Research Article

Analysis of Connectivity Duration In Vehicular Network

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Abstract: Vehicular ad-hoc network (VANET) is an eminent component of intelligent transportation systems. VANET offers communication between moving vehicles on the road and the road-side objects using wireless network. Nowadays, automobile manufacturers have embedded numerous applications of VANET in vehicles for a safer and entertaining journey. Due to the frequent disconnection property of VANET, it is necessary to improve vehicular connectivity. To facilitate the dissemination of important and time-sensitive messages, network connectivity between vehicles are of great importance. To determine connectivity duration (CD) in a probabilistic manner, an analytical model is proposed in this study. The model makes the use of various factors, including transmission range, node density, vehicle spacing density, safety distance, road length and size of the cell. The CD is determined for the one-lane road segment in VANET. The impact of transmission range, road segment length and safety distance on vehicular connectivity is measured. The influence of safety distance between neighboring vehicles on CD probability is also evaluated. The result shows that 3% better connectivity is achieved in the road segment having a high transmission range. In case of safety distance, 68% better vehicular connectivity for the road segment that has a high transmission range.

Keywords: Vehicular ad-hoc network, Connectivity duration,Transmission range, Intelligent transportation systems

1. Introduction

Intelligent transportation system (ITS) offers instantaneous information on the road for users and transportation system operators in the smart city to take better decisions by applying communication and sensor technologies. According to the US Department of Transportation, the ITS highlights the use of dedicated short-range communications (DSRC) in connected vehicle technology [1].

VANET is a self-organized and distributed network consisting of vehicles with changing mobility and patterns to build an ITS [2-5]. The components of VANET include vehicles and roadside infrastructure that uses wireless LAN technology to make vehicular communication possible. The vehicle comprises various sensors that communicate with the sensors of another vehicle and infrastructure present on nearby road. Since vehicles move at relatively varying velocities, intercommunication can increase road safety. In VANET, Wi-Fi [1], Wi-Max [6] and WAVE [1], which is an amendment in IEEE 802.11 known as IEEE 802.11p [7], facilitate vehicular communication.

VANET consists of various applications that are generally categorized into road safety, road traffic management and infotainment applications [2]. All these applications are time-critical and require connectivity between vehicles. Some of these applications are broadcast of alarm messages related to current traffic status, lane changing warning and intersection assistance to the vehicles in the vicinity [1]. If the connectivity between vehicles is available, then all these messages are delivered in the appropriate time, enabling the drivers inside vehicles to act accordingly. As a result, there is an opportunity to reduce congestion on the road, wastage of fuel and number of accidents.

Due to the changing velocity and topology, the connection between vehicles is maintained for a lesser duration. Figure 1 represents the situation of a vehicle on the road at time instant t and situation after a time interval. At time t, S_v and D_v are in the communication mode; however, after an interval of time (t+), they are in the disconnected state due to the failure of link between them. Link failure occurs when the vehicles are out of transmission reach due to their moving velocities.

When vehicles are in the communication area, they are in the connected state. If they are outside the vicinity, then they are said to be in the disconnected state. Connectivity duration (CD) is the time interval during which the vehicles are in the connected state. The vehicles on the road are randomly distributed. In addition, they are associated with varying densities due to changing topologies. It is a critical task to determine the connectivity between vehicles; which can be represented as direct and indirect connectivity [8]. Direct connectivity designates single-hop connections between nodes. The nodes can interact with each other without relay nodes. Indirect connectivity includes multi-hop forwarding. It does not involve direct communications between these vehicles. The use of relay vehicles is necessary to dispatch the data. Determining the probability of CD is a complex task due to the changing mobility and variation in vehicular speed. It is assumed here that the two vehicles S_v and D_v are driving in the same or opposite directions, D is the Euclidean distance between them and the vehicle S_v acts as a reference node. Connectivity between the node is maintained until the distance D between any two successive vehicles in the direction fulfills the condition $D < R$, where R is the communication area. Connectivity of the vehicle depends on factors such as transmission range and intervehicle spacing. To ensure connectivity, the distance concerning any two intermediate vehicles must be less than the

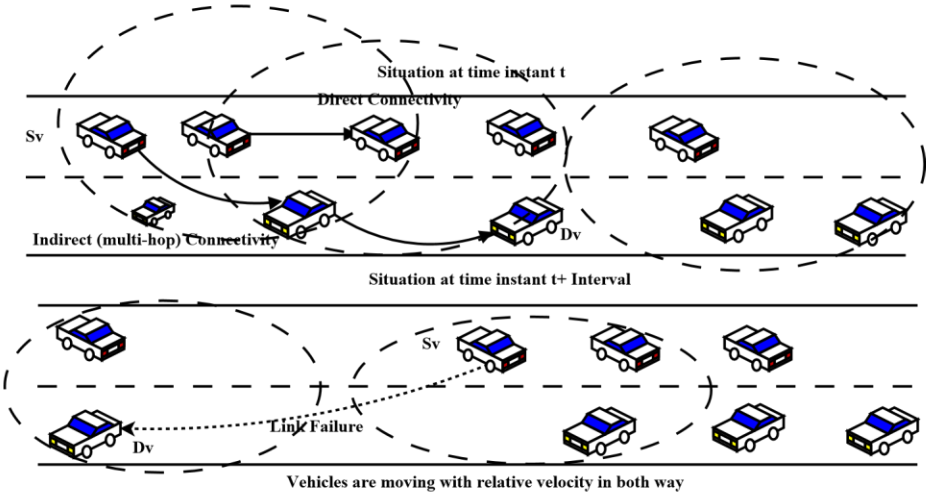

Fig.1. Vehicular connectivity

communication area. Various studies have used statistical modeling to evaluate the probability of network connectivity that depends on the above factors [7-11]. The density of vehicles and intervehicle spacing are interrelated with each other. The probability of the CD increases with extremely dense networks.

Vehicular connectivity is of prime importance to ensure consistent communication that improves the Quality of Service (QoS) in the VANET. Connectivity ensures more opportunities for vehicles to make wise and safe decisions about their actions and achieve better results. A mathematical framework designed by Panichpapiboon and Pattara-Atikom [12] highlights the importance of spatial node density on the intermediate hops traverse in the network topology. Similarly, Yan and Rawat [10] analysed V_2V connectivity using the mathematical model that considers acceleration, speed of the vehicles, transmission range, association time and headway distance. Shao et.al [13] used a Markov model to analyse V_2V and V_2R connectivity for one-way and two-way road scenarios.

Therefore, in this study, an analytical approach is proposed to determine CD between vehicles in a probabilistic manner. The impact of factors, such as transmission range, safety distance (S_d) and road segment length on the probability of CD, are evaluated for the one-lane road scenario in the VANET.

The organization of the paper is as follows. Section two describes methodology. The focus of the section is on the proposed analytical approach for the probability of the CD. Section three is the results and discussion. The last section focuses on the conclusion.

2. Methodology

System model

Easy distribution of time-sensitive facts in the VANET requires instant network connectivity [14]. When vehicles are within the communication reach of each other, a vehicle can get connected to another vehicle [15]. The CD determines the likelihood of vehicles in the connected state. Thus, when the transmission range is higher, connectivity among vehicles is higher too [16]. Connectivity of the vehicle shows an influence on performance metrics such as received packets and delays. The network becomes dense as more vehicles are in the coverage area; consequently, the delay is reduced and the received ratio of the packets is improved [17]. Due to the variation in vehicular density, the distribution of the vehicle is time-dependent. Thus, it is a complex task to determine CD.

One-lane road scenario that consists of two intersections j_i and j_j having road segment length as L is shown in Figure 2. The road segment is divided into partitions of the same size called a cell. The size of the cell is defined as $C_s = w \times R$, where R stands for the communication range and the weight parameter (w) lies between 0 and 1. Manually weight values are evaluated using an analogy of the Analytical Hierarchical Processing [21]. If C_s=1×R, the vehicle is located using randomly distributed fashion. The distance between the vehicles in any two separate cells becomes 2×*R*. Vehicles are distributed randomly and *K* indicates the total vehicles in an interval $w \times R$. When there is high transmission range and increasing vehicle spacing density (λ), partitions on the road segment are in the maintenance (repair) stage. There are several assumptions for deriving the connectivity model.

- On the road segment, the vehicles are randomly distributed [11, 16].
- Intervehicle space between adjacent vehicles can be represented as a stochastic distribution [10, 11].
- The distance among all vehicle pairs are independent and identically distributed (i.i.d) [14].
- All vehicles move with constant velocity when on the road segment [15].
- Packets are transmitted in the reverse direction of the movement direction of the vehicles [18].
- Every vehicle has an assigned transmission range using which it communicates with other vehicles [12].

Poisson distribution determines vehicle probability on the road and is calculated by Equation (1).

$$P(K) = \frac{wr\lambda}{k!} \times e^{-wr\lambda} \quad (1)$$

In case of probability, CD_{1-cell} indicates that each cell contains at least one vehicle and $C_s = w \times R$ is expressed in Equation (2).

$$CD1{-}cell = 1 - P = 1 - e{-}wr\lambda \quad (2)$$

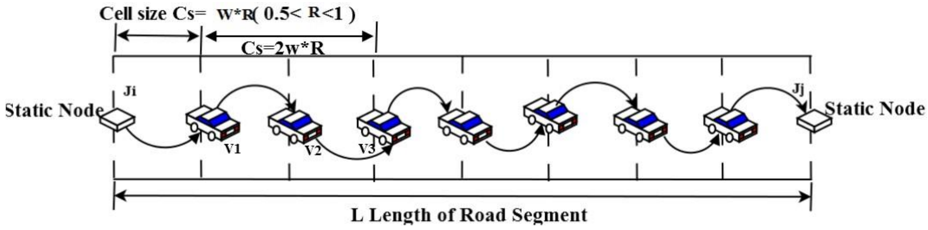

Fig.2. Vehicular connectivity

CD probability of the vehicles between j_i and j_j is illustrated by Equation (3), where *N* indicates total cells between intersections.

$$CD1{-}cell = 1 - P = (1 - e{-}wr\lambda)N \quad (3)$$

Connectivity Duration (CD) analysis using safety distance and transmission range

The vehicle driver must maintain a safe distance between the vehicle and the neighboring vehicles. If the vehicles are in the connected state, situations like car collisions may take place in the vehicular network as the scenario does not consider safety distance between vehicles. This ensures that the minimum safety distance is maintained between the two vehicles. The arrival time of the vehicles on a road are exponentially distributed with λ and the flow of traffic is λ vehicles/s. An ideal distance between two cars is approximately 11m, or the safety distance is 2 to 3s time interval between cars if the vehicle is a car [15]. The minimum safety distance between vehicles is known as distance headway (*DH*). The *DH* depends upon the type of vehicle, the weight of the vehicle and the speed of the vehicle. It is represented by h_i, where $i = 1,2,...,n$. Traffic theory suggests that safety distance between vehicles is *i.i.d* and it is exponentially distributed with β. *DH* is represented as a CDF and shown in Equation (4).

$$F_{DH}(h) = 1 - e^{\beta h} \quad (4)$$

In a free-flow state, the speed (V) of a vehicle is represented as the Gaussian distribution. Vehicular speed uses the variables V_{min} and V_{max}. The probability density function (PDF) is denoted by Equation (5).

$$g(V) = \frac{f(V)}{\int_{V_{min}}^{V_{max}} f(V) d_v} \quad (5)$$

Here, $f(V)$ uses μ as the average speed, standard deviation δ, and is denoted in the following Equations as a Gaussian PDF.

$$f(V) = \frac{1}{\delta\sqrt{2\pi}} e^{-(\frac{(v-u)^2}{2\delta^2})} \quad (6)$$

$$g(V) = \frac{2f(V)}{erf(\frac{V_{max}-\mu}{\delta\sqrt{2}}) - erf(\frac{V_{min}-\mu}{\delta\sqrt{2}})} \quad (7)$$

The average quantity of vehicles over a given road segment is represented in Equation (8). N_{lanes} indicates the available lanes on the roadway with road length (L).

$$N = \frac{L}{w \times R} \quad (8)$$

Based on traffic theory, $\beta = w$. The probability of the CD between two vehicles can be evaluated using Equation (9).

$$CD1{-}cell = 1 - P = (1 - e{-}w(R{-}Sd)\lambda)N \quad (9)$$

Here, S_d describes the safety distance, which is the minimum headway distance between vehicles. To ensure the safety of all vehicles on the road, $h_i \leq R - S_d$.

Hop count analysis for one lane road segment

Along with CD, hop count H_c and average hop distance are the two other parameters considered when determining the performance of the routing protocol. H_c is the measure that determines the number of hops visited by the source and the destination vehicles to achieve data transfer. It has been formulated using the below-mentioned Equation (10).

$$H_c = \frac{L}{(wR)+1} \quad (10)$$

Average hop distance is the distance taken by the source to the destination vehicle to forward the packet. It is determined by using Equation (11).

$$Averagehopdistance = \frac{L}{H_c} \quad (11)$$

3. Experimental Results and Discussion

Analytical Results

The CD probability of vehicles depends on various factors, like transmission range, vehicle spacing density, road length and size of the cell. Road segment length varies from 1000m-3000m. Vehicle spacing between two vehicles is assumed to be 0.015 vehicles/m. Analytical probability of CD is evaluated using condition, i.e., $C_s = 0.5R$, where $R = 250m$ The parameters used to evaluate the probability of CD are mentioned in Table 1. Thus, the influence of road segment length (L) on CD probability is evaluated analytically.

Table 1. Parameters used to evaluate the probability of CD

Parameter	Value
Communication Range (R)	250m & 500m
Spacing density between vehicles (λ)	0.015 vehicles/m
Length of the road (L)	1000m - 3000m
Cell size (C_s)	0.50 R, 0.75 R
Cells on the road amongst two intersections (	N) $N = \frac{L}{w \times R}$
Weight value (w)	0 to 1
Safety distance (S_d)	2m-20m

Experimental results

The CD is evaluated using simulation methodology that uses NS-2.35 [19]. VanetMobiSim is a widely adopted tool to prepare and validate IDM-IM [20] mobility scenarios. The number of vehicles used are 50. The traces are simulated for 300s with 4 traffic lights. The communication range varies from 250m and 500m. Vehicle spacing density is set at 0.015 vehicles/m. The simulation uses various traces mentioned in Table 2 and simulation settings are in Table 3. The probability of CD is measured for two separate conditions.

Table 2. Description of the various traces used in the simulation

Conn1000	1000	7	3

Conn1500	1500	18	9			
Conn2000	2000	40	22	4	50	300
Conn2500	2500	66	38			
Conn3000	3000	103	58			

Table 3. Parameters used to evaluate the probability of CD

Parameter	Simulation Value
Traces used	IDM-IM using VanetMobiSim
Velocity of the vehicle	Up to 20m/s
MAC protocol	IEEE 802.11p
Routing protocols used	ACO-IBR
Packet size	512-byte

The first condition uses cell size 0.5R and R = 250m and the second condition uses cell size 0.5R and R = 500m. For L = 1000m, the CD observed is 0.10 more in case of cell size 0.5R and R = 500m. For L = 3000m nearly equal CD is observed. The results are shown in Figure 3 and represented in Table 4.

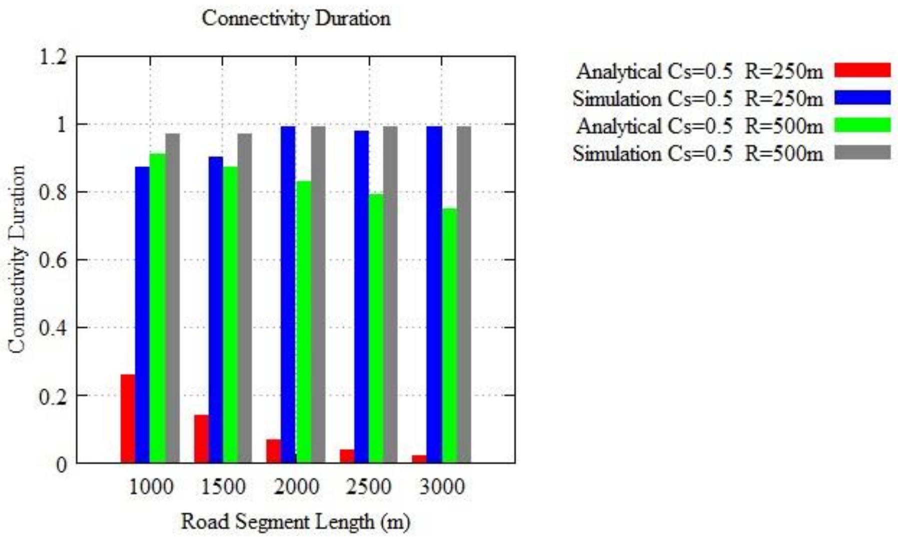

Fig.3. Simulation and analytical results for connectivity duration probability

Justification

As the road segment length and R are high, vehicles communicate with each other and remain connected for a slightly high duration. As well as there is scope for improvement in network partitioning on road segments, correlation and better agreement is achieved between vehicles. The CD probability becomes better in simulation and more communication exchange takes place between vehicles. In case of 500m transmission range, there is a very small variation in the mathematical and simulation results. When L is long, vehicles are dispersed in the communication vicinity and the probability of void region is higher. Thus, L produces less CD probability for less R. However, in analytical results, the CD probability reduces with the increasing transmission range.

Hop count and hop distance analysis

H_c is dependent on C_s, L and is evaluated for various L varied from 1000m to 3000m. H_c increases linearly with growing length of the road segment but reduces with the growing transmission range. Also, small-sized cells results in more H_c. Along with H_c, the average hop distance is evaluated for the various road segment lengths. As the road segment length and the transmission range increases, the average hop distance is increased linearly. The growth in the cell size also shows more average hop distance. The results are graphically represented in Figure 4 and represented in Table 4.

Table 4. Simulation Results

L	$C_s = 0.5R$ & $R = 250m$	$C_s = 0.5R$ & $R = 500m$

	Analytical	Simulation	H_c	Average Hop Distance (m)	Analytical	Simulation	H_c	Average Hop Distance (m)
1000	0.26	0.87	9	111.11	0.91	0.97	5	200.00
1500	0.14	0.9	13	115.38	0.87	0.97	7	214.29
2000	0.07	0.99	17	117.65	0.83	0.99	9	222.22
2500	0.04	0.98	21	119.05	0.79	0.99	11	227.27
3000	0.02	0.99	25	120.00	0.75	0.99	13	230.77

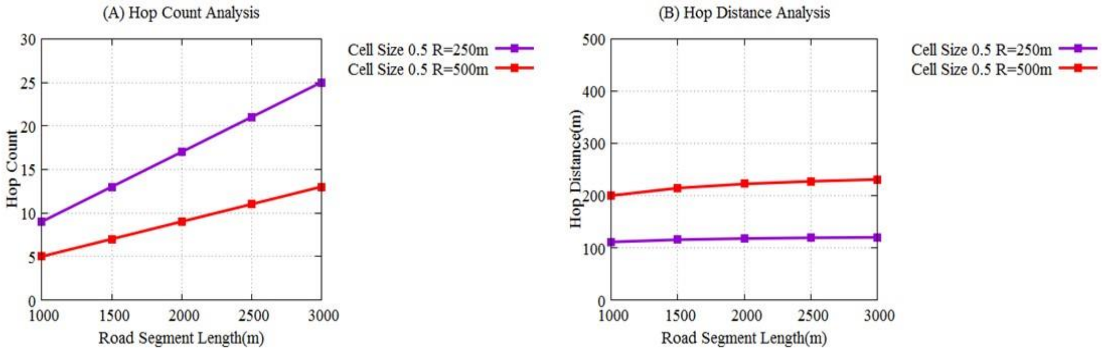

Fig.4. (A) Hop count & (B) hop distance analysis for the various length of the road segment.

Influence of safety distance and transmission Range on CD

To evaluate the influence of the safety distance on CD, a small change in S_d has been done with respect to various transmission ranges. Thus, the evaluation has been assessed for S_d = 2m, 5m, 10m and 20m with changes in the transmission range of 250m and 500m, while the cell size is kept constant, i.e., 0.50R. Table 5 represents results of influence of safety distance for various transmission range.

In case of $R = 500m$ and $L = 500m$, the CD is 0.44, 0.45, 0.46 and 0.49 more for the safety distance of 2m, 5m, 10m and 20m, respectively, as compared to $R = 250m$ and $L = 500m$. Also, for the scenario $R = 500m$ and $L = 1000m$,

CD probability is 0.65, 0.66, 0.66 and 0.69 more for the safety distance of 2m, 5m, 10m and 20m, respectively, as compared to $R = 250m$ and $L = 1000m$. In both cases, as the road segment length increases, the CD probability decreases. Therefore, from the results, it is evident that when the safety distance is less and the transmission range is more, then there exits better connectivity among vehicles. The results of CD are represented in Figure 5.

4. Conclusion

The V_2V communication is achieved through the Dedicated Short-range Communication standard. This study presents an analytical model of the CD probability for one-lane road scenarios. In case of 250m and 500m transmission

Table 5. Simulation Results

L	$R = 250m$				$R = 500m$			
	S_d (m)							
	2	5	10	20	2	5	10	20
500	0.51	0.50	0.49	0.46	0.95	0.95	0.95	0.95
1000	0.26	0.25	0.24	0.21	0.91	0.91	0.90	0.90
1500	0.13	0.12	0.11	0.09	0.87	0.86	0.86	0.85
2000	0.07	0.06	0.06	0.04	0.82	0.82	0.81	0.80
2500	0.03	0.03	0.03	0.02	0.79	0.78	0.77	0.76
3000	0.02	0.02	0.01	0.01	0.75	0.74	0.73	0.72

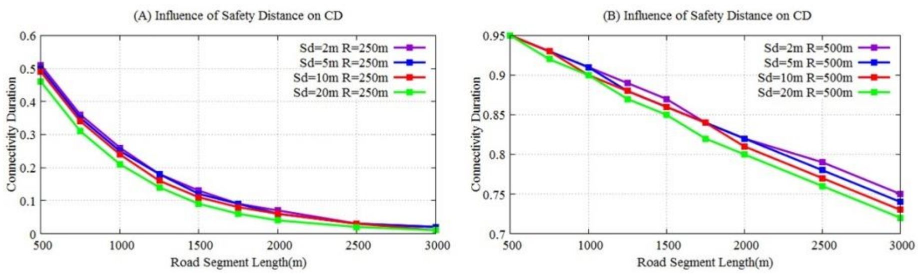

Fig.5. Influence of S_d on CD probability for various road segment with R = 250m & 500m.

range, there is variation observed in the analytical and simulation results. The experimental results indicate that a better transmission range between the vehicles achieves better CD. Moreover, there is an influence of transmission range, inter-vehicular spacing density, the arrival rate of the vehicles. There is less hop count and high average hop distance is observed for higher transmission range. When the safety distance is less and the transmission range is more, then there is better connectivity among vehicles. The result shows that 3% better connectivity is achieved in the road segment having a high transmission range. In case of safety distance, 68% better connectivity is there for the road segment that has a high transmission range. Better vehicular connectivity has improved influence on the QoS parameters such as successful delivery of the messages and less transmission time. Thus, the above-mentioned analytical model can be applied in real-time to determine CD..

References

1. C. A. R. Communication and C. Statement.: Launch of DSRC Technology to Connect Vehicles and Infrastructure in the U.S. in 2021. pp. 9-10, (2019).
2. Z. Khan, P. Fan and S. Fang.: On the Connectivity of Vehicular Ad Hoc NetworkUnder Various Mobility Scenarios. IEEE Access, 5, pp. 22559-22565, (2017).
3. Fang Li, Wei Chen, Yishui Shui, Ji Wang, Kun Yang, Lida Xu, Junyi Yu, ChangzhenLi.: Connectivity probability analysis of VANETs at different traffic densities using measured data at 5.9 GHz. Physical Communication, Volume 35, (2019).
4. N. Goel, G. Sharma and I. Dhyani.: A study of position based VANET routingprotocols. In: 2016 International Conference on Computing, Communication and Automation (ICCCA), pp. 655-660, Noida, (2016).
5. Mohammad A. Hoque, Xiaoyan Hong, Brandon Dixon.: Efficient multi-hopconnectivity analysis in urban vehicular networks. Vehicular Communications, 1(2), pp. 78-90, (2016).
6. S. I. Sou and O. K. Tonguz.: Enhancing VANET connectivity through roadsideunits on highways. IEEE Transactions on Vehicular Technology, 60(8), pp. 35863602, (2011).
7. B. Kenney.: Dedicated Short-Range Communications (DSRC) Standards in theUnited States. In: Proceedings of the IEEE, pp. 1162-1182, (2011).
8. C. Chen, X. Du, Q. Pei, and Y. Jin.: Connectivity analysis for free-flow traffic invanets: A statistical approach. International Journal of Distributed Sensor Networks, 2013(1), pp. 1-15, (2013).
9. L.-D. Chou, J.-Y. Yang, Y.-C. H. Y.-C. Hsieh, and C.-F. Tung.: Intersection-basedrouting protocol for VANET. In: 2010 Second International Conference, Ubiquitous Future Networks (ICUFN), pp. 268-272, (2010).
10. G. Yan and D. B. Rawat.: Vehicle-to-vehicle connectivity analysis for vehicularad-hoc networks. Ad Hoc Networks, 58, pp. 25-35, (2017).
11. L. Cheng and S. Panichpapiboon.: Effects of intervehicle spacing distributions onconnectivity of VANET: A case study from measured highway traffic. IEEE Communication Magazine, 50(10), pp. 90-97, (2012).
12. S. Panichpapiboon and W. Pattara-Atikom.: Connectivity requirements for selforganizing traffic information systems. IEEE Transactions on Vehicular Technology, 57(6), pp. 3333-3340, (2008).
13. C. Shao, S. Leng, Y. Zhang, A. Vinel, and M. Jonsson.: Performance analysis ofconnectivity probability and connectivity-aware MAC protocol design for platoonbased VANETs. IEEE Transactions on Vehicular Technology, 64(12), pp. 5596-5609, (2015).
14. W. Viriyasitavat, F. Bai, and O. K. Tonguz.: Dynamics of network connectivity inurban vehicular networks. IEEE Journal on Selected Areas of Communication, 29(3), pp. 515-533, (2011).
15. C. Li, A. Zhen, J. Sun, M. Zhang, and X. Hu.: Analysis of connectivity probabilityin VANETs considering minimum safety distance. In: 8th International Conference on Wireless Communication and Signal Processing, WCSP 2016, (2016).

16. G. Li, L. Boukhatem, and J. Wu.: Adaptive Quality-of-Service-Based Routing forVehicular Ad Hoc Networks with Ant Colony Optimization.IEEE Transactions on Vehicular Technology, 66(4), pp. 3249-3264, (2017).
17. G. Li and L. Boukhatem.: A delay-sensitive vehicular routing protocol using AntColony Optimization. In: 12th Annual Mediterr. Ad Hoc Network Workshop, MEDHOC-NET, pp. 49-54, (2014).
18. F. Li et al.: Connectivity probability analysis of VANETs at different trafficdensities using measured data at 5.9 GHz. Physical Communication, 35, pp. 1-11, (2019).
19. S. Dharmaraja, R. Vinayak, and K. S. Trivedi.: Reliability and survivability ofvehicular ad hoc networks: An analytical approach. Reliability Engineering Systems Saf, 153, pp. 28-38, (2016).
20. J. Harri, F. Filali and C. Bonnet.: Mobility models for vehicular ad hoc networks: asurvey and taxonomy. IEEE Communications Surveys & Tutorials, 11(4), pp. 19-41, (2009).
21. Yelure, B. and Sonavane, S.: ACO–IBR: a modified intersection-based routing approach for the VANET. IET Netw., 9(6), pp.348-359, (2020)..