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# Connectivity Modeling of Vehicular Ad Hoc Networks in Signalized City Roads

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***Abstract*—Connectivity in vehicular ad hoc networks (VANETs) exhibits stronger challenges than that in other general ad hoc networks. In this paper inter vehicular connectivity is analyzed among different length of vehicles that are running along the city roads. Considering the traffic signals, connectivity among the vehicles waiting at different intersections is analyzed taking the safe distance into account. Besides, car following model is used to formulate the connectivity among vehicles with different speed on a multi lane road with several intersections. Simulation results show that performance in terms of packet forwarding is very good for the vehicles with least speed. Duration of connectivity among vehicles at any intersection is reduced for the vehicles with higher speed.**

## I. Introduction

VANET is a communication network organizing and connecting vehicles to each other, which consists of instrumented vehicles and network infrastructure. Each vehicle is supposed to equip with on-board computing, wireless communication devices, and a GPS device enabling the vehicle to track its spatial and temporal trajectory. Vehicles are typically equipped with short-range communication devices where they can exchange information with other vehicles within their radio range, leading to the creation of ad-hoc wireless networks. The communication between vehicles can be used to realize the driver support and active safety services like collision warning, up-to-date traffic and weather information or active navigation systems. Moving vehicles equipped with communication devices can form exactly the mobile ad hoc networks, where nodes of these networks can have long transmission ranges and virtually unlimited lifetimes.

Other than the unique characteristics and routing issues in VANET, the popularity of GPS system, availability of traffic data and a wide range of commercial and public applications motivate to new studies of VANET research issues. However, VANETs pose many challenges on technology, protocols, and connectivity which increase the need for research in this field. Factors like efficient message dissemination, network scalability, and wireless transmission are still major research areas in the area of vehicular ad hoc networks. Connectivity in VANETs, which is affected by several factors including transmission power level, environmental conditions, obstacles, and mobility of the nodes has been a topic of interest, especially due to the recently increasing research activity. Normally, it is maintained by setting the transmission range so that a node can establish a link to any other node in the network either directly or over multiple hops. Besides, connectivity among vehicles is greatly influenced by the speed, traffic density, which varies along the road due to the presence of constraints or some irregular driving behavior.

Infrastructure-free environments and higher dynamic network topology cause frequent network partition. Moreover, vehicular ad hoc wireless networks is often deployed by the constraint of roadways where trees, buildings and other assorted obstacles influence the practical transmission effects as compared to generic open fields. Many analytical and experimental studies have focused on determining the minimum transmission range that provides connectivity while minimizing transceiver power for various levels of the node densities. We analyze the influence of several parameters on connectivity, including communication range, speed and length of vehicles. We also study the influence of traffic lights, lane change and car following models on the connectivity. Though, several researchers focus on traffic information based communication or connectivity of vehicles, to the best of our knowledge, no work consider the effect of vehicle length and safe distance on the connectivity of VANET in a city scenario, where speed of vehicles has to change to frequently to follow the traffic signals.

The rest part of the paper is organized as follows. Related work of the paper is given in Section II. The proposed problem is formulated in Section III. The connectivity model for the city scenario is designed in Section IV. Performance evaluation of the models is described in Section V and concluding remarks are made in Section VI.

## II. Related work

Inter-vehicle communication and connectivity are important research goals in VANET. In [2], authors design a vehicle-to-vehicle information system and use a car traffic simulator to extract some of the key connectivity metrics. They combine a realistic traffic simulator and characterize the mobility and connectivity in VANETs. Considering the dissemination of traffic information between vehicles, they use connectivity parameters for a VANET information system. However, the effect of safe distance between a front and rear vehicle is not

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considered in their analysis. In [4], authors propose a series of data forwarding strategies that are based on the position prediction of neighboring and destination nodes. The strategy considers the historical traffic forwarding method without using any existing street-aware information, such as information about intersection, traffic signals and traffic density, which is necessary in realistic traffic scenario.

In [5], a position-based routing scheme called Connectivity-Aware Routing (CAR) is proposed. Authors use inter-vehicle communication methods in a city and highway environment. They integrate the locating destinations with connected paths between source and destination and use the street-aware information. However, they have not analyzed the effect of connectivity among vehicles on routing. In [1], authors describe effect of several mobility models on inter-vehicle communications. Among these models, authors propose the car following model to compute velocity and distance between two cars. In VANET, communication of vehicles uses the velocity and distance of the vehicles. Hence, such car following model is useful to develop connectivity models taking speed of the vehicles.

The realistic traffic includes intersection, traffic signals and traffic density. Several researchers [2], [3] use traffic information to design the mobility modeling of traffic information system about vehicle. But, the traffic information must includes the length of vehicles and safe distance. The communication among vehicles is dependent on several factors such as safety distance, speed, length of the vehicles. In [1], authors analyze the stochastic model without random movements of vehicles, which computes the distance and velocity between the front and rear vehicle. They analyze the inter car communication based on the mobility of vehicles. In[6], authors consider the car-following model based on the space and velocity, and control the car acceleration to keep the rider comfortable. However, this paper does not analyze the connectivity taking car-following model into account.

In [7], authors utilize a fluid model and traffic flow to plan optimizing connectivity. Besides, they use a stochastic model to capture the randomness of individual vehicles. Considering the vehicular density, they determine the probability of communication to verify the connectivity. In this paper, we consider a city scenario with two lane road and use the street-aware information and car following model to analyze the connectivity among vehicles. We consider the safe distance and length of vehicle in analyzing the connectivity, when the vehicles either wait at the traffic square or pass through it after getting the traffic signal clearance.

## III. System model

Consider a two lane urban road with several intersections. As shown in Fig. 1, every intersection has traffic signals so that vehicles need to stop only at the signals that are red and drive through the signals that are green. Any vehicle approaching the intersection must stop at the signal for a fixed waiting period if the signal is red. Any vehicle at the intersection may drive straight, turn to left or right after reaching at a traffic square. For example, as shown in Fig. 1, vehicles traveling along lanes

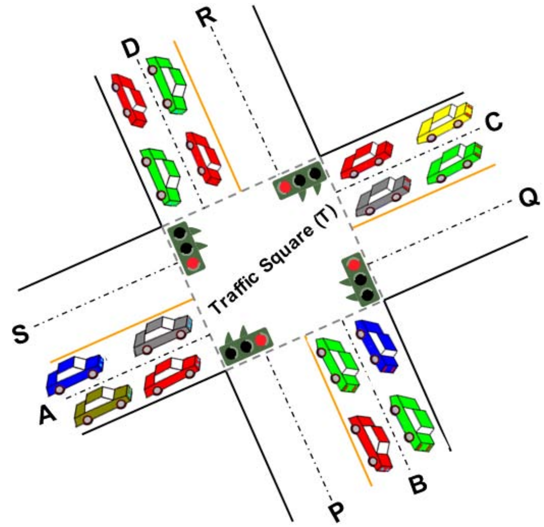


Fig. 1. The intersection of the scenario.

$A$ may drive either through lanes $P$, $Q$, or $R$ after arriving at the traffic square $T$. Each vehicle's motion is governed by the vehicle in front of it as they maintain a safe distance, which is quite reasonable as a vehicle moving on a road can never move further than the vehicle that is moving in front of it. When vehicles follow each other to the traffic sign, they form a queue at the intersections and wait for a fixed amount of time before crossing the intersection when it reaches the front of the queue.

### A. Notation

Let, $V_i$ be the normal speed of the *i*-th vehicle, which may vary from 20 Km/hour through 50 Km/hour.

$V_i^{safe}$: safe speed of the *i*-th vehicle, which is dependent on the speed of the front vehicle.

$V_i^{desired}$: desired speed of the *i*-th vehicle with respect to speed of the front one.

$d_w$: width of the lane.

L: length of each vehicle, which may be 5m or 10m.

$\tau_{i,j}$: safe distance between two vehicles.

$d_{i,j}$: real distance between two vehicles.

$R_c$: radio range of each vehicle.

## IV. Connectivity Analysis

Let us consider a large traffic square or circle $T$, where vehicles wait until they get traffic clearance and pass through it as soon as they see green signal. As shown in Fig. 2, a vehicle located at $A$ may go straight toward $Q$ or may turn to right and move along the lane $P$ or may turn to left and move along the lane $R$. Accordingly, the packets generated at node $A$ may be forwarded to the vehicles stopped along the lanes $B$, $C$ and $D$ as shown in Fig. 1. In our connectivity analysis, the vehicles along the lanes $B$, $C$ and $D$ should stop, when the vehicles along the lane $A$ are allowed to move due to green signal. It is quite reasonable as vehicles are

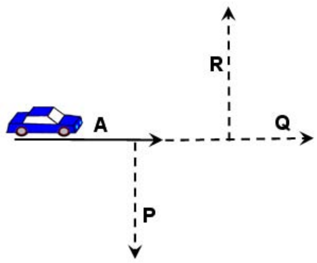


Fig. 2. The source and destination of intersection scenario.

controlled by the traffic lights to manage traffic density and to avoid accidents when pass through the city roads. As per the proposed scenario, a vehicle located at $A$ is considered as the source and the vehicles located at $B$, $C$ and $D$ are considered as the destination. Hence, in the current problem there is only one source and three different destinations located at three different lanes as shown in Fig. 1.

Let, the distance between the source $i$ to any destination $j$ be $d_{i,j}$. We utilize the distance of the source to a destination and analyze the duration of communication from the source vehicle to three different destinations. Any two vehicles are said to be connected if radio range of a vehicle $R_c < d_{i,j}$. Considering speed of the source node as $V_i$, the duration of connectivity between the source node $i$ and any destination $j$, $k$ and $l$ can be formulated as given in equation 1, 2, 3, respectively.

$$\mathrm{C}_{i,j} = \begin{cases} 0, & \text{if } d_{i,j} > R_c \\ \frac{d_{i,j}}{V_i}, & \text{if } d_{i,j} < R_c \end{cases}, \tag{1}$$

$$\mathrm{C}_{i,k} = \begin{cases} 0, & \text{if } d_{i,k} > R_c \\ \frac{d_{i,k}}{V_i}, & \text{if } d_{i,k} < R_c \end{cases}, \tag{2}$$

$$\mathrm{C}_{i,l} = \begin{cases} 0, & \text{if } d_{i,l} > R_c \\ \frac{d_{i,l}}{V_i}, & \text{if } d_{i,l} < R_c \end{cases}, \tag{3}$$

where, distance between any source $i$ and destination $j$, $k$ or $l$, which is $d_{i,j}$,$d_{i,k}$ and $d_{i,l}$, respectively could be given by the following equations.

$$d_{i,j} = \sqrt{(\frac{3d_w}{4} + \frac{L_i}{2})^2 + (\frac{d_w}{2} + \frac{L_i}{2})^2}, \tag{4}$$

$$d_{i,k} = \sqrt{(\frac{L_i}{2} + 2d_w + \frac{L_i}{2})^2 + (\frac{d_w}{2})^2}, \tag{5}$$

$$d_{i,l} = \sqrt{(\frac{3d_w}{2} + \frac{L_i}{2})^2 + (\frac{d_w}{2} + \frac{L_i}{2})^2}, \tag{6}$$

It is to be noted that speed of $i$-th vehicle that is passing through the traffic square is ($V_i$ and varies from vehicle to vehicle. In our analysis, three different categories of vehicles with different zones of speed are considered. The first category of vehicles may have speed zone-1, which varies from 10∼20 Km/hour. The second category of vehicles may have speed zone-2, which varies from 20∼40 Km/hour and the speed zone-3 that varies from 40∼60 Km/hour belongs the third category of vehicles. Besides, we consider length of a vehicle ($L_i$ to analyze its impact on the connectivity as it affects the speed and distance between a source and destination vehicle. In our analysis, two different lengths of vehicles are considered. The smaller vehicles are of 5 meters and larger vehicles are of 10 meters in length are used in our simulation. As shown in Fig. 1, instead of a single lane, a bi-lane signalized city road is considered for the connectivity analysis, where vehicles can overtake if there is space to do so. Besides, it is assumed that each vehicle has to maintain the safe distance, whenever they overtake or wait behind another vehicle along the same lane.

Taking $\tau_{i-1,i}(t)$ as the safe distance between (*i-1*)-th and *i*-th vehicle at an instant *t*, where (*i-1*)-th vehicle is running behind *i*-th vehicle, the speed of (*i-1*)-th vehicle can be expressed as given in equation 7, when it changes the lane.

$$V_{i-1} = f(V_i(t), \tau_{i-1,i}(t), P_{\emptyset}(t)), \tag{7}$$

where, $V_{i-1}(t)$ is speed of (*i-1*)-th vehicle at an instant $t$, and $P_{\emptyset}(t)$ is the probability of changing direction i.e. probability of turning to left or right at the time of overtaking. In our analysis, as long as the vehicles are waiting at an intersection to get the traffic signal clearance, speed of all vehicles is assumed to be 0. However, when the vehicles start moving upon getting the green signal, speed of back vehicle depends on the speed and direction of front one. For example, if the front vehicle turns to left and back vehicle has to go along the same direction, then back vehicle should maintain a safe speed in order to avoid collision with the front one. However, if the back vehicle has to go straight or turn right, when its front vehicle turns toward left, then its speed is independent of the front one, which is expressed here as the desired speed. Based on the above analysis, the connectivity duration between the *i*-th (front) and (*i-1*)-th (back) vehicle can be formulated as given in equation 8.

$$C_{i-1,i} = \frac{d_{i-1,i}}{V_{i-1}^{safe}}, \tag{8}$$

where, $d_{i-1,i}$ and $V_{i-1}^{safe}$ is the safe distance and safe speed, respectively between $i$ and (*i-1*)-th vehicle. Similarly, taking the real distance $d_{i-1,i}$ and desired speed of (*i-1*)-th vehicle as $V_{i-1}^{desired}$, the connectivity duration can be analyzed as given in equation 9.

$$C_{i-1,i} = \frac{d_{i-1,i}}{V_{i-1}^{desired}}, \tag{9}$$

It is to be noted here that each vehicle has to accelerate its speed as soon as it gets the traffic clearance. Hence, final speed of a vehicle changes from its initial one, which can be formulated from the laws of velocity as given in equation 10.

$$V_{i-1}^{'} = V_{i-1} + at, \tag{10}$$

where, $V_{i-1}$ and $V_{i-1}^{'}$ be the initial and final speed of (*i-1*)-th vehicle, respectively. $a$ is acceleration of the vehicle at an instant $t$. Taking the initial and final speed of (i-1)-th vehicle, its distance $S$ from its front vehicle $i$ can be formulated as

$$S = \frac{V_{i-1} + V'_{i-1}}{2} * t \quad (11)$$

Here, the distance $S$ could be considered as the real distance $d_{i-1,i}$ or safe distance $\tau_{i-1,i}$. Considering the safe and real distance in our analysis, the final speed of (*i-1*)-th vehicle can be formulated as given in equation 12.

$$V'_{i-1} = \frac{2 * (d_{i-1,i} + V_i * t - \tau_{i-1,i})}{t} - V_{i-1} \quad (12)$$

Taking speed of the front vehicle (*i*-th) as $V_i$, the safe speed of its rear vehicle (*i-1*) can be analyzed as given in equation 13.

$$V^{safe}_{i-1}(t) = min(V_i(t), V'_{i-1}(t)), \quad (13)$$

On the other hand, the desired speed $V^{desired}_{i-1}(t)$ of the rear vehicle can be analyzed as given in equation 14.

$$V^{desired}_{i-1}(t) \geq V_i(t), \quad (14)$$

## V. PERFORMANCE EVALUATION

In this section, our connectivity analysis is evaluated using NS2 VanetMobiSim [8] simulator. The simulation environment and respective results are described as follows.

### A. Simulation Setup

In order to evaluate our proposed models, we used VanetMobiSim [8], which is an efficient simulator and supports the vehicular mobility to a higher degree of realism. Besides, we consider NS2 simulator [9], as it provides packet level simulation over transport layer and supports ad-hoc routing protocols, propagation models, and data broadcasting. In NS2 simulator, mobility of nodes may be specified either directly in the simulation file or by using a mobility trace file. In our simulation, the trace file is generated by using VanetMobiSim. We consider two lanes along both directions and traffic signals at each intersection so that each vehicle has to stop for a predefined fixed time before moving straight or turning to left or right.

The number of vehicles in our simulation is taken to be 100 with variable speeds. The speed of the vehicles is categorized into three zones. The speed of zone-1 vehicles ranges from 10 km/hour∼20 km/hour, zone-2 vehicles ranges from 20 km/hour∼40 km/hour, and zone-3 vehicles ranges from 40 km/hour∼60 km/hour. Communication range of each vehicle is fixed at 250m and safe distance between any two vehicles is taken to be 5m∼25m. Length of each vehicle is considered to be 5m. In NS2 simulator, IEEE 802.11 MAC with two ray ground propagation model and dynamic source routing is used to simulate the packet delivery ratio, end-to-end packet delivery time.

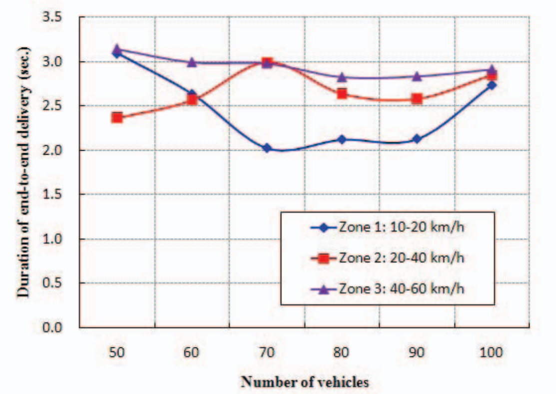


Fig. 3. Duration of end-to-end packet delivery with the fixed length of the vehicle(length=5m) without change in direction.

### B. Simulation Result

In this subsection, we present the simulation results in terms of duration of end-to-end packet delivery time and packet delivery ratio for different number of vehicles with and without changing the lanes. The end-to-end packet delivery time is defined as the duration of sending the first data packet until the last data packet delivery. Obviously, the end-to-end packet delivery time is related to the connectivity duration between the source vehicle that is passing through the traffic square and the destination vehicle that is static and is waiting for the traffic clearance. The connectivity among the source and destination vehicles is evaluated, when they pass through the traffic square. It is to be noted that the source nodes are the vehicles that are moving through the traffic square as they get traffic signal clearance, whereas the destination nodes are the vehicles that are static as they wait at the intersections of the traffic square to get the traffic signal clearance.

Upon getting the green signal, the source vehicles may or may not change their existing direction of motion and may drive straight through the traffic square, which affects the connectivity duration. The end-to-end packet delivery ratio is the ratio of packets sent from the source vehicle to the packets received by the destination one, which is related to throughput. In order to study the effect of connectivity on throughput, we prefer to analyze the end-to-end packet delivery ratio as shown in the following simulation figures. As shown in Fig. 3, the duration of end-to-end packet delivery for different speed of the vehicles is evaluated. In this figure, the length of the vehicle is fixed to 5m and it is assumed that no vehicle change the direction, i.e. they move straight without turning to left or right.

It is observed that the duration of packet delivery decreases, if vehicles move slower. When the vehicles move without changing the lanes, the duration of packet delivery fluctuates with different size of the traffic as shown in Fig. 3. The duration of end-to-end packet delivery for different speed of the vehicles with change in direction is shown in Fig. 4. Here, the fixed length of vehicle of 5m is also considered in our

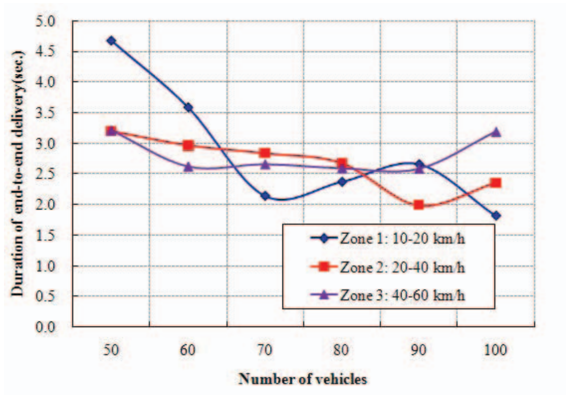


Fig. 4. Duration of end-to-end packet delivery with the fixed length of the vehicle(length=5m) with change in direction.

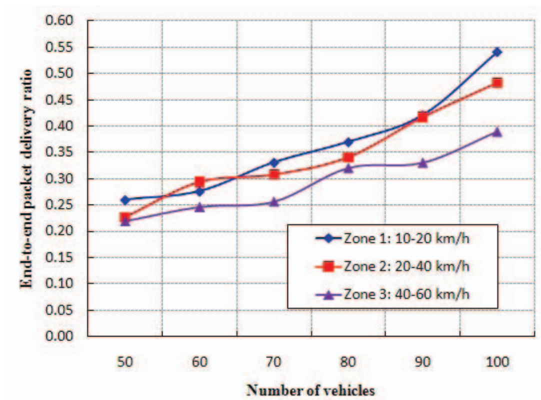


Fig. 5. End-to-end delivery ratio with fixed length of the vehicle(length=5m) and without change in direction.

simulation. It is observed that the duration of packet delivery is longer for slower vehicles, which gradually decreases with increase in number of the vehicles. The duration of packet delivery is reduced if speed of the vehicles is increased. However, this duration fluctuates with increase in number of vehicles, though its value is smaller for higher number of vehicles.

The end-to-end packet delivery ratio is evaluated as shown in Fig. 5 and Fig. 6. The end-to-end packet delivery ratio for different speed of the vehicles with fixed length (length=5m) and without change in direction is evaluated as shown in Fig. 5. It is observed that end-to-end packet delivery ratio decreases if speed of the vehicles is slower and the delivery ratio increases with increase in number of the vehicles. As shown in Fig. 6, the packet delivery ratio is better, when vehicles change their direction. Though the packet delivery ratio fluctuates with increase in number of vehicles, it gradually increases with increase in number of vehicles and speed when they change their existing direction.

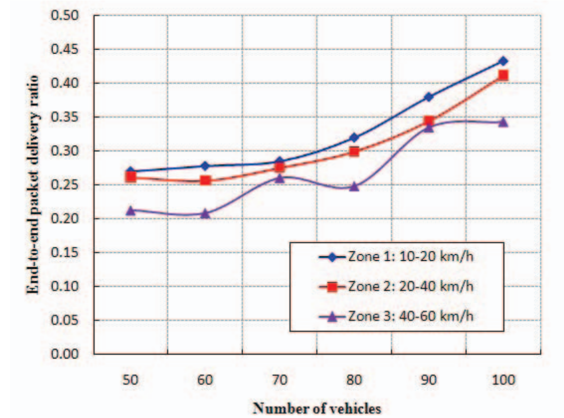


Fig. 6. End-to-end delivery ratio with fixed length of the vehicle(length=5m) and with change in direction.

## VI. Conclusion

In this paper, traffic connectivity for the vehicular ad-hoc networks is modeled taking various speed and safety distance between the cars that are running along bidirectional two lane roads. The connectivity at a large traffic square is analyzed when vehicles of different size pass through it. The connectivity is analyzed along the city roads where traffic signal is included in the analysis. Besides, the effect of change in lane due to overtaking of vehicles is also incorporated in the connectivity analysis. From the simulation result, it is observed that connectivity in terms of duration of packet delivery fluctuates with different speed of the vehicles and change in direction of vehicles also affects the connectivity. In our future work, we will analyze the connectivity among vehicles taking driver's behaviors into account.

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