Information Propagation Probability on Intersections in VANETS

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***Abstract*— Vehicular Ad-hoc Networks (VANETS) have recently received great attention as a tool to disseminate information among vehicles with the dual purpose of increasing road safety and comfort in driving. Most of the messages that vehicles exchange are characterized by a finite lifetime period, after which, their level of usefulness is greatly reduced. Thus, an important problem in VANETS is to find efficient ways to disseminate information on the target areas before this deadline expires. The problem of information dissemination has been extensively studied in the literature and a number of solutions have been proposed. However, no previous work has addressed the problem of calculating the probability to propagate information in a certain amount of time among vehicles on intersecting roads where no static infrastructure, such as repeaters, is used. In this paper, we derive a formula which gives a lower bound on this probability. We show that the propagation probability is strongly related to the traffic conditions of the road where the information is to be transmitted. We use the derived formula to estimate, via simulations, the minimal conditions required to ensure that information propagation occurs with high probability on intersections. We validate our analytical findings with simulation's results obtained using the VISSIM simulator.**

I. Introduction

The rapid evolution of *wireless data communication technologies*, which emerged in the last few years, has led researchers to explore their applications in *Mobile Ad-hoc Networks* (MANETS). MANETS are self-organized mobile wireless networks which are independent from infrastructure [5]. Mobile nodes are connected via wireless links forming networks of arbitrary topology. Nodes are free to move randomly and organize themselves arbitrarily; thus, the network's wireless topology may change rapidly and unpredictably. Such a network may operate in a stand-alone fashion, or may be connected to a larger network.

The main task of a special class of these networks is to collect (e.g. using on-board sensors) and propagate information among their nodes which finally has to be processed and transmit to base stations. *Vehicular Ad-hoc Networks* (VANETS) are a subset of MANETS where the mobility is restricted by the roadway. VANETS consist of instrumented vehicles, able to collect, process and communicate information among each other when their distance is within their transmission range. Recently, VANETS have attracted the interest of many researchers.

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A. Motivation

Government agencies and automotive companies are investing billions of dollars in an effort to reduce the terrifyingly high number of deaths and injuries caused by traffic accidents, as well as the related costs (damages, treating crash victims etc.) [13], [18]. Imagine how helpful it would be for drivers to have easy access to local danger warnings such as "icy road on 405 freeway" or "heavy traffic on Broadway boulevard", not only from the safety point of view, but also for making driving more comfortable. Additionally, dissemination of several information messages among vehicles has many applications in the areas of business and entertainment, such as chatting among passengers, advertisements of restaurants, notifications of open pharmacies in the area, etc. Vehicular ad-hoc networks offer a powerful framework in which to develop such services.

B. VANETS vs MANETS

VANETS consist of instrumented vehicles that among others, are equipped with the following: on-board sensors, a wireless communication system, a positioning system, a digital road map, a processor and a memory unit. Communicating vehicles exchange information messages that consist of a *message header* and a *message body*. Examples of header data include the Originator, the Message ID, the Time of creation, the Time to live, the Target area, etc. The message body can consist of different types of data either raw or processed depending on the application.

Vehicular ad-hoc networks, although being a subclass of mobile ad-hoc networks, have unique characteristics which differentiate them from traditional MANETS. VANETS are not constrained by scarce energy resources but are rather characterized by high mobility patterns and confined movement. High mobility is a result of the large speeds, which the vehicles can attain, leading to dynamic and rapidly changed network topologies and network fragmentation. The dynamic nature of the topology is enhanced by the unpredictable nature of the drivers' response to various events. VANETS are also characterized by the constrained, largely one dimensional movement of the vehicles along the roadway network which is fixed. The fore-mentioned characteristics pose design and modeling challenges different from traditional MANETS in the development of various network protocols as well as approaches to solve a variety of issues. In the last few years, research on VANETS has focused, among others, on problems related to message propagation speed, routing, data collection, information management and evaluation, etc.[21], [24], [26].

C. Framework

Vehicles participating on VANETS are traveling on static road networks. These roads can be described by their *length*, the *number of lanes*, the *arrival rate* of vehicles and the *speed range*. Vehicles can communicate with each other if their distance is less than their *transmission range*. Roads with heavy traffic density (i.e., the distance between the vehicles is very small) have high information propagation speed as the message is transmitted from vehicle to vehicle in multi hops, instead of been carried by them with the speed of the vehicle, as it happens in light traffic conditions.

Dedicated Short Range Communications (DSRC) [16] is a proposed variant of IEEE 802.11a [6], designed to operate within a frequency band (5.9 GHz), licensed solely for the purposes of vehicular communications.

Typically, a message of 1 Kb with a 2 Mbps wireless channel needs around 6 ms to be received and processed. By assuming a transmission range of 250 m and that the two vehicles communicating are apart distance equal to the transmission range, we can achieve propagation speed up to 150×10^3 Km/h.

D. Related Work and Our Contribution

The primary function of VANETS is to serve as a medium to propagate information. Applications can be divided in two categories: safety applications and non-safety applications which usually improve driving comfort. Safety applications involve the exchange of messages which notify vehicles of potential driving hazards and help prevent collisions. Some techniques of safety application can be found in [2], [5], [8], [10], [17], [25], [26]. Non-safety applications involve the exchange of messages which usually relate to accurate traffic monitoring, distributed passenger teleconferencing, music downloading and roadside e-advertisements. Techniques of non-safety applications are presented in [3], [11], [12], [20], [21].

Wu et al. in [24] computed the average message propagation speed on one road. The message propagation speed strongly depends on the traffic characteristics of the road such as the speed range of vehicles and the traffic density. The average message propagation speed gives a good approximation of the time a message needs to reach a target, but only when the target is on the same road with the vehicle transmitting the information. However, almost all applications need the messages to travel in different areas, which means that the route to the target includes different roads joined via intersections. The assumption used in [9] concerning the existence of repeaters at each intersection, guaranties the propagation between two vehicles traveling on intersecting roads, but it is impractical and extremely costly.

To the best of our knowledge, there is no previous work studying the probability to propagate the information among vehicles that drive on intersecting roads and where there is no static infrastructure, such as repeaters on intersections. In addition, using the propagation probability combined with the importance of the location of the intersection we can decide weather the installation of a static repeater will improve significantly the message propagation speed.

In this paper we provide a theoretical analysis of the probability to propagate information to at least one vehicle on an intersecting road with no informed vehicles, calling it h_2, when an informed vehicle drives on a road h_1 and it is close to h_2, given that h_1 and h_2 intersect. We show that this probability strongly depends on the traffic characteristics, arrival rate and vehicle's speed range of road h_2. We also show that, as time goes by, this probability increases. Using simulation, we are able to validate our analysis by comparing our theoretical results with the one's obtained from the simulation. Combining our results with the average message propagation speed on a road, provided by Wu et al., in [24], we can potentially calculate the probability that a message has to reach its target area in a given amount of time using graph theoretic algorithms that generate possible routes to the target area.

The remainder of this paper is organized as follows. In section II we present the problem formulation with the basic notations, definitions and assumptions used in the analysis. In section III we provide the theoretical analysis of a lower bound of the probability of information propagation among vehicles traveling on two intersecting roads. In section IV we present the simulation results performed with the VISSIM simulator [19] and we compare them with the theoretical calculations. Finally, in section V we conclude our work and give guidelines for future work.

II. Problem Formulation

In this section we introduce the formulation of the problem which we study and we present the basic notations, definitions and assumptions used in this paper.

We consider a roadway network which consists of a set of intersections $I = I_1, I_2, ..., I_w$, where I_j denotes the j^{th} intersection and w is the total number of intersections that exist in the network. These intersections are interconnected by a set of straight line roads. The road connecting intersection I_j with intersection I_k is denoted by h_{jk}. The roadway network accommodates a number of vehicles. Vehicle i is denoted by veh_i.

We assume one way traffic along the roads and vehicles on road h_{jk} travel from intersection I_j to intersection I_k. We study the information propagation to the direction of the traffic. When we refer to vehicles we refer to instrumented vehicles able to participate in VANETS. Also, we assume that all vehicles have constant transmission range denoted by r, which is the same for all vehicles. *Informed vehicles* are vehicles that have the information while *uninformed vehicles* are vehicles that do not. On each road h_{jk}, a vehicle travels with a constant speed that is selected uniformly and independently from the interval $[v_{min}(h_{jk}), v_{max}(h_{jk})]$. Vehicles move independently at their chosen velocity.

The number of vehicles entering a road h_{jk} is assumed to be a stochastic variable and the corresponding stochastic process is modeled as a Poisson process. Several experiments have shown that the outcomes of such a model are in good agreement with real measurements obtained in practise [1], [14]. The probability density function of the arrival process at road h_{jk} is thus given by the following formula:

$$P_z^{h_{jk}}(t) = \frac{(\lambda_{jk} t)^z}{z!} e^{-(\lambda_{jk} t)} \tag{1}$$

where λ_{jk} denotes the mean arrival rate at road h_{jk} and z denotes the number of arrivals in the time interval 0 to t. The equation describes the probability of seeing exactly z arrivals in the period of time from 0 to t.

Without loss of generality, for the remainder of our analysis we consider a segment of the roadway network as shown in figure 1.

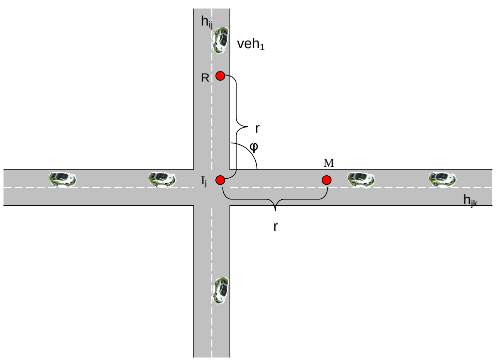


Fig. 1. Representation of an intersection in a road network presenting the basic notations

The segment presented in figure 1 includes intersection I_j and the roads h_{ij} and h_{jk} interconnect intersections I_i with I_j and I_j with I_k respectively (intersections I_i, I_k are not shown). The angle between roads h_{ij} and h_{jk} is denoted by φ. R is the point on h_{ij} that is r apart from intersection I_j and M the corresponding point of road h_{jk}. Finally, veh_1 is the *head of the information* (meaning that there are no other informed vehicles ahead of it) on road h_{ij} and is traveling with speed V_1. We start counting time, $t = 0$, at the point where veh_1 is of distance less than r from intersection I_j which means that it is able to transmit the information to road h_{jk}. This can happen by either having veh_1 getting the information before passing point R ($t = 0$ when veh_1 is at point R) or having the information transmitted to veh_1 by a following vehicle on h_{ij}, after passing point R and before reaching intersection I_j ($t = 0$ is when veh_1 receives the information).

Since we assume one-way vehicle traffic, we are interested in intersections where veh_1 has the opportunity to choose among two or more roads. Otherwise, if h_{jk} was the only choice, the probability of message propagation would be equal to 1 since veh_1 will definitely enter road h_{jk}.

There are two ways to propagate information from vehicles of road h_{ij} to vehicles of road h_{jk} at their intersection. The first way is by transmitting the information to a vehicle on h_{jk}. We call this probability $p_{tr}^{h_{ij}h_{jk}}$. The second way is the driving way and we call the probability $p_{dr}^{h_{ij}h_{jk}}$, where an informed vehicle from h_{ij} turns into h_{jk}. The probability $p_{tr}^{h_{ij}h_{jk}}$ is strongly related to the traffic characteristics of the road h_{jk} where the information is to be transmitted. Probability $p_{dr}^{h_{ij}h_{jk}}$ depends on what portion of the arrival rate road h_{ij} has, compared to the total arrival rate of the roads attached to intersection I_j.

III. Theoretical Analysis of Message Propagation Probability on Intersections

In this section we provide a lower bound of the probability to propagate information from an informed vehicle of road h_{ij} to a vehicle in road h_{jk} when these two vehicles are close to the intersection I_j. The reason we concentrate on a lower bound and not on the actual probability is because the calculation of the actual probability is extremely complicated as it needs to consider all possible propagation scenarios even if their contribution to the overall probability is very small. In this paper, we concentrate on the two basic scenarios to propagate information:
1) by transmitting the information from vehicles on road h_{ij} directly to vehicles on road h_{jk} and
2) by having the veh_1 driving into road h_{jk}

The following equation gives a lower bound of the probability to propagate the information combining the two aforementioned propagation ways:

$$p_{h_{ij}h_{jk}} = p_{tr}^{h_{ij}h_{jk}} + (1 - p_{tr}^{h_{ij}h_{jk}}) * p_{dr}^{h_{ij}h_{jk}} \tag{2}$$

.

In the following subsections we derive the formulas of calculating the probabilities $p_{tr}^{h_{ij}h_{jk}}$ and $p_{dr}^{h_{ij}h_{jk}}$.

A. Probability of Transmission of Information among vehicles on intersecting roads ($p_{tr}^{h_{ij}h_{jk}}$)

First, we study the different scenarios of transmitting information from vehicles on road h_{ij} to vehicles on road h_{jk}. We assume that there are no buildings to block signal transmission. By this assumption, information can be passed from vehicles at any point on road h_{ij} to vehicles on road h_{jk} which are of distance smaller than r.

As shown in figure 1, veh_1 is the head of information on road h_{ij}. We start counting time ($t = 0$) at the point where information enters road segment RI_j on veh_1. There are two different cases that we need to consider and we study them separately. In $case\ 1$, veh_1 was already informed before passing from point R. In $case\ 2$, veh_1 has passed from point R without the information and before reaching intersection I_j, a following vehicle transmitted the information to veh_1.

For our theoretical analysis, we compute the probability to propagate information from a vehicle traveling on road h_{ij} to a vehicle traveling on road h_{jk} in the time period $[0, y]$, where $y \leq \frac{r}{V_{max}(h_{ij})}$, which is the time needed by the fastest moving vehicle on h_{ij} to travel distance r. By choosing this specific bound we make the analysis less complicate since veh_1 will be able to cover distance less or equal to r. In addition, greater value for y, even though it will increase the propagation probability, it will also increase the theoretical time that a message needs to reach its target. This is because, we need to consider all the intersection that the message has to pass and add the time y of each one in the overall time up to the target area.

For each different case we need to consider two possible ways to transmit information to vehicles on road h_{jk}. The first way is to have a vehicle entering h_{jk} during time interval $[0, y]$. This vehicle will definitely catch the information from veh_1 since it is going to be of distance smaller than r from veh_1. The second way is to have, during the interval $[0, y]$, veh_1's transmission range to catch up with a vehicle that has entered h_{jk} before $t = 0$. This second way can appear when the vehicles that have entered h_{jk}, are moving slow enough that, at some point, the transmission range of veh_1 (which must be moving fast enough) catch them up. We call the probability of the first way, *probability of entering* and denote it by p_e, and the probability of the second way *probability of catching up* and denote it by p_c.

Case 1. veh_1**, has the information when it passes from point** R

It can be easily seen that $y \leq \frac{r}{V_{max}(h_{ij})} \leq \frac{r}{V_1}$, where $\frac{r}{V_1}$ is the time that veh_1 needs to cover distance r on road h_{ij}. Thus, we need to calculate the probability to have a vehicle entering road h_{jk} (from intersection I_j) during the time interval $[0, y]$, since it is definitely going to receive the information from veh_1. This gives us the *probability of entering* and can be determined by the following equation.

$$p_e = 1 - P_0^{h_{jk}}(y) \tag{3}$$

where $P_0^{h_{jk}}(y)$ is the probability of having zero vehicles entering h_{jk} during period y as defined in equation 1.

The calculation of the *probability of catching up* (p_c) is more complicated than p_e. We define $d(t)$ as the furthest away point from intersection I_j on road h_{jk} where the transmission range of veh_1 can cover in time t. It can be easily seen that any vehicle in between I_j and $d(t)$ is going to receive the message. Using basic trigonometric rules we provide the relation between $d(t)$, transmission range r, angle φ and V_1, which is given by:

$$d(t) = (r - V_1 t)cos\varphi + \sqrt{r^2 - (r - V_1 t)^2 sin^2\varphi} \tag{4}$$

In the case where ϕ is a right angle then $d(t) = \sqrt{r^2 - (r - V_1 t)^2}$. Also, we define X(t) as the distance from I_j on road h_{jk} that the vehicle closest to I_j has on time t, compared to all vehicles that have entered h_{jk} before $t = 0$.

$$X(t) = min(V_i' * (t - T_i)) \ i = 1, 2, ..., Z(\gamma) \tag{5}$$

where V_i' is the speed that vehicle i has on road h_{jk} and it is uniformly distributed in the range $[v_{min}(h_{jk}), v_{max}(h_{jk})]$, T_i is the time when vehicle i passed intersection point I_j ($T_i < 0$), γ is the period of time before $t = 0$ where there is a chance, the transmission range of veh_1 to catch up with the vehicles that have entered road h_{jk}. This period is equal to $\frac{r}{V_{min}(h_{jk})}$ which is the time that the slowest vehicle moving on h_{jk} needs to cover distance r. Finally, $Z(\gamma)$ is the number of vehicles that have entered h_{jk} during period $[-\gamma, 0)$.

The function distribution of $X(t)$ is given by the equation:

$$F_{X(t)}(d(t)) = \sum_{z=0}^{\infty} P[X(t) < d(t)|Z(\gamma) = z] * P[Z(\gamma) = z] \tag{6}$$

The points of time (T_i) at which $Z(\gamma)$ vehicles have entered road h_{jk}, are considered as random variables and are distributed independently and uniformly in the interval [-γ,0). This leads to $T_i \sim uniform(-\gamma, 0)$.
Since $T_1, T_2, ..., T_z$ and $V_1', V_2', ..., V_z'$ are independent and identical distributed (i.i.d), we can drop the subscripts. Following from (6), we have:

$$P[X(t) \leq d(t)|Z(\gamma) = z] = 1 - P[X(t) > d(t)|Z(\gamma) = z] = 1 - P[V' * (t - T) > d(t)]^z \tag{7}$$

In figure 2, we plot an example of functions $d(t)$ and $X(t)$ versus time. In this example, we assume that only one vehicle, veh_q, has entered h_{jk} during period $[-\gamma, 0)$. Also, we set $r = 250$ m, $V_1 = 11\ m/s$ (39.6 Km/h), $\varphi = 90°$ and the vehicle veh_q the position of which is represented with $X(t)$, moves with speed 10 m/s (36 Km/h) and enters h_{jk} from intersection I_j at $T_q = -5$.

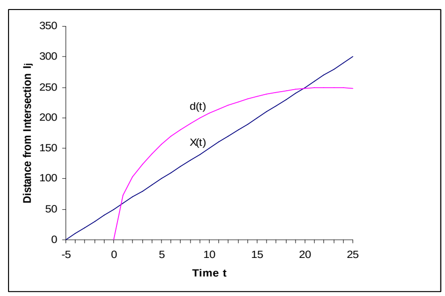


Fig. 2. Example of catching up case. Plot of d(t) and X(t) vs time

We observe that $d(t)$ is smaller than $X(t)$ at the beginning of plot whereas, later on, at some point around $t = 0.5$, it catches-up with $X(t)$ and afterwards it becomes greater than $X(t)$ until around $t = 20$. After that, $X(t)$ is again greater than $d(t)$. The catching period is $[0.5, 20]$. By keeping this in mind, we see that it is not enough to study the possibility that $X(t)$ is smaller than $d(t)$ just on time y (which is when $d(t)$ gets its greatest value) but it is necessary to see if, at any time during the period [0, y], $X(t)$ becomes smaller than $d(t)$.

So, the probability of transmitting the information in the catching up scenario is given by the following equation:

$$p_c = \int_0^y F_{X(t)}(d(t))dt \tag{8}$$

Case 2. veh_1 **passed point** R **without carrying the information and it got informed before reaching intersection** I_j

This case is more complicated than $case$ 1. veh_1 did not have the information when passing from point R. The information was transmitted to it by a following vehicle on h_{ij} before reaching point I_j. We consider $t = 0$ the time when veh_1 gets the information. We call S the position of veh_1 on segment of road RI_j, on time $t = 0$ and s the distance that point S has from R. Figure 3 shows the notations of $case$ 2.

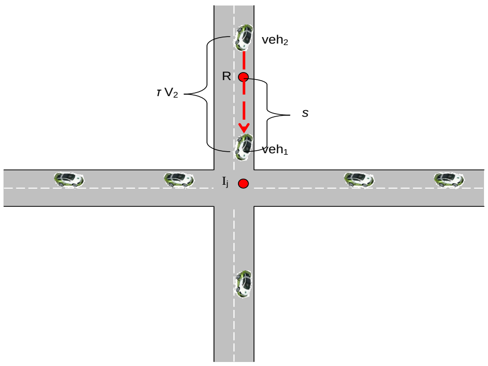


Fig. 3. Case 2 scenario where veh_1 got the information at some point after passing from point R

In case when the time needed by veh_1 to reach I_j, which is $\frac{r-s}{V_1}$, is greater than or equal to y, then this scenario is very similar to case 1. If $y > \frac{r-s}{V_1}$, we need to consider the probability that the vehicle veh_2 which travels with speed V_2, following veh_1, will pass point R by time $t = \frac{r-s}{V_1}$ after which, veh_1 will not be on h_{ij}. If veh_2 passes from R before veh_1 passes from intersection I_j, then it can also transmit the information to vehicles entering road h_{jk} until time y expires. In order not to have an informed vehicle in RI_j during some time in period $[0, y]$ the following must hold:

- veh_1 passed point R without having the information and a vehicle veh_2 transmits the information to veh_1 at time $t = 0$. This means that the distance between veh_1 and veh_2 is smaller than r on time $t = 0$.
- on $t = \frac{r-s}{V_1}$, which is the time needed by veh_1 to pass from intersection I_j, veh_2 must not have passed from point R. In order for this to happen V_1 must have been greater than V_2.

In other words, since V_1 is greater than V_2, veh_1 must have either entered h_{ij} before veh_2 or passed veh_2 at some time just before passing from point R. In the former case, since the distance between the two vehicles remained smaller than r from the beginning until the end of the road where veh_2 transmitted the information to veh_1, we can conclude that it is highly unlikely that their distance became greater than r just before veh_1 exited road h_{ij} and veh_2 did not pass point R. In the latter case, since veh_1 passed from veh_2 and at that time neither of the vehicles was informed, it means that veh_2 got the information from following vehicles just after the passing of veh_1 and before the distance of the two vehicles became greater than r. The only possible way that there were no informed vehicles between R and I_j during period of y is in the extreme case where veh_1 was very close to intersection I_j at the time when veh_2 received the message and immediately propagated it to veh_1. Then, the time needed by veh_1 to exit road h_{ij} should not be enough for veh_2 to cover the distance from R given that the distance between the two vehicles on the time of transmission was smaller than or equal to r.

It is obvious from the previous discussion that the circumstances under which there are no informed vehicles in the area RI_j during the period of $[0, y]$ are extremely rare to occur. Therefore, we reach the reasonable assumption that in the scenario of $case$ 2, during the period $[0, y]$ there is at least one informed vehicle in the area RI_j to propagate the information to any vehicle entering road h_{jk}. This means that the *probability of entering* is given by the same formula as in $case$ 1.

$$p_e = 1 - P_0^{h_{jk}}(y) \tag{9}$$

Now we need to calculate the *probability of catching up* (p_c). For this probability we are going to work the same way as in the previous case only now, we have $Q(t, s)$ instead of $d(t)$, which is a random variable depending on time and the initial value of s, given that s is uniformly distributed along RI_j.

$$\begin{aligned} Q(t, s) = \\ &(r - s - V_1 t)cos\varphi + \sqrt{r^2 - (r - s - V_1 t)^2 sin^2\varphi} \end{aligned} \tag{10}$$

In the case that φ forms a right angle then $Q(t, s) = \sqrt{r^2 - (r - s - V_1 t)^2}$. The function distribution that we are interested in is given by $F_{Q(t,s)-X(t)}(0)$. So,

$$\begin{aligned} &F_{Q(t,s)-X(t)}(0) = \\ &\int_0^r \sum_{z=0}^{\infty} P[Q(t, s) - X(t) < 0 | Z(\gamma) = z] \\ &* P[Z(\gamma) = z] * f_s(s)ds \end{aligned} \tag{11}$$

Finally, same as in $case$ 1, we want to see if during period $[0, y]$, $Q(t, s)$ gets bigger than $X(t)$. So, the *probability of catching up* is given by the following equation:

$$p_c = \int_0^y F_{Q(t,s)-X(t)}(0)dt \tag{12}$$

Now that we know the probability to transmit the information for both cases we need to combine them in order to calculate the overall probability $p_{tr}^{h_{ij}h_{jk}}$ to transmit the information from road h_{ij} to road h_{jk}. To do so, we need to find the probability for each case to happen separately.

In order for $case$ 1 to happen, veh_1 must pass point R carrying the information without any other vehicle in RI_j to transmit it. We call veh_2 the vehicle that is in front of veh_1 on h_{ij}. The probability that veh_2 does not have the information is equal to the probability that veh_1 and veh_2 are of distance greater than r. If we call τ the time gap between these two vehicles then their distance, $dist_{veh_1,veh_2}$ is equal to $\tau * V_1$.

In [15] is given that the time gaps between vehicles are distributed according to the following pdf and PDF,

$$p_\tau(\tau) = \lambda e^{-\lambda\tau} \text{ and } P_\tau(\tau > T) = e^{-\lambda T}, \tag{13}$$

respectively. So, the probability that $case\ 1$ happens is:

$$P_{cs_1} = P_\tau(\tau > \frac{r}{V_1}) = e^{-\lambda \frac{r}{V_1}} \tag{14}$$

Regarding $case\ 2$, it is sufficient to see that it is the compliment of $case\ 1$ since either veh_1 is in the road segment RI_j when it gets the information or, it passes R and enters RI_j with the information. So

$$P_{cs_2} = 1 - P_{cs_1} \tag{15}$$

So, the overall probability to have the information transmitted to road h_{jk} from road h_{ij} during a period of time y is

$$\begin{aligned} & p_{tr}^{h_{ij}h_{jk}} = \\ & P_{cs_1} * (p_e^{cs_1} + (1 - p_e^{cs_1}) * p_c^{cs_1}) + \\ & P_{cs_2} * (p_e^{cs_2} + (1 - p_e^{cs_2}) * p_c^{cs_2}) \end{aligned} \tag{16}$$

.

B. Driving Probability where veh_1 turns into road h_{jk} ($p_{dr}^{h_{ij}h_{jk}}$)

In this paragraph we are going to derive the probability $p_{dr}^{h_{ij}h_{jk}}$, which is the probability that vehicle veh_1 drives on road h_{jk}. In previous subsection where we calculated the $p_{tr}^{h_{ij}h_{jk}}$, the time needed by veh_1 to reach intersection I_j is definitely less than or equal to the time period y, which is the period we study the probability of transmission to road h_{jk}. For simplicity reasons however, we ignore the time gap between y and the time that veh_1 needs to reach intersection and make the choice of which road to drive on.

$p_{dr}^{h_{jk}}$ is strongly related to the intersection we are studying, since we need to consider all the other possible roads that a vehicle approaching intersection h_{jk} may choose. In the intersection I_j of figure 1 we only need to consider two choices: veh_1 can either go straight or turn left. However, in general cases, there are more complicated intersections, where the driver has more roads to choose. The general equation covering all cases is:

$$p_{dr}^{h_{ij}h_{jk}} = \frac{\lambda(h_{jk})}{\sum \lambda(h_{jb})} \text{ for all b such that road } h_{jb} \text{ exists.} \tag{17}$$

Now, we have everything needed to calculate all the terms of the equation 2, which gives the lower bound of the probability of information propagation $p_{h_{ij}h_{jk}}$, from informed vehicle on road h_{ij} to uninformed vehicles on road h_{jk}.

IV. Simulation Validation

In this section we validate our theoretical findings with simulation results. We conduct our simulations on VISSIM, a microscopic simulation. In all simulations we did, we used VISSIM to model the setup shown in figure 4. For simplicity we set angle φ equal to $90°$. Since the probability of information propagation with the driving way depends only on the average arrival rates of the roads that the vehicle reaching the intersection may follow, there is no need to simulate this case because we assume that the arrival rates are given. Hence, we concentrate on the validation of the information transmission probability $p_{tr}^{h_{ij}h_{jk}}$. Information transmission probability, as it is shown in equation 16, is only related to the traffic characteristics of the road intended to receive the information.

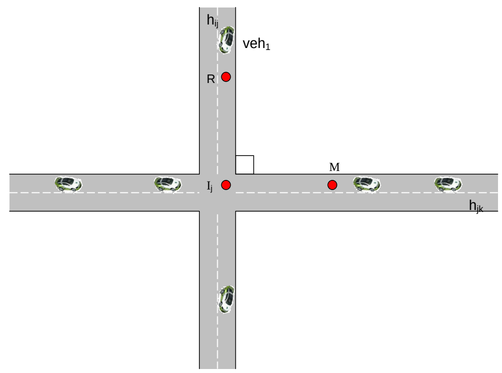


Fig. 4. Intersection setup used in VISSIM

The setup parameters are the vehicle arrival rates on road h_{jk}, the range of speeds attained by the vehicles on road h_{jk} and the speed of veh_1 moving on road h_{ij} and driving towards intersection I_j. Each simulation generates ascii files which include the position coordinates of the vehicles at each simulation step. The simulation step is set to 100 ms. We also developed an application on C++ to process the simulator's output in order to generate information with which we can infer whether any vehicle on road h_{jk} eventually receives the desired information from veh_1 and at what time. The transmission range of each vehicle is constant and it is set to 250 m. We consider that vehicles that are of distance less than the transmission range can exchange message. Since the transmission speed is much bigger (250 m in 6 ms) compare to the vehicle speed, we consider as zero the transmission time. Therefore, we do not use any specific wireless communication model for the measurements. For each set of parameters we repeat the simulation one hundred times and we calculate the frequency with which the information is successfully transmitted. The probability of information transmission is estimated by dividing the number of successes by the number of times we have repeated the simulation. The estimated probability is then compared with the theoretical probability obtained using the derived equation 16.

At first, we give insights of how the information transmission probability varies with respect to different parameters. We calculate the probability using the equation 16 we derived in the previous section. In all calculations we keep the speed range of road h_{jk} constant in the interval (60-80 Km/h). In figure 5 we plot the probability versus the time window for different arrival rates. The time window is the time which elapses from the instant when veh_1 passes from point R. As expected, the probability increases in a concave fashion with increasing time window. In addition, as the arrival rate increases so does the probability.

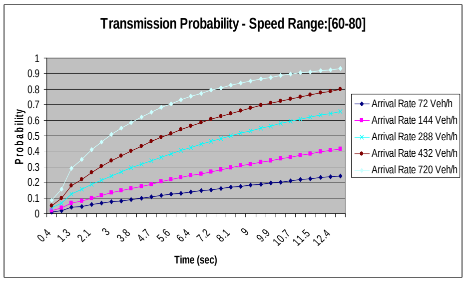


Fig. 5. Theoretical results of Transmission Probability for different arrival rates

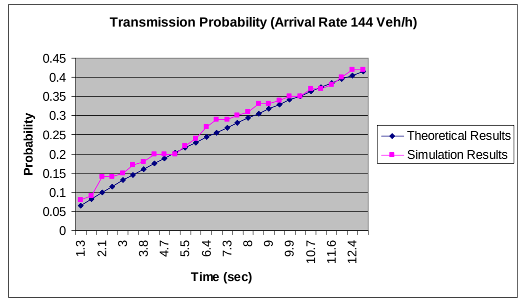
In figure 5 we can see that as time goes by, the probability increases for all the arrival rates. This is because, when time increases, it increases the chances to have a vehicle entering h_{jk} (*probability of entering*) as well as it increases the chances to have the transmission range of veh_1 catching up with a vehicle that has entered h_{jk} before $t = 0$ (*probability of catching up*). Also, we see that the probability increases when the arrival rate increases since there are more vehicles entering road h_{jk}.

In figures 6 (a and b) we present our theoretical results in comparison with the simulation's. They show how the probability increases as time increases for specific values of the arrival rates. We choose arrival rates that are low enough (144 Veh/h - 1 vehicle in 25 seconds and 540 Veh/h - 1 vehicles in 7 seconds) to keep the probability from getting its highest value (close to 1) very soon. In this way we can better observe the relation of the different results during a longer period of time.

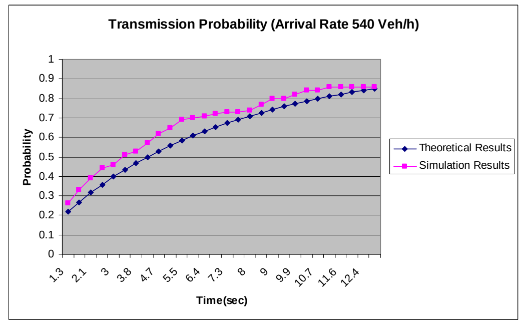
In figures 6 (a and b) we observe that the simulation probability, for most of the cases, is slightly higher than the theoretical one, whereas there are some cases that the results are equal. Also, we see that the trends that the plots have, are similar for theoretical and simulation probabilities for both values of arrival rates. This is a good support of the estimation of the actual probability that our analysis provides.

Finally, figures 7 (a and b) show the relation of theoretical and simulation results regarding the increase of probability as the arrival rate increases. The time is fixed and it is equal to the time needed by a vehicle with speed ‘q65 Km/h to cover distance r.

As in the previous figures, our theoretical results follow the same trend as the simulation's ones which supports the validation of our analysis. Moreover, figures 7 show that, for high arrival rates (1100 Veh/h - 1 vehicles every 3 seconds) the transmission probability is very close to 1. This is because, it is highly unlikely for such arrival rates, not to have any vehicle entering road h_{ij} after 14 seconds. Another useful observation is that for arrival rates greater



(a)



(b)

Fig. 6. Comparing Theoretical with Simulation results of Transmission Probability for arrival rates 144 Veh/h and 540 Veh/h

than 500 Veh/h (1 vehicle every 7 seconds) the information transmission probability is greater than 0.8, after passing time of 14 seconds.

V. Conclusions and Future Work

In this paper we study the problem of information dissemination in VANETS and we provide a measure of the probability to propagate information on intersecting roads where no static infrastructure is used. We present a lower bound on the probability to propagate information between vehicles of two roads, close to their point of intersection. We show that this probability is strongly related to the arrival rate of the vehicles entering the road where the information is to be transmitted to. We also show that, as the time allowed for propagation increases, so does the probability. We validate our results with simulation evaluation using VISSIM, a widely used micro-simulator.

One area of future work will be to study more scenarios to transmit information. This will slightly increase the probability of information transmission. Another area would be to create a road map graph where each road represents an edge and each intersection a node. By calculating the information propagation speed of each road as well as the probability to propagate information at every intersection, we can estimate the probability to have the information reaching an area in a given amount of time.

Finally, we are planning to study more realistic traffic conditions, where vehicles have accelerated and decelerated, their movement depends on the movement of other vehicles,

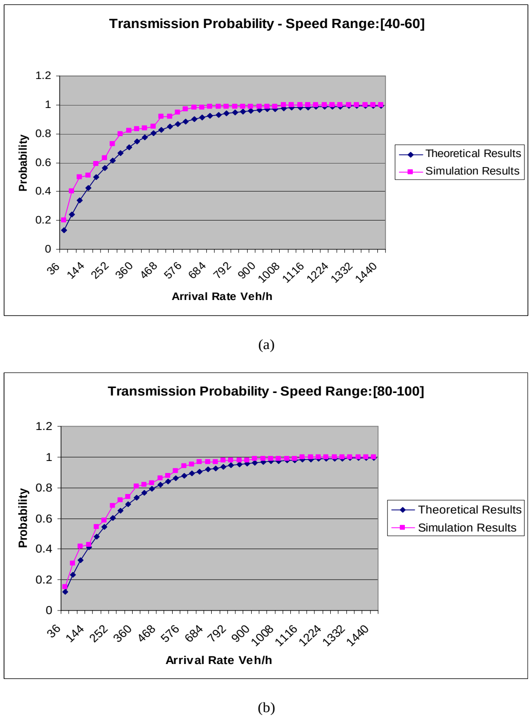


Fig. 7. Comparing Theoretical with Simulation results of Transmission Probability after 14 seconds

traffic lights can be introduced on intersections, etc. In addition, we plan to add more lanes in roads and different moving directions which will increase the possible ways to propagate information. This will definitely increase the propagation probability in intersections which will speed up the overall message propagation.

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