

When considering *micro-mobility*, one should look at the driver's point of view. When a driver approaches an intersection, it should slow down then act according to the traffic signs or traffic lights he or she reads, and to the presence of other cars approaching the same intersection. To obtain a similar behavior, the existing Intelligent Driver Model [17] is extended to derive the *Advanced Intelligent Driver Model (AIDM)* supporting intersection management. To this end, deceleration and acceleration models inspired by the Akcelik's acceleration/deceleration model [18] are added in proximity of road intersections, so that vehicles approaching a traffic light or a crossroad reduce their speeds or stop. Included are also a set of rules describing the actions taken by drivers at intersections depending on the class of traffic signs, the state of traffic lights and other vehicles currently inside the intersection or waiting for their turns. Finally, a vehicle overtaking model has also been included in order to allow vehicles to change lane and overtake each others. We chose the *Minimizing Overall Braking decelerations Induced by Lane changes (MOBIL) [19]* model as the lane changing model, due to its implicit compatibility with the AIDM.

V. Performance Evaluation

In order to evaluate the performance of the routing protocols described above, we used the open source network simulator ns-2 in its version 2.27 as it is widely used for research in mobile ad hoc networks. We provide first a description of the scenarios characteristics and then describe the results we obtained.

A. Scenario Characteristics

In this paper, we consider squared urban areas of 1000x1000m constituted of three different cluster categories: downtown, residential and suburban. The different obstacle densities for these three categories are summarized in Table II(b). Vehicles are able to move freely on the urban graph respecting roads and intersection rules, more specifically, speed limitations and stops. Vehicles are able to communicate with each others using the IEEE 802.11 DCF MAC layer. The radio transmission range as been deliberately over-evaluated and set to 250m for VANETs as we wanted to avoid biased performance evaluations due to disconnected networks. The simulation parameters are given in Table I. We test each protocol with a spatial model with stop signs only, and with 30% of traffic lights and 70% of stop signs, as we also want to evaluate the effect of traffic lights in urban areas.

Vehicles are randomly positioned on intersections. Then, each vehicle samples a desired speed and a target destination. After that, it computes the shortest path to reach it, taking into account single flow roads. Eventually, the vehicle moves and accelerates to reach a desired velocity according to streets regulations. When a car moves near other vehicles, it tries to overtake them if the road includes multiple lanes. If it cannot overtake, it decelerates to avoid the impact. When a car is approaching an intersection, it first acquires the state of the traffic sign. If it is a stop sign or if the light is red, it decelerates and stops. If it is a green traffic light, it slightly reduces its speed and proceeds to the intersection. At target destination, the car decelerates and stops, then samples a new destination. The different parameters for the micro-model are given in Table II(a)

We finally decomposed our performance analysis in three different scenarios, where we fixed the parameters according to Table III. In the first scenario, we want to see the influence of mobility, whereas in the second scenario, we are interested in the data traffic rate, and finally, in the last scenario, the objective aims at observing the effect of the network density. Each point is the average of 10 samples, while the error bars represent a 95% confidence interval.

Network Simulator	ns-2 2.27
OLSR Implementation	NRLOLSR
$Hello^{olsr}$ Interval	0.5s
TC^{olsr} Interval	2s
AODV Implementation	AODV-UU
$Hello^{aodv}$ Interval	3s
Simulation time	200s
Simulation Area	1000m x 1000m grid
Number of Nodes	40, 50, 60, 70, 80
Tx Range	250m
Speed	Uniform
Density	$\#nodes \cdot \frac{\pi \cdot range^2}{X_{dim} \cdot Y_{dim}}$
Data Type	CBR
Traffic Source/Destination	Random
Data Packet Size	512 bytes
MAC Protocol	IEEE 802.11 DCF
MAC Rate	2 Mbits/s
Confidence Interval	95%

TABLE I

SIMULATION PARAMETERS

Param	Description	Value
a	Maximum Acceleration	$0.9m/s^2$
b	Maximum Deceleration	$0.5m/s^2$
l	Vehicle Length	5m
s_{com}	Minimum Congestion Distance	2m
t	Safe headway time	1.5s
b_{sav}	Maximum "safe" deceleration	$4m/s^2$
p	Politeness	0.5
a^{th}	Lane Change Threshold	$0.2m/s^2$
T^{light}	Traffic Light Transition	10s

(a) Micro-model

Clusters	#obstacles per $100m \times 100m$
Downtown	2
Residential	0.5
Suburban	0.1

(b) Macro-model

TABLE II

VEHICULAR MOBILITY MODEL PARAMETERS

B. Simulation Results

We measured several significant metrics for MANETs routing:

- *Packet Delivery Ratio (PDR)*– It is the ratio between the number of packets delivered to the receiver and the number of packets sent by the source.
- *Routing Overhead (RO)*– It represents the number of routing bytes required by the routing protocols to construct and maintain its routes.
- *Delay*– It measures the average end-to-end transmission delay by taking into account only the correctly received packets.
- *Hops*– It provides an expected data route length.

We see in Fig. 2 that the average velocity does not have any effect on the PDR, which is a strange results as mobility is a common metric in performance evaluation, and previous results have shown that both protocols were sensitive to it. We also obtained similar behaviors for other performance metrics, but did not include them for the lack of space. Actually, the explanation for this behavior comes from the micro-model

Scenarios	Data Rate	Network Mobility	Nodes Density
Network Mobility	0.8 Mbits/s	v^{min}=0m/s, v^{max}=20m/s to v^{min}=15m/s, v^{max}=35m/s	11.78
Data Rate	0.02 Mbits/s to 2 Mbits/s	v^{min}=15m/s, v^{max}=35m/s	11.78
Network Density	0.8 Mbits/s	v^{min}=15m/s, v^{max}=35m/s	1.96 to 15.7

TABLE III

SIMULATION SCENARIOS

and its interaction with the spatial environment. Indeed, when modeling smooth transitions and realistic interaction with urban traffic regulations, a fixed initial velocity does not make any sense. Instead, we define an *average desired velocity* a driver aims at reaching with a smooth acceleration. However, this desired velocity is subject to speed limitations that cannot be exceeded, or to any obstacle that either reduces or even stops the car. Accordingly, there is no guarantee that this velocity can even be reached during the simulation.

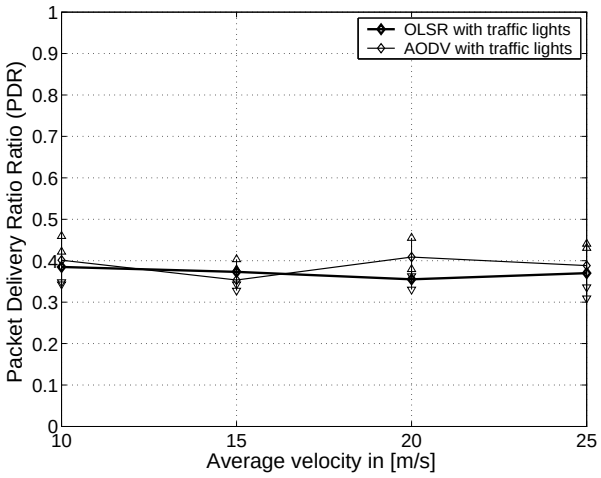
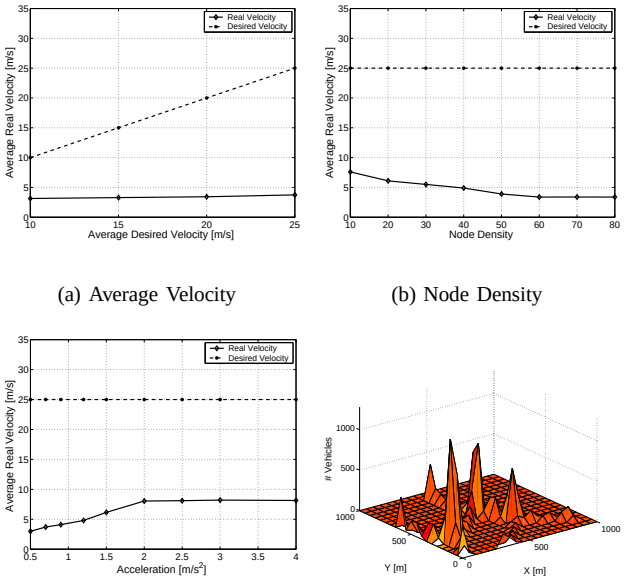


Fig. 2. Packet Delivery Ratio (PDR) as a function of Average Velocity

In order to illustrate this effect, we show in Fig. 3(a) and Fig. 3(b) the speed decay from the desired speed that vehicles experience in our scenarios. As we can see, there is a drastic decay for either a varying density or varying desired velocity. The question we may ask is what is the main limiting factor that leads to this effect? We can see in Fig. 3(c) that one on the parameters is cars acceleration (resp. deceleration). Actually, this should not be strange as when we observe urban traffic, smooth transitions are a major criteria for traffic jams (even without any obstacles). On the same figure, we also see that as the speed decay stabilizes for large accelerations, the decay actually becomes dependent to the distance between two intersections, which is a second parameter which influences cars velocity in our model. Finally, we can see, on Fig. 3(d), the non uniform distribution of vehicles on the simulation area, illustrating yet another specificity of realistic mobility modeling creating this effect. **The major**

conclusion is that pure mobility as defined by previous works cannot be used as an evaluation metric for vehicular ad hoc networks. We should rather define new metrics as acceleration/deceleration factors, or distance between two intersections.



(a) Average Velocity

(b) Node Density

(c) Acceleration/Deceleration

(d) Spatial Distribution of Vehicles in the Network

Fig. 3. Illustration of Vehicular-specific Motion Patterns

Figure 4 shows the average PDR against the CBR throughput. The first observation we can make is that neither AODV nor OLSR clearly outperforms the other. The PDR variation between both protocols never goes above 10%. This small variation comes from AODV and OLSR core functionalities. Indeed, in our scenarios, we are increasing the data traffic rate, yet keeping the number of CBR source constant. For small data rates, OLSR performs better due to the fact that all routes are computed at no extra cost, while AODV must initiate several route discovery processes. When the rate of route discoveries is small, so is the probability for intermediate nodes to know an active route to a destination node. Consequently, a large number of AODV route requests (RREQ) must travel up to the destination node. However, as the data rate increases, so does the chance for intermediate nodes to have cached active routes, while OLSR must completely reconfigure its routing tables. Accordingly, there is a threshold below which OLSR is beneficial for VANET, and above which AODV becomes attractive. From Fig. 4, this threshold is situated around $0.8Mbits/s$.

The Routing Overhead (RO) is depicted in Fig. 5. It revives the old cleavage between proactive and reactive routing protocols. Indeed, reactive protocols have been initially developed to reduce the routing overheads created by the proactive approaches. However, this assumption was shown to be valid if the traffic rate, and so the route discovery rate,

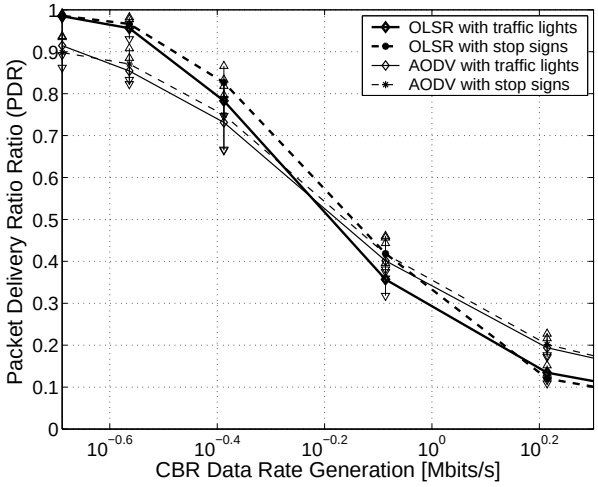


Fig. 4. Packet Delivery Ratio (PDR) as a function of Data Traffic Rate

was not too large. Above a certain traffic rate threshold, it was assumed that table-driven approaches were more attractive than on-demand schemes. In Fig. 5, we actually see that this cleavage also exists in VANETs. We observe that the control traffic of OLSR exhibits the expected characteristics of being independent of the data traffic rate, while the control traffic, generated by AODV, increases with the data rate. For data rate below $300kbit/s$, AODV has a lower routing overhead than OLSR, while for data rate above this threshold, the control traffic generated by AODV explodes.

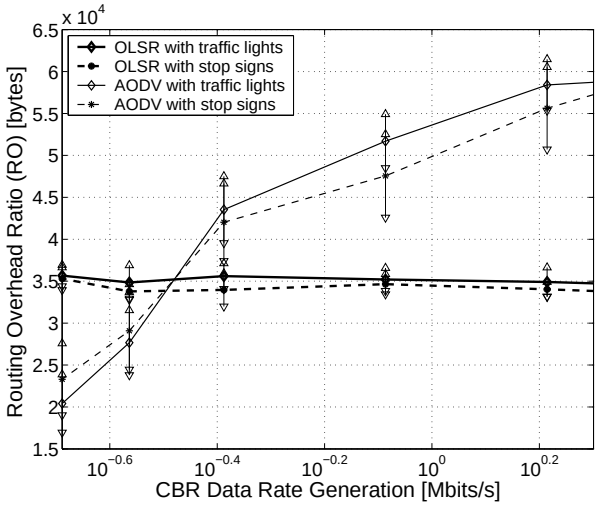


Fig. 5. Routing Overhead (RO) as a function of Data Traffic Rate

We observe in Fig. 6 that OLSR consistently presents the lowest delay, regardless of data traffic. This may be explained by the fact that OLSR, as a proactive protocol, has a faster processing at intermediate nodes. When a packet arrives at a node, it can immediately be forwarded or dropped. In reactive protocols, if there is no route to a destination, packets to that destination will be stored in a buffer while a route discovery is conducted. Accordingly, the performance improvement in

term of delay raises up to 250% between AODV and OLSR.

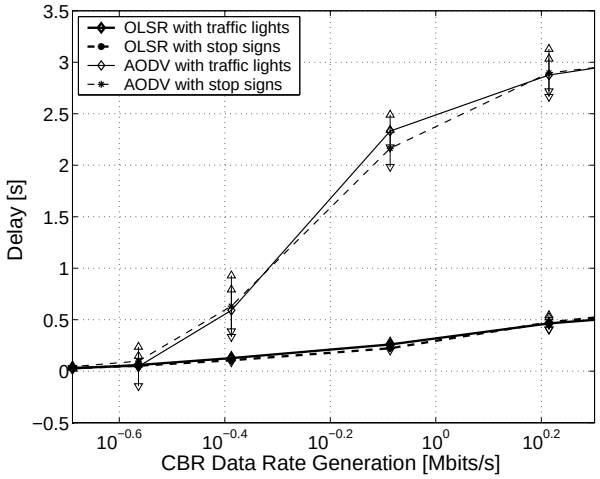


Fig. 6. End-To-End Delay as a function of Data Traffic Rate

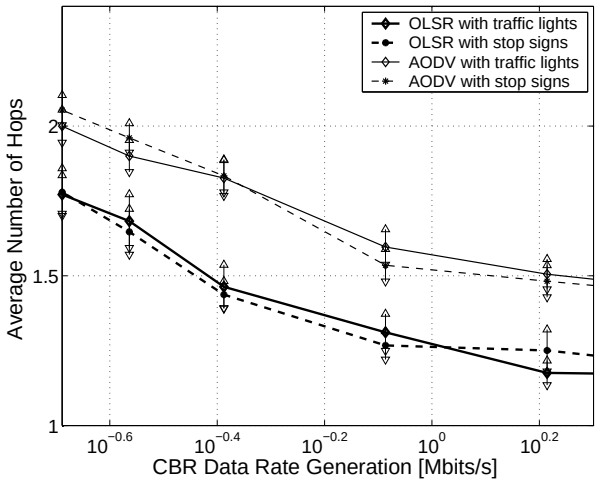


Fig. 7. Number of Hops in the Path as a function of Data Traffic Rate

Finally, we show in Fig. 7 the expected number of hops of the CBR routes, which reflects the average end-to-end route length. Three remarks may be made on this figure. First, the maximum average number of hops never goes beyond 2 hops. According to the simulation area and the transmission range, it should be situated between 3 and 4 hops. By looking at Fig. 4, we see that the number of hops is not related to the data rate, as we have 2 hops and 95% PDR at low rate. The only explanation comes from the non-uniform distribution of vehicules in the simulation environment. Indeed, vehicles are aggregating at intersections, and the intersections are globally located toward the center of the simulation environment. Accordingly, the effect increases the connectivity at the intersection and between intersections, and consequently lowers the number of hops. Second, we see that the number of hops of AODV is always larger than the number of hops of OLSR. As the maximum number of hops is approximately 2 hops on average, and as MPR has been purposely created to optimize the number of hops in its two hops neighborhood, it is not surprising that AODV creates routes 15% longer than OLSR. The last remark is that the path length actually decreases as the CBR rate increases. This is also not a surprise since an increased number of hops also increases the probability to loose packets. So, as the network becomes saturated, only packets with the shortest path may be correctly received. This is, unfortunately, a major illustration of *network unfairness toward traffic flows*.

In the next set of figures, we display results obtained for the second scenario. Node density is defined as a node's average number of neighbors and is computed as mentioned in Table I. Fig. 8 shows the typical bell shape of AODV and OLSR's PDRs. For small densities, there is not enough nodes to ensure network connectivity. So, as we increase the density and leave the *supra-critical* [1] zone, the PDR gets improved until the density of nodes reaches the *critical*[1] value. Then, as the density still increases, we drop into a *super-critical*[1] zone, where extra nodes are able to provide some redundancy for route management. As neither OLSR nor AODV are configured to benefit from load balancing in our implementation, the extra number of nodes soon becomes a drawback for the MAC layer. Consequently, the PDR starts dropping. The critical density in our simulation is between $4-6$ nbrs/vhcl on average.

Although this situation is common in MANETs, it is worsen by the non uniform distribution of nodes in the simulation area. Indeed, due to traffic regulations and vehicles configurations, urban traffic tends to cluster at intersections, which locally increases the density and decreases the performance of VANET routing protocols. The interesting part in Fig 8 is that AODV and OLSR are sustaining the clustering effect differently. For low density, OLSR outperforms AODV. Then, similarly to Fig. 4, a threshold is reached, as the density increases, above which AODV starts outperforming OLSR.

In order to analyze this graph, we separate the graph in three regions: *supra-critical*, *critical*, *and super-critical* densities. In the supra-critical density (4 nbrs/vhcl and below), OLSR performs better than AODV, which is a noteworthy effect here as OLSR seems to handle network disconnection better than AODV. Network disconnections are an unwanted, yet common, problem in VANETs. It therefore seems that OLSR could be a good candidate for *routing in sparse VANET networks*. Then, in the critical category, OLSR still maintains its advantage toward AODV. Indeed, when cars are aggregating in intersections, the MPR nodes become more stable, which increases the stability of OLSR and helps improving the PDR. Finally, in the super-critical category, the PDR for both

[1]Critical, supercritical or supracritical are usual terms employed in the percolation theory, referring to supra- or super- critical node densities for a network to percolate

protocols drops. However, the PDR of OLSR drops faster than AODV, which seems to be handling saturated networks better than OLSR. One explanation must again be sought in the intersection. As the density of car locally increases, the periodic maintenance of OLSR reduces its capability of accessing the channel for data traffic, while the AODV's RREQ packets have a high chance to find a close intermediate node with an open route.

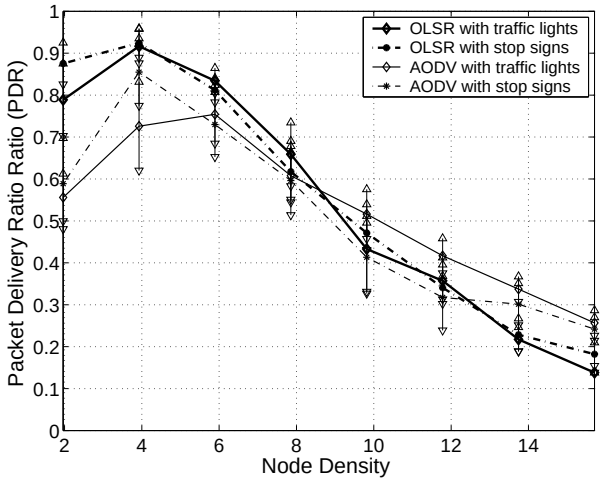


Fig. 8. Packet Delivery Ratio (PDR) as a function of Vehicles Density

Similarly to Fig. 5, the next figure depicts the RO of OLSR and AODV as a function of the node density. We can see on Fig. 9 that as we could expect, both ROs increase with the density. As in Fig. 5, we clearly see a transition threshold for the control traffic generated by OLSR and AODV. For node densities below 8 nbrs/vhcl, the control traffic overhead of AODV is smaller than OLSR. However, as the density increases, the cost of repeated route discovery procedures in AODV introduces a large control traffic overhead, and OLSR ends up outperforming AODV up to 100%.

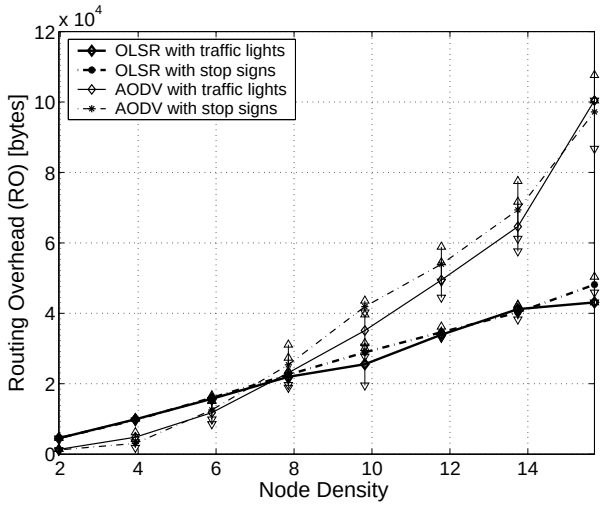


Fig. 9. Routing Overhead (RO) as a function of Vehicles Density

Figure 10 depicts the end-to-end packet delay. For both supra-critical and critical densities, both protocols have similar delays. However, in the super-critical zone, AODV's delay explodes and, as the confidence interval are illustrating, it is also more unstable. As the access to the channel becomes harder, when a RREQ finds an intermediate node with an active route the delay can be lowered. However, the penalty for not finding any intermediate node becomes prohibitive as the network becomes locally saturated. On the other hand, routes that OLSR could maintain despite the congested channel are ready to use. So, we have an ambiguous result here, where in saturated networks, OLSR has a lower PDR than AODV, yet the packets that it manages to carry are delivered with a much smaller delay.

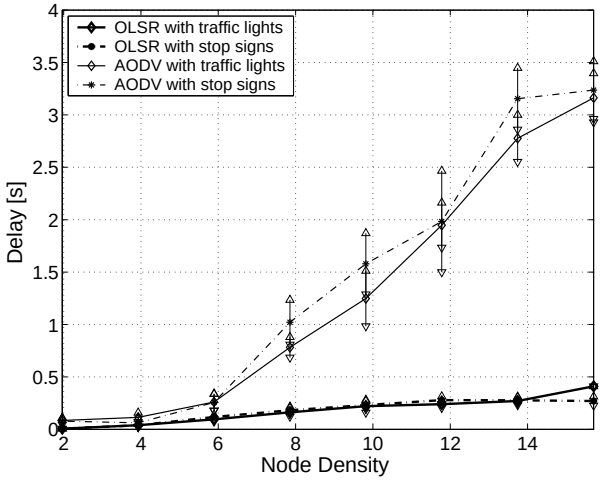


Fig. 10. End-to-End Delay as a function of Vehicles Density

Finally, Fig. 11 shows the expected number of hops of the CBR routes as a function of the density of vehicles. Similar remarks may be formulated as for Fig. 7 on the maximum number of hops and on the $\approx$ 15% increase in the number of hops of AODV compared to OLSR. Yet, the average number of hops' behavior toward the density of vehicles is slightly different. Indeed, Fig. 11 has a typical bell shape. As the density of vehicles increases, so does the path length. By looking at Fig. 8, we see that the PDR is similarly increasing. Accordingly, unlike Fig. 7, network disconnections due to a low vehicle density are restricting multi-hop communications. Then, the density increases as the length of multi-hop routes. However, after a certain threshold, the network becomes saturated and a similar effect can be observed as with the increased data rate. The conclusion from this is that, similarly to MANETs, reliable multi-hop communication may only occur in a particular threshold, where the network density is large enough to be connected, yet moderate enough in order to limit the channel saturation. But the situation is worsen in VANETs by the clustering effect at the intersections, as the density might be too large to keep reliable single hop communications, yet too low to maintain multi-hop communications.

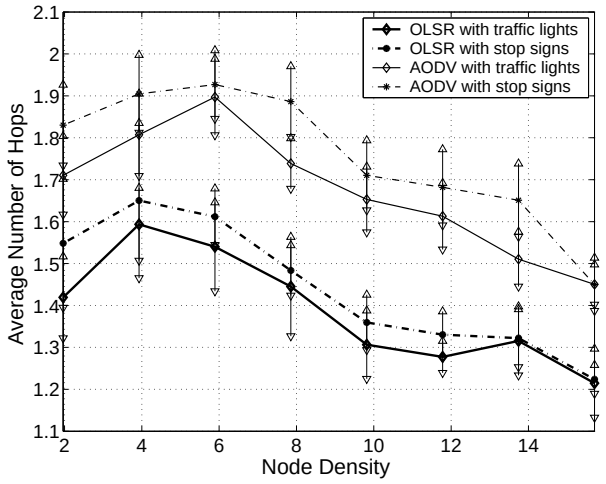


Fig. 11. Number of Hops in the Path as a function of Vehicles Density

VI. Conclusion and Future Works

In this paper, we evaluated the performance of AODV and OLSR for vehicular ad hoc networks in urban environments. The traffic regulations and the vehicles characteristics handled by the vehicular mobility model (VMM) we used, are creating a clustering effect at intersection. This effect has a remarkable properties on standard performance evaluations of ad hoc protocols. The first one is that neither the initial nor the maximum velocity has any influence on routing protocols in urban environments. Indeed, due to the interaction with the spatial environment and also other neighboring cars, vehicles experience a non negligible speed decay independent of the network velocity. Then, a second property is local increase of nodes density, which clearly has a consequence on both tested ad hoc routing protocols.

We tested OLSR and AODV against node density and data traffic rate. Globally, we found that OLSR outperforms AODV in VANETs. For most of the metrics we used in this paper, OLSR has better performance that AODV. Indeed, OLSR has smaller routing overhead, end-to-end delay and route lengths. And for the PDR, where OLSR may be outperformed by AODV after a certain threshold, the performance loss is limited to 10%. Accordingly, unlike a previous study for MANET ([7]), which suggested that neither OLSR nor AODV could outperform each others, or even all previous studies described in Section II, OLSR, a proactive protocol, is more fitted to VANET than reactive ones.

We also illustrated in this paper how vehicular ad hoc networks in urban environment experience particular motion patterns. More precisely, we showed that the average velocity was not a valid parameter to evaluate routing protocols in VANET under realistic motion patterns. Accordingly, for future realistic performance evaluation, one should rather evaluate ad hoc protocols against new metrics, such as acceleration/deceleration capabilities of the drivers, or the length of street segments instead of simple average mobility.

For this study, we deliberately parametrized the network to be fully connected, as we wanted to avoid biased results from disconnected graphs. However, as stated in the paper, network disconnections is also a major property of VANETs and we will performs similar tests with shorter transmission range. We are also interested in evaluating the effect of heterogeneous vehicles in urban environments on routing protocols for VANETs. Finally, we plan to include geographical forwarding protocols in future performance evaluation as they are more suited to dense networks or to frequent network disconnections.

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