Journal of Information Technology Research
Volume 15 • Issue 1

An Analysis of Route Duration Times in Vehicular Networks Considering Influential Factors

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ABSTRACT

Vehicular ad hoc networks (VANETs) are part of intelligent transportation systems (ITS) and their main objective is to provide communication between vehicles. As self-organizing and configuring networks, with decentralized control, their performance is totally dependent on the route duration times. This study proposes an analysis of the route duration times in vehicular networks, considering three influential factors: speed, density, and travel orientation. Simulation experiments corroborate that the route duration times increases in denser networks and when vehicles travel in the same direction. However, contrary to common sense, unexpectedly, it is demonstrated that the route duration times in realistic vehicle environments do not decrease as the vehicle speed increases due to the mobility restrictions in this environments (stops at traffic lights and road crossings, braking to avoid collisions, acceleration and deceleration).

KEYWORDS

Analysis, AODV, Influential Factors, Protocols, Routing, Routing Duration Times, VANETs

INTRODUCTION

Vehicular Ad Hoc Networks (VANETs) are mobile networks whose main objective is to provide communication between vehicles (cars, trucks, buses, etc.) and are part of Intelligent Transportation Systems (ITS) (Alves Jr & Wille, 2015). The goal of ITS is to improve the user experience (drivers, passengers, and pedestrians) in traffic by providing safety, conscious and efficient use of resources, and entertainment. It provides real-time information such as adverse road conditions, weather, congestion, and local tourist information. This information helps to plan the route, reducing environmental pollution, improving vehicle performance and contributing to the users' well-being (Alam & Ferreira, 2016) (Li, Zhen, Sun, Zhang, & Hu, 2016), (Alrawi, 2017), (Hong Zhang and Xinxin Lu, 2020).

The nodes of such networks communicate with one another by means of radio-frequency signals. As radio signals have a limited power, each node can directly communicate with those vehicles within transmission coverage. However, frequently there is the necessity of transmitting information to

DOI: 10.4018/JITR.299927
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some out-of-range vehicles. In order to accomplish that, the vehicles must cooperate with each other, acting as routers (finding routes and passing information from origin to destination). The sending/receiving of information only occurs when the origin vehicle has a route to the destination vehicle (Almohammedi, 2016). As vehicular networks are self-organizing and configuring networks, with decentralized control, their performance is utterly dependent on the existence of routes and the time these routes stay established (while a route stays established, both the origin and the destination are able to send and receive data) (Alves Jr & Wille, 2016).

In VANETs, the main communication challenges are related to connectivity problems between vehicles due to short route duration times (Tong, L.; Xia, Z.; Shi, S. & Gu, X., 2018). Knowing and evaluating these times and the factors which most impact them could help developing more adequate protocols and applications in order to optimize network connectivity, as well as to contribute to a more efficient vehicular communication infrastructure. In these networks, the main factors that can influence the route duration times and network connectivity are: speed, density, travel orientation and transmission range of the vehicles (Alves Jr & Wille, 2016).

Most of the analyses of route duration times and network connectivity are carried out through numerical studies (Raw, Kumar Soni, Singh, & Kaiwartya, 2014), (Ajeer, Neelakantan, & Babu, 2011), (Nazar & Alsabbagh, 2016). Such studies take into consideration the values of speed, density and movement orientation of the vehicles (the most influential factors), but do not consider the infrastructural conditions (roads, squares, intersections and traffic lights) and also the vehicular flow (traffic jams). Because of this, some results may not faithfully represent the reality of vehicular mobility.

This work aims to analyze route duration times, general network connectivity and performance metrics to identify which are the most important factors in the environment where a system will operate. The logic of the analysis corresponds to comparing different situations. The first study considers two scenarios with opposite mobility characteristics (more specifically, a scenario where the vehicles movement are unrestricted and a scenario where the vehicles movement are conditioned by the streets layout in an urban homogeneous environment). The second study considers a scenario whose only aim is to evaluate the impact of the vehicles movement orientation on the performance of the network. The identification of the most important factors related to network performance is an information that may help industry and academia to develop, for example, better routing protocols.

The rest of this work is organized as follows: Section 2 presents related work. The main contribution of this work, i.e., an approach to study the influence of physical factors on the performance of vehicular mobile networks, is given in Section 3. Section 4 shows the results of the simulations. Finally, Section 5 presents the conclusion and future work.

RELATED WORK

The author in (Tong, L.; Xia, Z.; Shi, S. & Gu, X., 2018) has developed RAODV (Robust Ad-Hoc On Demand Distance Vector), a protocol that takes into consideration the node speed in order to select the most stable route in MANETs (the route with the lowest average speed). Simulation results have showed that the protocol is capable of selecting stable routes, thus lowering the network overload and increasing the packet delivery rate.

The authors in (Aliesawi, Alheeti, & M. Alfahad, 2018) have shown a routing protocol, the U-AODV (Urban-Ad-Hoc On Demand Distance Vector). Its objective is to minimize link interruptions which may occur in the network. In this regard, it considers factors such as speed and vehicle travel orientation in order to select the next hop during route discovery stage. In reducing link interruptions, the U-AODV proved to be more efficient when compared to AODV, mitigating network overload and increasing the packet delivery rate.

The study in (Hussain, Wu, Memon, & Khuda Bux, 2019) has taken into consideration factors such as speed, broadcast radius range, and road length in order to propose an application capable of easing the congestion of vehicles at toll stations. The vehicles that use this application and are at a toll station tell other coming vehicles to slow down, thus reducing queuing. The simulation results showed that the system is capable of reduce traffic congestion.

The authors in (Umer & Afzal, 2018) have proposed a connectivity model comprised of a double communication ring. The model takes into consideration the number and the speed of different kinds of vehicles (buses and automobiles) present on the road. This model is comprised of a primary and a secondary ring. The fast-moving vehicles (automobiles) make up the primary ring, while the slow-moving vehicles (buses) constitute the secondary one. When routes break because of the vehicle speeds in the primary ring, the secondary ring may be used for the creation of new routes (the probability of interruption due to speed is lower in this ring). This study proved effective in improving network connectivity, bringing down the delay in data delivery.

The authors in (Manel & Lamia, 2017) have presented the routing protocol SODV (Speed based Ad Hoc on Demand Vector link Routing Protocol). The SODV takes into consideration the instantaneous speed geometric average in order to establish the most stable route (the one with the geometric average closest to the origin node instantaneous speed). The geometric average was chosen because it portrays reality better than arithmetic average does. Simulation experiments have shown that the SODV protocol presented a shorter delay than the AODV routing protocol.

It can be noted that some studies consider problems pertaining to network connectivity and link/route interruptions, as well as the use of influential factors for several purposes. In addition, these works perform analytical studies to determine the performance of mobile networks using models that are not as rich in detail. Thus, they do not respond adequately to particular aspects of the environment considered. Our work, on the other hand, very carefully considers road infrastructure conditions and vehicular traffic in the system study.

VANET'S PERFORMANCE ANALYSIS

This section shows the metrics used to evaluate the vehicular network performance. In addition, a single standardized metric (based on the route duration time) is proposed.

Performance Metrics

The following quantities are considered:

- **Route Duration Rate - RDR:** Corresponds to the successful connection percentage during the simulation time. The Equation 1 formally defines the RDR:

$$RDR = \left(\frac{x}{t}\right) * 100 \tag{1}$$

where x is the average of the duration times of all established routes and t the simulation total time.

- **Route Interruption Index - RII:** Corresponds to the number of interruptions of an established route.
- **Packet Delivery Rate – PDR:** It is the ratio between the number of packets received at destination (Nr) and the number of packets sent by the source (Ng), i.e., $PDR = Nr \,/\, Ng$.
- **Routing Overload - RO:** It is the ratio between the number packets received at destination (Nre) and the total number of routing packets sent by the source (*Ndr*), i.e., $RO = Nre \,/\, Ndr$.
- **Average Packet Delay - APD:** It is the average delay undergone by data packets from source to destination. The delay includes total transmission time, i.e., propagation time, waiting time (queuing), route establishing time, etc. The Equation 2 formally defines the APD:

$$APD = \frac{1}{Np}\sum_{i=1}^{Np}\left(tr - te\right) \quad (2)$$

where *tr* is the exact time instant when destination receives a packet, *te* is the exact time instant when origin sends a packet and *Np* is the number of packets sent.

General Network Connectivity

As defined by Equation 3, the route duration time (ΔT) is the time interval in which a source and a destination vehicle remain connected using at least two hops (if there are no two hops, a direct connection (link) is formed):

$$\Delta T = t2 - t1, \forall r \geq 2 \quad (3)$$

where t1 is the exact time instant when a given route was established, t2 is the exact time instant when that route was broken and r is the number of hops.

Then, the general network connectivity (C) is defined as the average of the duration times of all established routes in a network during a given time interval TT, and it is given by Equation 4:

$$C = \frac{1}{n}\sum_{i=1}^{n}\Delta T^{(i)} \quad (4)$$

where $\Delta T^{(i)}$ is the duration time of route i and n the number of established routes. The general network connectivity is measured in seconds and its maximum value is TT.

Simulation Scenarios

In this study, three different simulation scenarios are employed. The logic of the analysis corresponds to comparing two different situations. First, the results obtained from Scenarios 1 and 2 are compared to each other to show the effect of mobility on the network performance.

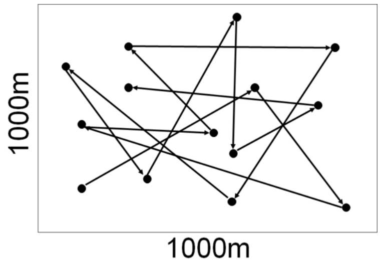
Thus, a typical vehicular network scenario (Scenario 2), where the movement of nodes is conditioned by the arrangement of streets in an urban and homogeneous environment, is compared to a situation of total freedom of movement (Scenario 1). The comparison between these two situations makes it possible to highlight the factors that have the greatest impact on the system. Finally, Scenario 3 has the sole objective of evaluating the impact of the direction of movement of the nodes on the network performance. In this case, the two situations correspond to a pair of nodes moving in the same direction or in an opposite one.

The Network Simulator (NS-2) (Greis, 2019), the vehicular mobility simulator VanetMobiSim (Härri, Filali, Bonnet, & Fiore, 2006), and the random mobility simulator Setdest (Sarkar, Choudhury, & Majumder, 2018) were used for these analyses.

Scenario 1

As illustrated in Figure 1, the Scenario 1 is a quadrangular area of 1,000 m x 1,000 m with no roads or squares. In this scenario, vehicles travel according to the Random Way Point (RWP) mobility model. In RWP, each node stops for a period of time at a predefined interval. Next, the nodes randomly select one of the possible paths from their starting points, with a speed ranging from MIN to MAX. In reaching the destination, a node remains standing for a predefined amount of time and restarts the process. Such model represents a non-real environment (without the characteristics of a realistic vehicular

Figure 1. Scenario 1



mobility model). For this scenario, the vehicle stop time is 1 second (Purnomo, Widyawan, Najib, Hartono, & Hartatik, 2018). In this scenario the vehicles mobility is free of obstacles or intersections and the contacts between vehicles are short-lived ones (Mahajan, Potnis, Gopalan, & Wang, 2010).

Scenario 2

As illustrated in Figure 2, the Scenario 2 is a quadrangular area of 1,000 m x 1,000 m (Alam, Sher, & Husain, Integrated Mobility Model (IMM) for VANETs simulation and its impact, 2009). Squares with 100 m x 100 m were chosen because this is the default value in most cities. This scenario corresponds to a Manhattan's grid with horizontal, vertical and intersection streets that represent a real and urban environment (Mir & Filali, 2014), (Spaho, et al., 2013), (Sallum, dos Santos, Alves, & Santos, 2018). The vehicles can move according to the mobility model implemented in the VanetMobiSim software, which considers a system with dual lane, acceleration, deceleration and overtaking without collisions. Some random traffic lights are present. The speed of a vehicle is conditioned by the speed of the vehicle ahead. This scenario is compatible with that found in large cities.

Scenario 3

As illustrated in Figure 3, Scenario 3 there are two quadrangular areas of 2,000 m x 1,000 m (with 30 vehicles in each one), where vehicles travel according to the VanetMobiSim's mobility model. On area A, the vehicles may move clockwise or counter-clockwise. On area B, the vehicles travel in a clockwise movement. Thus, in the central region, two situations may happen: the creation of routes with vehicles traveling either in the same or in opposite directions.

Figure 4 (a cutout of the central region of Figure 3) shows that 6 road-side units were inserted and they act as source and destination in a cross-communication mode. Cross-communication means: the

Figure 2. Scenario 2

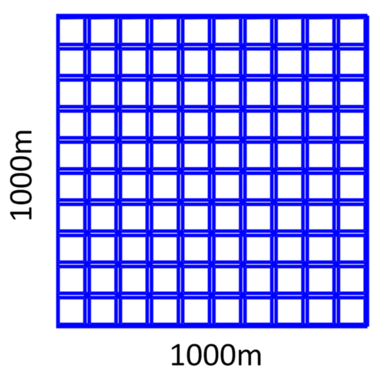


Figure 3. Scenario 3

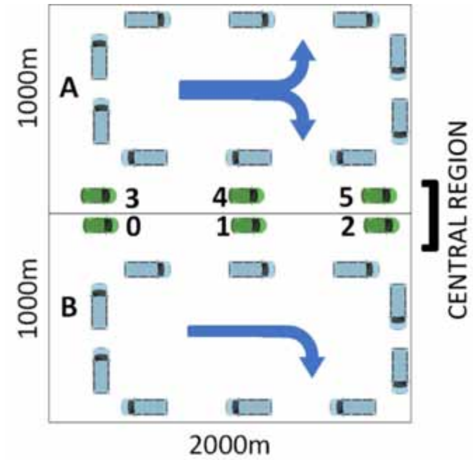
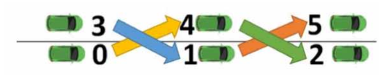


Figure 4. Central region of figure 3



fixed point 0 communicates with point 4 and point 4 with point 2. The fixed point 3 communicates with point 1 and point 1 with point 5. This network topology was used to ensure route establishment between vehicles in areas A and B.

Simulation Setup

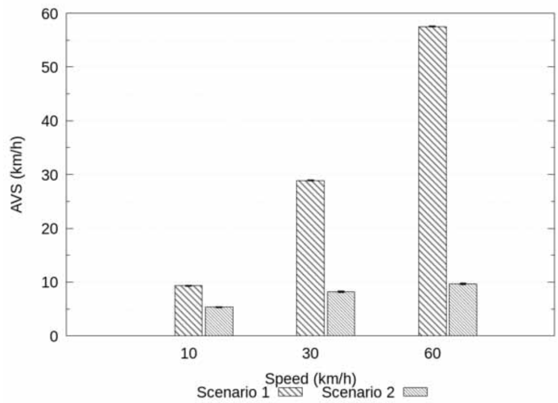
In this work, the traffic is modeled as constant bit rate (CBR - with 4 messages / s), considering the UDP transport protocol and the AODV routing protocol (Sallum, dos Santos, Alves, & Santos, 2018). The radio propagation model used is the Two Ray Ground, while the MAC layer is in accordance with the IEEE 802.11p standard (Jiang & Delgrossi, 2008). Five simultaneous connections are considered, where source and destination are chosen at random at the beginning and remain operative until the end of the simulation. The simulations are performed for 600 seconds for Scenarios 1 and 2 and for 2,000 seconds for Scenario 3. All the presented results are averages of 35 simulations with the same traffic model, but with different mobility scenarios. For these simulations, the confidence interval considered is 95%.

SIMULATION RESULTS

In this section, simulation results of all discussed models are presented. The charts show on the x-axis the influential factors (speed, density and travel orientation) variation and on the y-axis the values obtained for the set of performance metrics, namely, Route Duration Rate (RDR), Route Interruption Index (RII), Packet Delivery Rate (PDR), Routing Overload (RO), and Average Packet Delay (APD).

Initially, it is observed that, in Scenario 2, is due to the fact that VanetMobiSim represents the vehicles behavior more faithfully (stops at traffic lights and road crossings, braking to avoid collisions, acceleration an deceleration, etc.), the average speeds of the vehicles (AVS) are very close to each other regardless of achievable maximum speeds (10, 30 and 60 km/h), as shown in Figure 5. This

Figure 5. AVS for the Scenarios 1 and 2



suggests that the impact of speed in real environments is mitigated. Scenario 1 corresponds to an opposite situation where vehicles are free to move in the area.

Another factor that must be considered when analyzing the scenarios is related to the vehicles ability to establish connections. In Scenarios 1 and 2 a reduced number of vehicles (nodes) or a reduced transmission radius substantially decreases the network connectivity probability (see analytical development in Appendix 1) with negative impact on all metrics.

Simulation Model 1: Analysis of Speed Variation

In this case the vehicles have speeds that vary between 10 km/h and 60 km/h, the transmission radius is 250 m and the number of vehicles varies from 10 to 100. The goal is to evaluate the influence of speed on the route duration time.

Figure 6 shows the RDR as function of speed for Scenario 1 and for Scenario 2. The figure is further divided into three boxes according to the number of vehicles considered: 10 vehicles in box (a), 50 vehicles in box (b), and 100 vehicles in box (c). Note in Scenario 1 (RWP) that as the speed increases, the RDR decreases (as expected). However, for Scenario 2 (VanetMobiSim), the RDR does not necessarily decrease as the vehicles hardly reach maximum speed.

Figure 7 presents the RII versus speed variation. As can be observed on Scenario 1, the RII increases as vehicles speed up. This behavior is obtained as a function of the vehicles driving away

Figure 6. RDR for simulation models 1 and 2

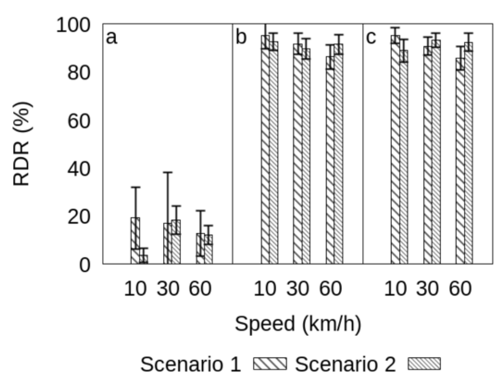
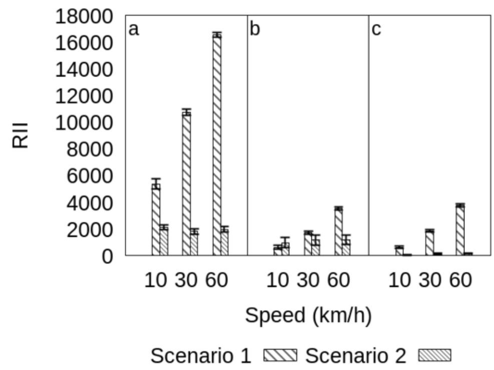


Figure 7. RII versus speed



from each other's transmission range, breaking the already established connections. However, for Scenario 2, as the vehicle speeds do not vary too much, the routes do not easily break, because vehicles remain longer in connection. Thus, the RRI for a more realistic scenario does not necessarily increase as vehicles speed up.

It can be observed in Figure 8 that, for the least realistic scenario (Scenario 1), the RO increases as vehicles speed up. This fact is due to the constant route interruptions that occur because of speed variations. The route interruptions incur in new discovery processes, generating more routing packets than data packets in the network. However, in a more realistic scenario, where there are less route interruptions due to less variation of the average speed, the RO varies little as vehicles speed up (except when the connectivity probability is low).

As can be seen in Figure 9, for Scenario 1, the PDR will slightly decrease as vehicle speeds increase. This behavior occurs on account of more route interruptions. However, in Scenario 2, the PDR does not necessarily decrease as speed goes up. This occurs due to low vehicular mobility (similar average speeds), resulting in less route interruptions.

Figure 10 shows the APD in function of the vehicles speed. It is possible to observe that APD, in Scenario 1, presents higher values than in Scenario 2. This happens in function of a higher number of interruptions of the established routes caused by high vehicular mobility, and an extra time will be required for new route discoveries to be made (Liu & Yang, 2013).

Figure 8. RO increase

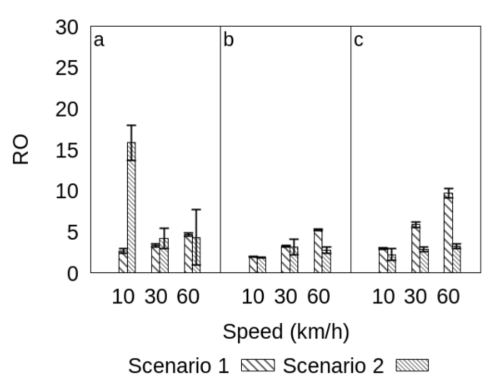


Figure 9. PDR decrease

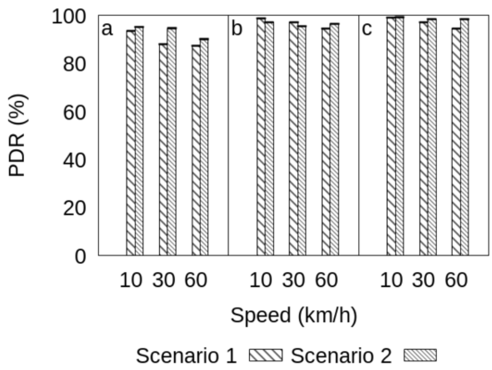
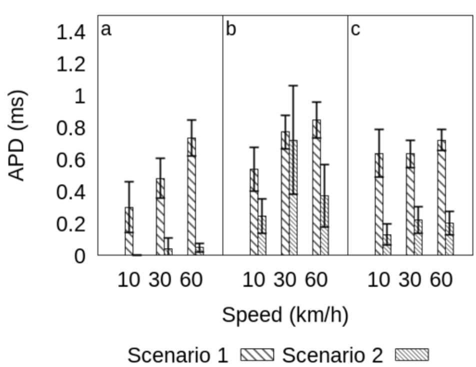


Figure 10. APD for simulation models 1 and 2



Simulation Model 2: Analysis of Density Variation

When the network metrics are observed under the point of view of vehicular density variation (given a fixed speed), it is possible to observe that the RDR (Figure 6) increases or remains stable as the number of vehicles increases in both scenarios. This fact occurs because the denser the network the greater the chance of establishing routes (as shown in Appendix 1, the connection probability increases directly with the number of vehicles).

As can be seen Figure 7, the RII decreases or remain stable as the number of vehicles increases. This is due to the fact that routes do not break easily if the number of vehicles increases. Figure 8 shows that the RO increases (given a fixed speed) as the number of nodes increases in the network. This happens because of the reduction in route interruptions in the network due to a higher vehicular density. As observed in Figure 9, the PDR increases as the number of nodes increases in the network. This occurs because of fewer interruptions of the network established routes, on account of the high vehicular density.

However, the APD (Figure 10), in Scenario 1, does not necessarily decrease as the number of vehicles increases. This fact is observed because the denser the area the higher the number of routing packets which are forwarded by the network, causing a higher delay on data delivery. Besides, when a vehicle receives routing packets while is transmitting data packets, the transmission is broken and data packets are stored in queue until all routing packets are sent.

Simulation Model 3: Analysis With Variation in Travel Orientation

In this case, the movement orientation of the vehicles is considered. Vehicles can travel in the same or in opposite direction. The speed varies from 10 km/h to 60 km/h, the number of vehicles is 66 and the transmission radius varies from 150 m to 350 m. The objective is to analyze the influence of the vehicle displacement direction on the time duration of the routes.

Figure 11 shows the RDR as a function of movement orientation versus speed, for Scenario 3. The figure is further divided into three boxes according to the transmission radius considered: 150 m in box (a), 250 m in box (b), and 350 m in box (c). It can be observed that when vehicles travel in opposite directions (from a radius of 250 m), the RDR slightly decreases as speed goes up. Regarding displacement, vehicles travel away from each other's transmission range more easily, therefore, routes will break more frequently, decreasing the RDR. However, when vehicles move in the same direction, they remain longer within each other's transmission radius, thus enabling routes to keep operative for as long as possible. However, with a 150 m radius, the RDR is too low because the contact between vehicles is reduced during the whole simulation and the connectivity probability (Appendix 1) is lower in relation to the other transmission radius.

The Figure 12 shows that the RII increases, in both directions, as the speed of the vehicles increases. In opposite direction, vehicles travel away from each other's transmission radius more easily. This distancing causes several disconnections, increasing the RII. However, in the same direction,

Figure 11. RDR as a function of movement

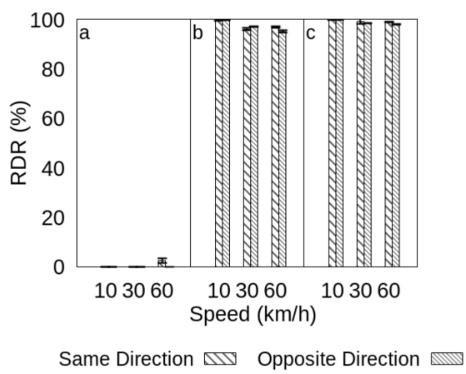
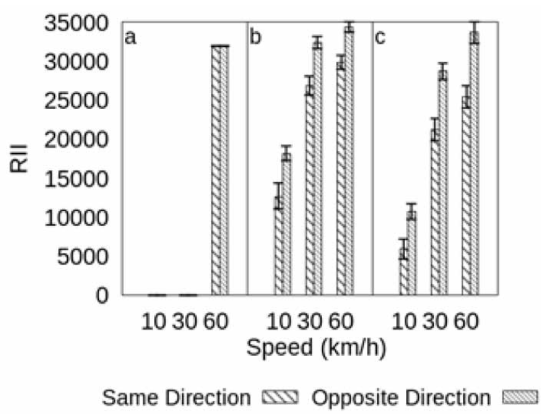


Figure 12. RII increases



although the routes may be broken they will quickly be restored, for the chance of a vehicle getting into another's transmission radius is bigger, because the vehicles always move in the same orientation in the central region of the scenario.

In Figure 13 we observe the RO increases with speed. In this case, one can observe what happens due to constant route interruptions, the RO is greater in the case of opposite direction.

Figure 14 shows the PDR and it is possible to observe that the PDR decreases the speed increase. Thus, better performance is found when vehicles travel in same direction.

It is observed that the constant route breaks cause the delay to increase as a function of speed (Figure 15) (when the routes break, the data packets are queued until the route is reestablished and, with that, the APD increases). Vehicles traveling in opposite direction also raise the APD.

Factors With Greater Influence in General Network Connectivity

This section aims to point out the most influential factor (speed, density, or travel orientation) on general network connectivity, by analyzing all results provided by Equation 4, applied to every simulation model on each scenario. As can be seen in Table 1, for Scenarios 1 and 2, the most influential factor on network connectivity (makes connectivity higher) is density, followed by speed. This behavior is due to the fact that the higher the density the higher the probability of connection.

Besides, Table 2 shows that in Scenario 3, the most influential factor on general network connectivity is the movement of vehicles in the same direction. Such event is because same

Figure 13. RO for simulation model 3

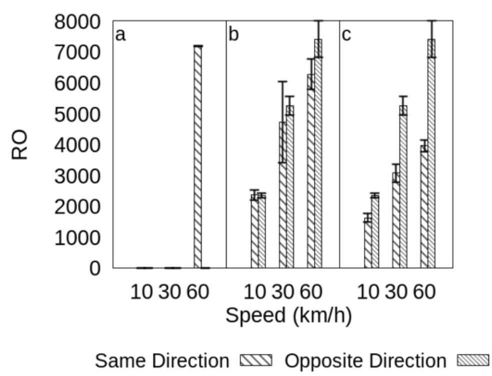


Figure 14. PDR decreases

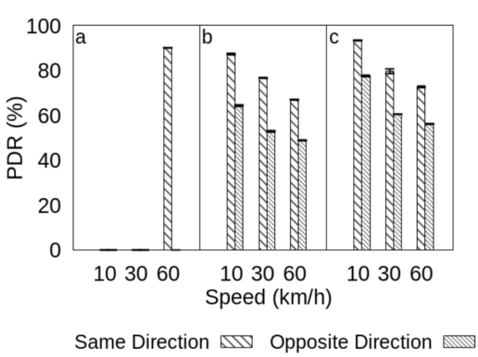


Figure 15. APD for simulation model 3

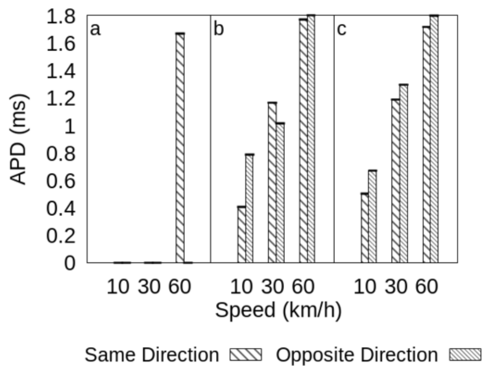


Table 1. General Network Connectivity: Speed and Density

Factors	Scenario 1	Scenario 2
Speed	388.75	395.63
Density	596.48	524.65

Table 2. General Network Connectivity: Movement Orientation

Factors	Scenario 3
Same Direction	1318.80
Opposite Direction	1307.55

direction traffic favors the vehicle's permanence within each other's range and contributes to increase network connectivity.

CONCLUSION

This study has proposed an analysis of the implications of route duration time and metrics which impact vehicular network performance, considering three influential factors, namely speed, density and movement orientation.

Simulation experiments proved that the RDR increases as the network becomes denser and when vehicles travel in the same direction, minimizing the interruptions of established routes, thus reducing the network overload and contributing to a higher packet delivery rate. However, contrary to common logic, in a more realistic scenario (Scenario 2), the RDR will not decline with an increase in speed. This is because the vehicle speeds are very close to each other due to realistic mobility characteristics (stops at traffic lights and road crossings, braking to avoid collisions, acceleration and deceleration).

As for the least realistic scenario (Scenario 1), the RDR decreases as the speed increases, because of the constant route interruptions which occur due to the vehicles high mobility, thus degrading network performance (increasing routing overload, decreasing the packet delivery rate, and increasing the packet delivery delay). Besides, the simulations demonstrated that the PDR also increases slightly or remain stable when vehicles travel in the same orientation. In this case, vehicles remain longer within each other's radio transmission range. Thereby, even if some routes break, they will soon be reestablished. However, when vehicles travel in opposite directions, the RDR decreases due to the increase in the number of broken routes.

Simulations have also shown, based on Equation 4, that the most influential factor on connectivity in the first and second scenarios is the density. Besides, simulation experiments concerning Scenario 3 showed that a relative displacement between vehicles is an influential factor on the general network connectivity, and the same-direction travel has a positive impact on all metrics.

A new routing protocol that considers, in its cost function, the factors that effectively impact the performance of the system (as evidenced in this work) is going to be proposed as future work.

FUNDING AGENCY

The publisher has waived the Open Access Processing fee for this article.

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APPENDIX: ADDITIONAL INFORMATION

Let be a set of *n* nodes, each one with a transmission radius r_0 (m), distributed according to a homogeneous punctual Poisson process in area A (m^2). According to Bettstteter (Bettstetter, 2002), the probability (*Pi*) of a node having no neighbors (i.e., be isolated) is given by $Pi = e^{\pi \rho r_0^2}$, where $\rho = n / A$ is the node density. In the case where the nodes are randomly positioned on a uni-dimensional axis with length x_{max}, then the probability *Pi* is given by $Pi = e^{-2\rho r_0}$, where $\rho = n / x_{max}$ is the node density. Thus, the network connectivity probability (i.e., the probability that no one of the *n* nodes will be isolated), assuming independent events, is $Pc = (1 - Pi)^n$. Results for *Pc* are presented in Table 3 with A = 10^6 m^2 and r_0 = 250 m (for Scenario 1), and x_{max} = 2,000 m and *n* = 24 vehicles (for Scenario 3). Because of the physical limitations imposed by Scenario 2, probability values which are a little smaller than those in Scenario 1 are expected.

Although the equations presented were obtained for fixed networks, according to Bettstteter they can be used for mobile networks as long as border effects (in the simulation scenarios) can be minimized.

Table 3. Connectivity Probability in Scenarios 1 and 3

Scenario 1			
Vehicles	10	50	100
Pc	22.0%	99.7%	100%
Scenario 3			
Radius (m)	150	250	350
Pc	51.4%	94.2%	99.5%