Impact of Density, Load, and Mobility on the Performance of Routing Protocols in Vehicular Networks

Bruno G. Mateus *, Carina T. de Oliveira †, Arthur Callado *, Stenio Fernandes ‡, Rossana M. C. Andrade *
* Federal University of Ceara (UFC), Brazil
† Joseph Fourier University (UJF), France
‡ Federal University of Pernambuco (UFPE), Brazil

***Abstract*—Designing routing protocols in vehicular network is a challenging task due to the high mobility of nodes, the instability of wireless links, and the diversity of deployment scenarios. Several routing protocols have been designed with the goal of solving one or more specific problems of each scenario. In this paper, we present a performance evaluation of routing protocols in vehicular networks addressing the impact of density, load, and mobility pattern. Four protocols are evaluated in urban and highway scenarios. The results presented in this paper provide guidelines for network designers in planning efficient routing protocols for vehicular network, able to adapt to different scenarios.**

***Index Terms*—vehicular networks, routing protocol, performance evaluation**

I. Introduction

Vehicular networks are expected to support a variety of applications including road safety services, traffic monitoring, and infotainment delivery. Since most of these applications suggest the existence of multi-hop communication, the main concern is whether the performance of routing protocols can meet the requirements of such applications. However, designing an efficient routing protocol is a particularly challenging task due to rapid topology changing and frequent disconnection [1]. Another issue is the impact of different scenarios, such as urban, rural, and highway environments.

In particular, the scenario is an issue that strongly affects the mobility of nodes in a vehicular network. For instance, highways are expected to experience relative speeds of up to 100 km/h and frequent networks disconnections, while urban scenarios are more likely to form highly dense networks during rush hours. However, network partitions can occur frequently during late night hours in highway and urban scenarios as fewer vehicles are running.

A number of routing protocols have been designed to address specific problems of each scenario. For example, Abedi et al. [2] address the problem of low-latency routing in a highway scenarios. In contrast with routing protocols developed in the highway or the city environments, Wan et al. [3] proposed routing algorithms which can predict the lifetimes of wireless links in rural scenarios.

Due to the specificity of protocols, a primary challenge in vehicular networks is the design of routing protocols that can perform well in a wide range of scenarios. Despite the efforts that have been made, it is still unclear which specific characteristics are required to develop an efficient routing protocol able to present a satisfactory performance in various types of vehicular networking scenarios. As a first step in this direction, this paper proposes the analysis of the impact of vehicle density, network load, and mobility pattern on the performance of a routing protocol on urban and highway scenarios. Our extensive simulation results provide guidelines for network designers in planning vehicular network deployments.

The rest of the paper is organized as follows: Section II discusses related work. In Section III we present the environment used in the simulations and the modeling scenarios used. The results are analyzed in Section IV. Finally, we present the conclusions and future work in Section V.

II. Vehicular Routing Protocols

This section presents the protocols that are used in the performance evaluation. Although our performance evaluation does not cover all the available routing protocols, we believe that the evaluated protocols constitute a good representation of existing protocols.

A. Multi-hop Routing Protocol for Urban Vanets (MURU)

MURU [4] uses the Expected Disconnection Degree (EDD) metric to select routes with the lowest breakage probability. EDD is calculated according to the information about velocity and moving trajectory of each vehicle along the path. Each vehicle is assumed to be equipped with a Global Positioning System (GPS) device and digital maps. The protocol calculates the shortest physical path between nodes based on these maps.

The source node starts discovery by sending RREQ messages limited by a rectangular area, which is calculated according to the length of street blocks and the position of source and destination. When a node receives a RREQ message, it determines the EDD between itself and the node that sent the message. Then it updates the EDD in the packet. While it waits a time proportional to the EDD (backoff time), it listens to the RREQ messages from other neighbors. If the node does not discard the RREQ message during this time, it will retransmit within a rectangular area smaller than that of the previous node. According to the protocol, a node discards an RREQ message if it receives a new RREQ with a lesser value in the EDD. Once the destination receives some RREQ messages concerning different routes, it chooses the route with the lowest total EDD and sends a response to the source, containing the chosen path. The authors report that MURU always chooses paths with the lowest EDD.

B. Receive On Most Stable Group-Path (ROMSGP)

ROMSGP [5] groups vehicles using information regarding their speed and direction of movement. The main goal is to ensure that the chosen paths consist of vehicles that are moving together (similar direction and speed). Therefore, routes involving vehicles of the same group are considered stable. Given a set of possible routes, the protocol chooses the path with the longest Link Expiration Time (LET). It is assumed that each vehicle has a GPS device and its position is checked every second. Information about the group is included in the RREQ messages. When a vehicle receives a RREQ, it compares the identifier of its group with the identifier of the vehicle that originated the message. If they are in different groups, the link between them is penalized, being marked as unstable, and the RREQ message is discarded. This mechanism prevents the retransmission of packets through unstable links. The ROMSGP reduces network overhead by avoiding the sending of control messages, routing requests, and error messages due to unstable links.

III. Simulation Environment

We use ns-2.34 simulation to compare the performance of routing protocols. Table I presents the simulation parameters. We compare the performance of AODV [6] and DSR [7] with that of MURU and ROMSGP.

We evaluate the performance of the routing protocols using two scenarios: urban and highway. We use real maps generated by OpenStreetMap (OSM)[1] to represent both scenarios. The urban map covers an area of one square mile with approximately twenty one-way and two-way streets, and eighty street crossings, most of them with traffic lights. The highway scenario consists of five-mile long stretch of highway with eight lanes of vehicles, four in each direction. The vehicules movements are generated using the open source micro-traffic simulator SUMO[2].

We analyze the impact of three different network conditions:

- Density: the amount of vehicles per unit area;
- Load: the number of traffic sources;
- Mobility: the type of scenario (urban and highway).

We present the results with a confidence interval of 95%. We focus on the most significant results that can guide the design of an efficient routing protocol in vehicular networks.

IV. Simulation Results

In this section, we present the results of the simulation-based performance evaluation. The impact on control packets is examined first, followed by the delivery rate. Also in the end, a table that compares the selected protocols is given.

[1]Openstreetmap foundation, http://www.osmfoundation.org

[2]SUMO, http://www.sumo.sourceforge.net

TABLE I
SIMULATION SETUP

Parameter	Value
MAC protocol	IEEE 802.11
Application	CBR traffic
Transmission range	400 m
Propagation model	TwoRayGround
Mobility model	*Krauβ car-following*
Simulation time	200 s
Interval between packets	0.5 s

A. Control Packets

In this experiment, we measure the number of control packets generated by each routing protocol. Control packets are essential to ensure network operations, especially those of routing protocols. However, the increase of the number of control packets causes the network congestion, which results in the degradation of the number of delivered data packets. Therefore, mechanisms to reduce control packets are required.

Figure 1 shows the change in the number of control packets when increasing the number of nodes. From Figures 1(a) and 1(c), we can see that DSR is the protocol that sends more control packets in the urban scenario, followed by AODV. As DSR is a source routing protocol, when a link breaks and a source node has no alternate route available in cache, it starts a new route discovery procedure. On the other hand, any node in AODV can get new routes to the destination, so when a link breaks, an intermediate node may initiate the routing procedure, decreasing the number of control messages to restore the broken path. In relation to the vehicular protocols, density variation influences the urban and highway scenarios in different ways. In the urban scenario, the intersections with traffic lights tend to concentrate a greater number of vehicles, while regions without signaling have a higher traffic flow. On the other hand, in highway scenarios, vehicles are distributed almost uniformly along the way, allowing greater flow of traffic on the roads. Therefore, the increase in vehicle density affects sending control packets more smoothly, as presented in Figures 1(b) and 1(d). As we see in the highway scenario, when the network is sparse, the performance of MURU and ROMSGP protocols is similar. Moreover, the difference between the numbers of packets sent is much smaller if compared with a network under the same conditions in the urban scenario. This is due to the mobility pattern of the landscape characteristics of the road added to the overload control mechanisms used by protocols. In the scenario of a highway in a sparse network, the mechanism used by MURU (based on the broadcast area) becomes less restrictive than that used by ROMSGP, as some paths formed by nodes that are moving in the opposite direction to the movement of the source node will be propagated due to the proximity of the routes, whereas only paths that contain nodes moving in the same direction of the source node will be propagated by the ROMSGP. However, when the network density increases, the

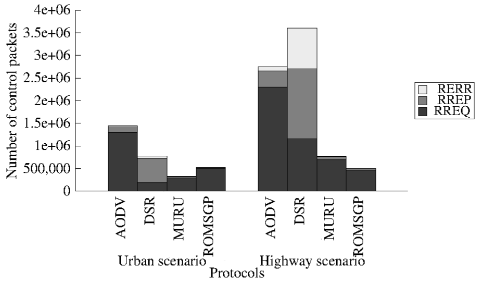


Fig. 3. Number of control packets sent by each routing protocol based on the number of sources in simulated scenarios.

area of broadcast becomes more restrictive than the grouping of vehicles made by ROMGSP, but because of the increased number of vehicles, the number of paths also increases both directions. Thus, as the only restriction imposed by ROMSGP is a way to use the nodes that are moving in the same direction, many of the new paths may be used.

Figure 3 shows the number of control packets according to the type of control packet (RERR, RREP, and RREQ), scenario, and for each routing protocol. In the highway scenario, most reply messages are sent, so we conclude that more paths are established. However, due to the high number of error messages, we can conclude that many of these paths break during transmission of data messages. Moreover, we can see that in sparse networks the change of scenario is a determining factor for the performance of control of MURU and ROMSGP overload mechanisms. While in the urban scenario, MURU sends less control packets, in the highway scenario it is ROMSGP that sends less control packets. Furthermore, DSR sends more RREP than RREQ in both scenarios. As DSR does not use a sequence number on the RREQ packages, a single RREQ can be answered many times.

As far as network overloading is concerned, the protocols developed for vehicular networks performed better in both scenarios because of the control overload mechanisms implemented by them. By using the parameters of mobility, they can avoid sending unnecessary control messages, especially when the network is very dense. To better understand the impact of network load on the performance of the protocols, simulations were performed varying the number of vehicles present in the source scenarios. The number of source vehicles varied from 10% to 60% of all vehicles. Figure 2 shows the effect of increasing the number of source nodes in the amount of control packets needed to keep the network running. When the network load increases, the number of control packets sent increases. This is due to the greater number of data packets sent. As the four protocols were simulated using the reactive strategy, it is expected that as the number of sources increases, the amount of control packets sent will grow as well.

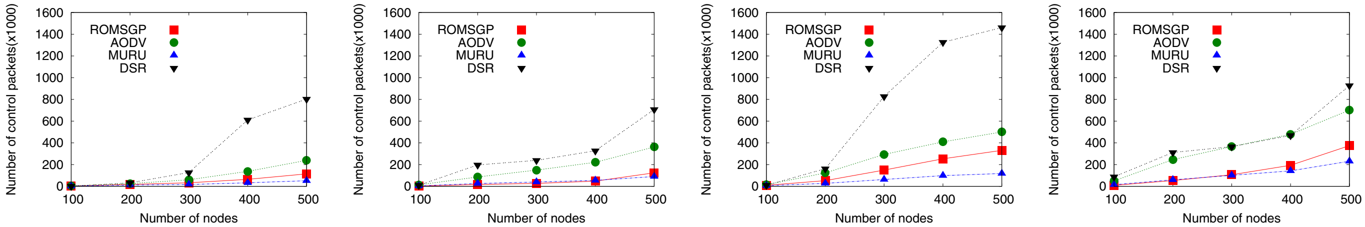
Figure 2(a) shows the performance of protocols in a network with 100 vehicles. As the network represented in this scenario is sparse, the protocols suffer from a shortage of ways to perform routing. For this reason, several route request messages are sent by the protocols, especially AODV, which results in the greatest amount of transmission of control packets. The same problem does not occur with ROMSGP and MURU due to the overload control mechanism they use, which limits message forwarding requests. Although the DSR protocol is not efficient in scenarios with high mobility, it stood out in this scenario compared to AODV because of the caching mechanism it uses. Figure 2(c) shows similar behavior of the simulated protocols, i.e., as the number of sources increases, the more the protocols overload the network. As stated earlier, the MURU and ROMSGP protocols suffer less with increasing network loads thanks to the control mechanisms they use. In this context, due to the dynamics of the network and the largest number of existing paths, the DSR was the protocol that most overloaded the network.

Regarding the results obtained in the simulation of highway scenarios (Figures 2(b) and 2(d)), we can observe a different behavior of the AODV and DSR by comparing the results achieved in the urban scenario. Looking at the performance of DSR in the highway scenario, we can observe that increasing the network load does not result in an increase in the number of control packets sent. This is because in the highway scenario DSR can use the cached alternative routes more efficiently. Thereby, when the network load is high, AODV is the protocol that sent more control packets.

B. Delivery Rate

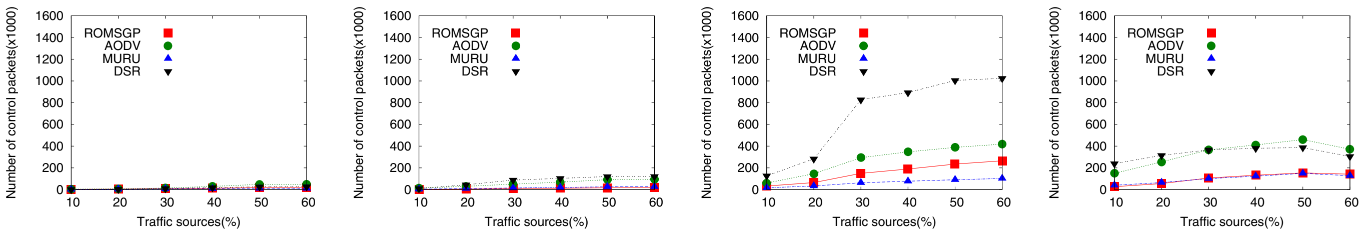
Figure 4 demonstrates the impact of network density on the rate of delivery for urban and highway scenarios. In the urban scenario, the increase in density affects the rate of delivery in two distinct ways (Figures 4(a) and 4(c)). In sparse networks, the increase in density results in a greater number of possible paths to be used in routing, which in turn results in better delivery rates. However, when the network becomes very dense the delivery rate becomes impaired, and from that point on, increased density shall adversely affect the delivery rate. It is noteworthy that the behavior of the delivery rate is determined not only by the density of the network, but also by the number of source nodes. In this case, the greater the amount of source nodes, the greater the number of control packets needed to keep the network running. However, as network load increases, packet losses become more frequent, thus degrading the delivery rate.

In Figures 4(a) and 4(b) the network load is small (10% of source nodes). For this reason, the AODV and DSR protocols become more efficient when the density is low, while ROMSGP and MURU suffered delivering packets due to the mechanism implemented to avoid network overloading, and which is responsible for filtering the existing paths, electing those that can be used. As the network becomes denser, the protocols suffered more with network overloading. However, the ROMSGP and MURU protocols can better deal with this problem, thus softening the impact on the delivery rate. On the other hand, the DSR and AODV protocols had their performance significantly affected by sending excessive control packets, resulting in a sharp drop in the rate of delivery. Comparing the best delivery rate achieved by the protocols



(a) Urban: 10% of traffic sources (b) Highway: 10% of traffic sources (c) Urban: 30% of traffic sources (d) Highway: 30% of traffic sources

Fig. 1. Impact of density on the number of control packets.



(a) Urban: 100 vehicles (b) Highway: 100 vehicles (c) Urban: 300 vehicles (d) Highway: 300 vehicles

Fig. 2. Impact of load on the number of control packets.

with the rate achieved with the densest network, we can see more clearly how effective the routing protocols for vehicular networks are.

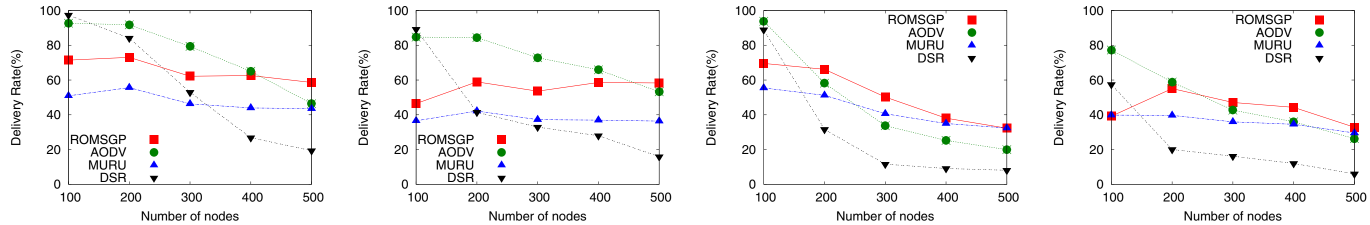
Figures 4(c) and 4(d) show the performance of the protocols in a network with 30% of source nodes. A greater number of nodes generating messages only accelerates the process observed in the previous scenario: the degradation of delivery rate due to increased density and network load. As we can observe when the network density is low, the AODV and DSR protocols are more efficient for the same reasons previously discussed. However, when the density rises to two hundred vehicles, we observe a different behavior in the urban scenario compared to the previous scenario: the protocol that achieves the best delivery rate is ROMSGP and not AODV, due to network overhead generated by control packets sent. In turn, in the highway scenario, the ROMSGP protocol becomes more efficient after the vehicle density exceeds three hundred vehicles, as increasing road density affects sending control packets, and hence the network overhead, more subtly.

Figure 5 shows the impact of raising the delivery rate in urban and highway scenarios. Figures 5(a) and 5(b) illustrate the performance of the simulated protocols when applied to a sparse network, more specifically with one hundred nodes. As this is a sparse network, that is, with few possible paths to be used in routing, the ROMSGP and MURU protocols do not exceed the typical MANETs protocols, because they implement mechanisms to avoid overloading the network. Conversely, although avoiding some paths is not stable, it allows the delivery of data packets.

Perkins et al. [8] show through simulations that the DSR protocol is more efficient in networks that have low load and / or whose nodes have low mobility, whereas AODV is more efficient in networks with high load and increased mobility of the nodes. Figure 5(a) shows exactly this behavior. At first, when the network load is low, the DSR protocol delivers more packets than AODV. However, as the network load increases, the performance of DSR decreases to the point where AODV exceeds the rate of delivery over DSR. The same behavior can be observed in Figure 5(b).

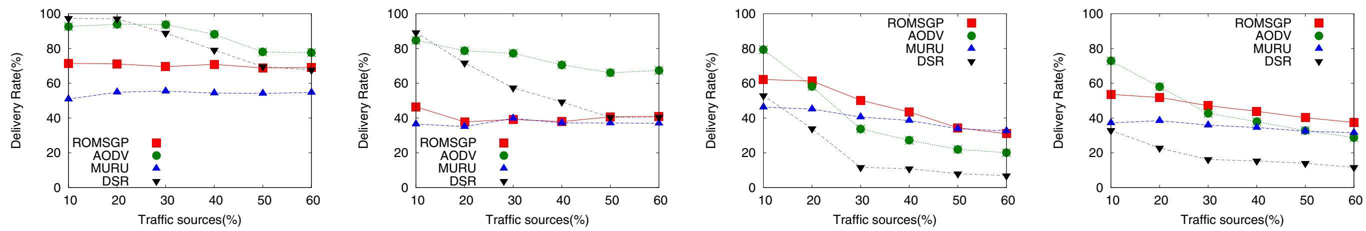
Figuress 5(d) and 5(c) illustrate similar behavior. In all of them, as the network load increases, the delivery rate of the protocols decreases. However, small differences are noticeable. In Figures 5(d) and 5(c), when the network load is minimal, AODV is the protocol with the best delivery rate. According to the increasing number of source nodes, more data packets are sent, so more control packets are needed to ensure the delivery of data, thus generating a network overhead. For this reason, protocols such as AODV and DSR, which do not implement efficient overload control mechanisms, have their performance most affected. On the other hand, protocols like MURU and ROMSGP that implement overload control mechanism are mildly affected in their performance. Thus, when the network load is maximum, the protocols with better delivery rates are ROMSGP and MURU.

Table II presents an overall summary of delivery rate. Note that AODV and DSR present better delivery rate when the network is sparse. When the network reaches its maximum density, vehicular protocols outperform AODV and DSR. In conditions where network overhead is high, due to the increased number of sources, MURU presents the best performance among the simulated protocols. In addition, MURU presents the smallest variation of delivery rate. We may also note that in the highway scenario mobile ad hoc protocols achieve better delivery rates. However, unlike that observed



(a) Urban: 10% of traffic sources (b) Highway: 10% of traffic sources (c) Urban: 30% of traffic sources (d) Highway: 30% of traffic sources

Fig. 4. Impact of density on the delivery rate.



(a) Urban: 100 vehicles (b) Highway: 100 vehicles (c) Urban: 300 vehicles (d) Highway: 300 vehicles

Fig. 5. Impact of load on the delivery rate.

TABLE II
COMPARISON OF PROTOCOLS IN RELATION TO THE DELIVERY RATE.

Conditions	**10% of sources**		**30% of sources**		**50% of sources**	
	Urban	**High-way**	**Urban**	**High-way**	**Urban**	**High-way**
Max Delivery Rate	DSR	DSR	AODV	AODV	AODV	AODV
Max Delivery Rate under Max Density	AODV	AODV	MURU ROMSGP	ROMSGP	MURU	MURU ROMSGP
Minor variations in Delivery Rate	MURU ROMSGP	MURU	MURU	MURU	MURU	MURU

in the urban setting, AODV achieved the better delivery rate, even when the network density was maximal. However, the protocols for vehicular networks were those with minor variations in the delivery rates.

V. CONCLUSIONS AND FUTURE WORK

We presented a performance analysis of two protocols for vehicular networks, namely MURU and ROMSGP, in different network scenarios and operating conditions. Comparisons were made with well-known protocols of mobile ad hoc networks, namely AODV and DSR. We showed that routing protocols still have to evolve to achieve satisfactory performance. A first general research direction is to consider metrics that use information available in various scenarios. A second general research direction is the need for an overload control mechanism able to adapt its behavior according to network density. The evaluated mechanisms do not achieve good performance in sparse networks due to the high number of packets dropped, while in dense networks the performance is satisfactory.

Our future work will focus on the development of an adaptive routing protocol that takes into account the guidelines indicated by this work. Therefore, it is expected to develop a protocol that adapts to network conditions, such as density, mobility pattern, the type of scenario, among others. Moreover, to decrease the gap between our evaluation and possibles results in the real scenario, we intend to use the 802.11p, that is a protocol created to support this kind of network.

REFERENCES

[1] J. Bernsen and D. Manivannan, “Routing protocols for vehicular ad hoc networks that ensure quality of service,” in *International Conference on Wireless and Mobile Communications (ICWMC)*, 2008.

[2] A. Abedi, M. Ghaderi, and C. Williamson, “Distributed routing for vehicular ad hoc networks: Throughput-delay tradeoff,” in *IEEE International Symposium on Modeling, Analysis & Simulation of Computer and Telecommunication Systems (MASCOTS)*, 2010.

[3] S. Wan, J. Tang, and R. Wolff, “Reliable routing for roadside to vehicle communications in rural areas,” in *IEEE International Conference on Communications (ICC)*, 2008.

[4] Z. Mo, H. Zhu, K. Makki, and N. Pissinou, “MURU: A multi-hop routing protocol for urban vehicular ad hoc networks,” in *International Conference on Mobile and Ubiquitous Systems - Workshops*, 2006.

[5] E. Sakhaee, T. Taleb, A. Jamalipour, N. Kato, and Y. Nemoto, “A novel scheme to reduce control overhead and increase link duration in highly mobile ad hoc networks,” in *IEEE Wireless Communications and Networking Conference (WCNC)*, 2007.

[6] C. Perkins and E. Royer, “Ad-hoc on-demand distance vector routing,” in *IEEE Workshop on Mobile Computing Systems and Applications (WMCSA)*, 1999.

[7] D. B. Johnson, D. A. Maltz, and J. Broch, “DSR: The dynamic source routing protocol for multi-hop wireless ad hoc networks,” in *Ad Hoc Networking*. Addison-Wesley, 2001.

[8] C. Perkins, E. Royer, S. Das, and M. Marina, “Performance comparison of two on-demand routing protocols for ad hoc networks,” *IEEE Personal Communications*, vol. 8, no. 1, pp. 16–28, 2001.