Performance of VANET Safety Message Broadcast at Rural Intersections

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Abstract—This paper develops a new analytic model for the performance and reliability analysis of safety-related message broadcast in vehicular ad hoc networks (VANETs) at rural intersections. First, a semi-Markov process (SMP) model for characterizing channel behavior of IEEE 802.11 based VANET is deployed to interact with the M/G/1 queue through fixed-point iteration. Then, the mean transmission delay between two nodes is derived. Furthermore, given two communicating nodes placed at the same intersection, the node reception probability that a node successfully receives the broadcast message from a sending node is computed. Consequently, the packet reception ratios are derived through integration of the node reception probabilities over the intended range of the sending node. The analytical model takes intersection geometry, IEEE 802.11 backoff counter process, hidden terminal problem, and non-saturated message arrival into account. From the obtained numerical results under various network parameters, the new model is validated and new observations are obtained.

Keywords—Intersection, broadcast, hidden terminal problem, vehicular ad hoc networks, semi-Markov process, M/G/1 queue

I. INTRODUCTION

Dedicated Short Range Communication (DSRC) vehicular ad hoc networks (VANETs) can support many safety-related applications such as one-hop or multi-hop broadcasting to disseminate real-time traffic information or safety-related messages [1]. These applications require highly reliable and real-time communications between mobile nodes under adverse environments. Cooperative intersection collision avoidance is likely to be among the first and one of the most important quality of service (QoS) critical applications of DSRC communications. Information detected by both vehicle-based and the infrastructure-based sensors can be combined to produce better real-time knowledge of the “state map” of an intersection [2]. Wireless DSRC communication between the vehicles and the infrastructure and among vehicles makes it possible for each vehicle to have complete intersection state map information, so that it can then use its own intelligence and threat assessment logic to determine whether to alert a driver to avoid potential car collisions. Potential safety applications at intersections could be blind collision avoidance and rear-end collision avoidance.

The performance of the broadcast message dissemination in DSRC system has been studied. Several important reliability metrics such as Packet Reception Probability (PRP), Packet Reception Ratio (PRR) and Packet Delivery Ratio (PDR), etc. are defined and evaluated [3-8], [11-14]. Normally, PRP and PRR were evaluated by simulations [3]. In [4-7], analytical models were proposed to obtain PRR expressions in one-dimensional (1-D) IEEE 802.11 based broadcast MANETs with hidden terminals. Assuming spatially Poisson distributed nodes, and saturation packet generation, PRR of beacon message broadcast in 1-D DSRC VANETs was investigated in [8]. Unfortunately, very few of network scenarios in real applications can be abstracted as 1-D models. Recently, we have conducted PRR analysis in a special two-dimensional (2-D) MANET (two parallel lines approximate two opposite roads on highway) [9]. To date, there is no analytic model on performance evaluation of IEEE 802.11 broadcast VANETs at intersections.

In this paper, we evaluate the performance and reliability of safety message broadcast VANETs at 2-D intersections. First, a semi-Markov process (SMP) model interacting with M/G/1 queue models and its solutions are introduced to derive channel performance and node transmission probabilities given node density distribution around intersections (adopt either 1-D or 2-D depending on how close the node is placed from the center of the intersection). The node reception probability that a node at an intersection successfully receives the broadcast message from a sending node at the same intersection is computed. Consequently, the PRRs are derived through integration of the node reception probabilities over the intended range of the sending node. This paper is organized as follows. Section II presents a SMP model interacting with the M/G/1 queue through fixed-point iteration for characterizing channel behavior of IEEE 802.11 based VANET. Section III derives the performance and reliability expressions in the broadcast VANETs at intersections. Section IV demonstrates and discusses the numerical results from the analytic model and compares them with a detailed simulation model. The paper is concluded in Section V.

II. SYSTEM MODEL AND PERFORMANCE ANALYSIS

A. Assumptions for IEEE 802.11 Broadcast VANET

In the proposed model, we assume that IEEE 802.11 broadcast DCF works under the following scenario.

1) We consider a VANET with nodes distributed randomly on cross roads at intersections. Each crossing road has one lane per direction so that each intersection can be
approximated by cross lines, as shown in Fig. 1. Nodes in each road are distributed according to the 1-D spatial Poisson distribution. Let the average number of nodes per meter (density) in one line be \( \rho \), then the probability \( P(i,l) \) of finding \( i \) nodes in length \( l \) is given by

\[
P(i,l) = \frac{(\rho l)^i e^{-\rho l}}{i!} \tag{1}
\]

For networks in which transmitters and/or receivers are located or move around randomly at rural intersections where traffic is smooth over a large area, the Poisson point process is a good approximation.

2) All nodes have the same deterministic transmission range, carrier sensing range, and the same interference range, denoted as \( R \).

3) At each mobile node, packet arrivals follow a Poisson process with rate \( \lambda \) (in packets per second). In addition to its tractability, the Poisson arrival process is a good approximation of message arrivals in packet-data networks [6].

4) Each vehicle has an infinite queue to store the packets at the MAC layer. Hence, each vehicle can be modeled as an M/G/1 queue. The network as a whole is a set of interacting M/G/1 queues.

5) The impact of node mobility on the performance is not considered in the paper. It was proven in [4] that high node mobility has a minor impact on the performance of the one-hop direct message broadcast network with high data transmission rates.

6) The intersection under analysis is widely separated from other intersections, so there is no overlap of communication ranges. Hence, distance between intersections >> node’s transmission range.

7) Channel condition sensed by one vehicle is the same as that sensed by other vehicles in the intersection under consideration.

Due to the contention medium, the overall problem can be seen as a set of interacting M/G/1 queues, one queue for each vehicle. We simplify the problem by developing an SMP model for the tagged vehicle that does not directly keep track of the queued requests but captures the channel contention and backoff behavior. This SMP model interacts with the M/G/1 queues of the other vehicles through fixed-point iteration.

### B. SMP Model for IEEE 802.11 Broadcast

The behavior of a tagged node for packet transmission is approximated by the SMP model developed in [10]. The tagged vehicle is in idle state if there is no packet in its queue. After a packet is generated, the vehicle senses channel activity for DIFS period. If the channel is detected not busy during this period (with probability \( 1-q_b \)), the vehicle goes from idle state to transmission state. Otherwise, the node will randomly choose a backoff counter in the range \([0, W_0-1]\). The backoff counter will be decreased by one if the channel is detected to be idle for a time slot \( \sigma \) (with probability \( 1-p_b \)). If the channel is busy during a backoff time slot \( \sigma \), the backoff counter of the tagged node will be suspended and deferred for the duration \( T \) of a packet transmission time plus an idle DIFS with probability \( p_b \), where \( T=E[PA]/(R_d \times 10^6)+T_{d}+\text{DIFS}+\delta \). \( R_d \) represents the data rate. \( PA \) is length of the packet. Hence, \( E[PA]/(R_d \times 10^6) \) is the average time to transmit the packet. \( T_d \) presents the packet header transmission time including physical layer header time and MAC layer header time. \( \delta \) is the propagation delay. When the backoff counter reaches zero, the packet will directly be transmitted (an SMP transition occurs from 0 state to state \( \text{XMT} \) with probability one). In \( \text{XMT} \) state, a packet is transmitting. After the packet transmission, if there is no packet left in the queue of the tagged node (with probability \( 1-\rho \)), the node will go from \( \text{XMT} \) to idle state and wait for a new incoming packet. If there are packets left in the queue after a packet transmission (with probability \( \rho \)), the node will sense the channel again for DIFS time and then randomly choose a backoff counter before transmitting the next packet.

Define the mean sojourn time in state \( j \) as \( \tau_j \). Taking into account the mean sojourn time in each state, the steady-state probabilities of the SMP are given by:

\[
\pi_i = \sum_{j=0}^{\infty} \pi_j \tau_j, \quad i=0,1,2,\ldots, \tag{2}
\]

In the above equation, \( \pi_j (i=0,1,2,\ldots) \) denote steady-state probabilities of the embedded DTMC, which are derived in Eq. 4 of [11]. Therefore, the steady-state probability that a node is in the \( \text{XMT} \) state is given by

\[
\pi_{\text{XMT}} = \frac{1}{2} \left[ \frac{1}{p_b + q_b (1 - p_b)} \right] \left[ \frac{(\sigma + p_b T)(1 - (1 - p_b)(1 - q_b))}{2T + 2(1 - p_b)(1 - q_b)} \right] \tag{3}
\]

Therefore, the mean service time for a packet transmission is derived from [10] [11]:

\[
E[S] = \frac{(\sigma + p_b T)(1 - (1 - p_b)(1 - q_b))(W_d - 1) + T}{2}
\]

\[
\text{Var}[S] = E[S^2] - (E[S])^2
\]

From the tagged vehicle’s point of view, \( p_b \) is the probability that it senses channel busy during one time slot in the backoff process. Since channel is detected busy if there is at least one neighbor (i.e., a vehicle in the transmission range of the tagged vehicle) transmitting in a backoff time slot of the tagged vehicle, we have
\[ p_b = 1 - \sum_{i=0}^{\infty} (1 - P_{\text{SMT}}) \frac{(\beta \rho_s \gamma i)^i}{i!} e^{-\beta \rho_s \gamma} = 1 - e^{-\beta \rho_s \gamma} \]  

where \( P_{\text{SMT}} \) is the probability that a neighbor is transmitting in a backoff time slot of the tagged vehicle, \( \Delta_b \) is the carrier sensing range of the tagged vehicle, which will be iteratively derived later in this paper.

Since the probability that a backoff time slot is the first backoff time slot is \( 1/W_0 \) and non-first backoff time slot is \( (1-1/W_0) \), the probability that a neighbor’s transmission is detected by a backoff time slot of the tagged vehicle is given by

\[ P_{\text{SMT}} = \frac{1}{W_0} T - \text{DIFS} + 2\sigma^2 \tau_{\text{SMT}} + \left(1 - \frac{1}{W_0}\right) \frac{2\sigma^2}{T} \tau_{\text{SMT}} \]  

In Equation (5), three unknown parameters are:

- \( \rho \): the probability that there are packets in the queue of the tagged vehicle,
- \( p_b \): the probability that the channel is detected busy in one time slot by the tagged vehicle,
- \( q_b \): the probability that the channel is detected busy in DIFS time by the tagged vehicle.

Hence, we denote \( p_b = g(\rho, p_b, q_b) \) and the reciprocal of mean service time for M/G/1 queue to be \( \mu = h(\rho, p_b, q_b) \). By utilizing fixed-point iteration, the parameters \( \rho, p_b, q_b, \tau_{\text{SMT}} \) as well as the mean and the variance of the service time are determined, which are subsequently used for the performance indices computation in the next section.

III. PERFORMANCE INDICES

A. Packet Transmission Delay

The packet transmission delay is defined as the average delay a packet experiences from the time at which the packet is generated until the time at which the packet is successfully received by all neighbors of the node that generates the packet. The mean transmission delay \( E[D] \) includes the queuing delay and medium service time (due to backoff, packet transmission, and propagation delay, etc.).

The expected queuing delay is obtained from the Pollaczek-Khinchin mean value formula of the M/G/1 queue:

\[ E[D_q] = \frac{2\text{Var}[S]+2\mu E[S]^2}{2\mu^2 E[S]} \]  

The average packet transmission delay is then calculated as

\[ E[D] = E[D_q] + E[S] \]  

B. Packet Reception Probability

Packet reception probability (PRP) is defined as the probability that a node within the transmission range of the sender successfully receives a packet from the tagged node (i.e., sender).

Given a transmitting node \( O \) placed at coordinates \((x_0,0)\) (see Fig. 1), \( U \) is one of the receivers within transmission range \( R \) of node \( O \). The position of \( U \) is either at \((x_0,0)\) or at \((0,y_0)\) \( (|x-x_0| \leq R, y_0^2 + x_0^2 \leq R^2) \). The probability that the node \( U \) receives the broadcast message from the tagged node \( O \) successfully is denoted as \( P_r(x_0,x_i) \) or \( P_r(x_0,y_i) \).

There are two factors affecting the performance of packet reception probability: hidden terminal problem and collisions due to concurrent packet transmissions.

Impact of hidden terminals at \( O \)’s transmission: According to assumption 7, \( \pi_0 \) and \( P_{\text{SMT}} \) can be derived based on the SMP model and its solution in Section II. Note that \( \pi_0 \) and \( P_{\text{SMT}} \) for the nodes in hidden terminal areas (denoted as \( \pi_0^{(1)} \) and \( P_{\text{SMT}}^{(1)} \)) can be calculated by Equations (2) and (5) assuming all nodes are distributed in a 1-D line (This assumption is reasonable because all such hidden nodes are located far away from the intersection and distance between intersections is long enough, so that the impact of transmission from nodes on the other side of the crossing roads can be neglected). On the derivations of \( \pi_0^{(1)} \) and \( P_{\text{SMT}}^{(1)} \), \( \Delta_b \) in Equation (4) is equal to \( 2R \). Hence, we have the probability that node \( O \)’s receiving the broadcast message from node \( O \) is free from the hidden terminals:

\[ P_{\text{h}}(x_0,x_i,0,y_0) = \sum_{i=0}^{\infty} (1 - 2 \pi_0^{(1)} \frac{\Delta_b^2}{i!} e^{-\Delta_b^2}) \]  

where \( \Delta_b \) is average number of nodes in the hidden terminal area of \( O \)’s transmission. According to the definition of hidden terminals, the potential hidden terminal area should be area where the nodes are within node \( O \)’s receiving range but out of \( O \)’s carrier sensing range in both x-axis and y-axis, as shown in Fig. 2. Thus, \( \Delta_b \) is expressed as

\[ \Delta_b = \begin{cases} 
|x_0 - x_i| + 2\beta \max(0, R - |x_0 - y|) & \text{if } U \text{ in } (x_0, y_0) \\
\beta \max(0, R - x_0, R - y_0) & \text{if } U \text{ in } (0,y_0) 
\end{cases} \]

Impact of concurrent collisions In addition to collisions caused by the hidden nodes, transmissions from nodes within the interference range of the tagged node during the time at which the tagged node transmits may also cause collisions. When the tagged node transmits in a slot time, collisions will take place if any node in the interference range of the tagged node transmits in the same slot.

According to assumption 7, \( \pi_0 \) and \( P_{\text{SMT}} \) of the transmitting node and concurrently transmission nodes are the same for all vehicles approaching to the intersection (denoted as \( \pi_0^{(2)} \) and \( P_{\text{SMT}}^{(2)} \)), which can be derived by Equations (2) and (5) based on the SMP model [10] via setting the tagged node in the center of the intersection. (This approximation is based on the
assumption that the transmission range and carrier sensing range are long enough so that all associated nodes closing the intersection can sense each other very well). Therefore, the derivations of $\pi_0^{(2)}$ and $P_{XM}^{(2)}$, $\Delta_0$ in Equation (4) is equal to $4R$.

Given that both $O$ and $U$ sense the channel idle, $O$ will withstand the transmission during a slot. In order to prevent interference due to concurrent collisions to $U$’s receiving the broadcast message sent by $O$, no transmission in $D(O,R)\cap D(U,R)$ is allowed, where $D(s,l)$ denotes the disk set of radius $l$ centered at $s$.

Case 1: $U$ in $(x,0)$

i) The average number of nodes transmitting in the concurrent slot in area between $O$ and $U$ is 
$$n_1 = \beta |x - x_o| \pi_0^{(2)}$$

ii) Suppose node $V$ is at $(x',0)$, where $\max(x, x_o) - R < x' < \min(x, x_o)$, and $\max(x, x_o) < x' < \min(x, x_o) + R$. The probability that the node $V$ starts transmitting during the slot is the probability that node $V$ intends to transmit and all nodes in $A_s = D(V,R) \cap D(O,R) \cap D(U,R)$ are not transmitting state, which is expressed as 
If $\max(x, x_o) - R < x' < \min(x, x_o)$,
$$P_r(x', x_o, x) = \pi_0^{(2)} \sum_{i=0}^{\infty} \frac{(\beta |x' - \max(x, x_o)|)^i}{i!} e^{\beta |x' - \max(x, x_o)|}$$
$$= \pi_0^{(2)} \sum_{i=0}^{\infty} \frac{\beta |x' - \max(x, x_o)|}{i!} e^{\beta |x' - \max(x, x_o)|}$$

then, the average number of nodes that start transmission during the slot is the probability that node $W$ intends to transmit and all nodes in $A_s = D(V,R) \cap D(O,R) \cap D(U,R)$ are not transmitting state, which is expressed as 
$$P_r(x', x_o, x) = \pi_0^{(2)} \sum_{i=0}^{\infty} (1 - P_r^{(2)}) \frac{(\beta |x' - \max(x, x_o)|)^i}{i!} e^{\beta |x' - \max(x, x_o)|}$$

Suppose node $W$ is at $(0, y')$, where $0 < y' < \min((R^2 - x^2)^{1/2}, (R^2 - x_o^2)^{1/2})$, and $-\min((R^2 - x^2)^{1/2}, (R^2 - x_o^2)^{1/2}) < y' < 0$. The probability that the node $W$ starts transmitting during the slot is the probability that node $W$ intends to transmit and all nodes in $A_s = D(W,R) \cap D(O,R) \cap D(U,R)$ are not in transmitting state, which is expressed as 
$$P_r(x', x_o, x) = \pi_0^{(2)} \sum_{i=0}^{\infty} (1 - P_r^{(2)}) \frac{\beta |x' - \max(x, x_o)|}{i!} e^{\beta |x' - \max(x, x_o)|}$$

where 
$$\Delta_0 = \max(0, R - y' - \max(\sqrt{R^2 - x^2}, \sqrt{R^2 - x_o^2})) + \max(0, R - y' - \min(\sqrt{R^2 - x^2}, \sqrt{R^2 - x_o^2}))$$

Then, the average number of nodes that start transmission during the slot that collides with the transmission from $O$ is 
$$n_2 = 2\beta \sum_{i=0}^{\infty} (1 - P_r^{(2)}) \frac{\beta |x' - \max(x, x_o)|}{i!} e^{\beta |x' - \max(x, x_o)|}$$

where 
$$\Delta_0 = \max(\min(y, y_o - \sqrt{R^2 - x^2}, y_o - \sqrt{R^2 - x_o^2}), 0) + \max(\min(y, y_o - \sqrt{R^2 - x^2}, y_o - \sqrt{R^2 - x_o^2}), 0)$$

Then, the total average number of nodes that may transmit concurrently is 
$$\tilde{n}_2 = n_1 + n_2$$

Therefore, given Poisson node distribution, the probability that no nodes within the reception range of $U$ start transmission during the slot that collides with the transmission from $O$ is 
$$P_{un}(x, y, x_o) = q_0 \left( \frac{\pi_0^{(2)}}{y} \right)^0 \exp(-n_1) + 1 - q_0$$

$$= q_0 \exp(-n_2) + 1 - q_0$$

Case 2: $U$ in $(0, y)$

i) Suppose node $V$ is at $(x',0)$, where $\max((-R^2 - y^2)^{1/2}, x_o - R) < x' < \min((-R^2 - y^2)^{1/2}, x_o + R)$. The probability that the node $V$ starts transmitting during the slot is the probability that node $V$ intends to transmit and all nodes in $A_s = D(V,R) \cap D(O,R) \cap D(U,R)$ (See $A_s$ in Fig. 3) are not in transmitting state, which is expressed as 
$$P_r(x', x_o, y) = \pi_0^{(2)} \sum_{i=0}^{\infty} (1 - P_r^{(2)}) \frac{(\beta |y - \max(y, y_o)|)^i}{i!} e^{\beta |y - \max(y, y_o)|}$$

where 
$$\Delta_0 = \min(0, x - \min(x, x_o), x - \sqrt{R^2 - x^2}, x_o - \sqrt{R^2 - x_o^2}, 0) + \max(0, \sqrt{R^2 - x^2} - \min(x, x_o))$$

Then, the average number of nodes that start transmission during the slot that collides with the transmission from $O$ is 
$$n_2 = 2\beta \sum_{i=0}^{\infty} (1 - P_r^{(2)}) \frac{\beta |y - \max(y, y_o)|}{i!} e^{\beta |y - \max(y, y_o)|}$$

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Therefore, given Poisson node distribution, the probability that no nodes within the reception range of $U$ start transmission during the slot that collides with the transmission from $O$ is 
$$P_{un}(x, y, x_o) = q_0 \left( \frac{\pi_0^{(2)}}{y} \right)^0 \exp(-n_1) + 1 - q_0$$

$$= q_0 \exp(-n_2) + 1 - q_0$$

Fig. 3 Impact of concurrent collisions at intersection
Therefore, given Poisson node distribution, the probability that no nodes within the reception range of U start transmission during the slot that collides with the transmission from O is

$$P_{c}(x_o, y_o) = q_b \left( \frac{\pi z_o}{4} \right)^{\frac{1}{2}} \exp(-\pi z_o) + 1 - q_b$$  

$$= q_b \exp(-\pi z_o) + 1 - q_b$$  \hspace{1cm} (10)

Packet Reception Probability Taking hidden terminal, and possible packet collisions into account, the PRP that the node U receives the broadcast message from the tagged node O is

$$P_r(x_o, x_o, y_o) = P_h(x_o, x_o, y_o) P_{c}(x_o, y_o)$$  \hspace{1cm} (11)

C. Packet Reception Ratio (PRR)

Packet reception ratio (PRR) is defined as the percentage of nodes that successfully receive a packet from the tagged node among the receivers that are within the transmission range of the sender at the moment that the packet is sent out.

Since safety applications at intersections are more concerned about PRRs over a certain range from the center of intersection, here we focus on PRR evaluation over range from \((x_o, 0)\) to \((x, 0)\) and from \((0, 0)\) to \((0, y)\) (where \(x - x_o \leq R\), and \(x^2 + y^2 \leq R^2\)). Given the reception probability of each node in Equation (11), the average number of nodes in \(dx\) (or \(dy\)) that successfully receive the broadcast message from the tagged node is \(P_r(x, x, y)dx\) or \(P_r(x, y)dy\). For a coverage distance with range \(x\) or \(y\) from the center of the intersection, PRR over a coverage range of node \(O\) can be found by integrating the probabilities that nodes with distance \(x\) or \(y\) to the center of the intersection within an incremental range successfully receives the broadcast message from \(O\). Therefore,

$$PRR(x_o, x) = \frac{\int_{x_o}^{x} P_r(x, x, 0)dx}{\beta x}$$  \hspace{1cm} (12)

and

$$PRR(x_o, y) = \frac{\int_{0}^{y} P_r(x, y, 0)dy}{\beta y}$$  \hspace{1cm} (13)

IV. MODEL VALIDATION AND NUMERICAL RESULTS

In this section, we apply the proposed model to DSRC communication system for safety message disseminations [1]. In order to validate the proposed analytic model, we extend 1-D event-driven simulation program in [6] to 2-D intersection simulation. The communication nodes are Poisson distributed on an intersection with length of 2500m on each of the crossing roads. Each node is equipped with IEEE 802.11 based wireless ad hoc network capability with communication parameters as listed in Table I. Communication range (transmission/cARRIER SESSING) is \(R=500m\). Each node generates broadcast message with rate \(\lambda\) and average message length \(E[PA]=200\text{bytes}\). Our simulation duration is 2 seconds and simulation resolution is 1 \(\mu s\). Fig. 4 and Fig. 5 depict the mean transmission delay and the packet reception ratios from (0,0) to (500,0) (i.e., \(PRR(0, 500)\)), respectively, over the density of nodes in transmission range of a transmitting (or tagged) node on the center of the intersection. As shown in Fig. 4 and Fig. 5, analytical results (lines) practically coincide with the simulation results (symbols), which helps build the proposed intersection model and validation of the approximations (Equations (4) and (8)) and assumptions (Assumption 2, and 7)) made in the analytic model.

We also observe from Fig. 4 and Fig. 5 that with the same density and communication parameters, the mean transmission delay at the intersection is higher than that in 1-D highway (e.g., for \(\beta=0.2\), \(R_c=24\text{Mbps}\), \(E[D]_{1-D}=0.29\text{ms}\), \(E[D]_{intersection}=0.4\text{ms}\) and PRRs at the intersection is lower than that in 1-D highway (e.g., for \(\beta=0.2\), \(R_c=24\text{Mbps}\), PRRs \(\beta=0.86\), \(PRR_{intersection}=0.80\)). The explanation for the observation is that the number of nodes within carrier sensing/transmission range at the intersection is higher than that in 1-D highway with the same density of nodes on the road.

<table>
<thead>
<tr>
<th>TABLE I</th>
<th>PARAMETERS FOR COMMUNICATIONS IN DSRC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
<td>Value</td>
</tr>
<tr>
<td>Modulation</td>
<td>BPSK, QPSK, 16-QAM, 64-QAM</td>
</tr>
<tr>
<td>Coding Rates</td>
<td>1/2, 2/3, 3/4</td>
</tr>
<tr>
<td>OFDM Symbol Duration</td>
<td>8 (\mu s)</td>
</tr>
<tr>
<td>Signal Bandwidth</td>
<td>10 MHz</td>
</tr>
<tr>
<td>Channel Data Rate</td>
<td>6, 9, 12, 24, 27 Mbps</td>
</tr>
<tr>
<td>DIFS for 802.11a</td>
<td>64 (\mu s)</td>
</tr>
<tr>
<td>Slot time, (\sigma)</td>
<td>16 (\mu s)</td>
</tr>
<tr>
<td>SIFS for 802.11a</td>
<td>32 (\mu s)</td>
</tr>
<tr>
<td>Propagation delay, (\delta)</td>
<td>1 (\mu s)</td>
</tr>
<tr>
<td>Preamble Length</td>
<td>40 (\mu s)</td>
</tr>
<tr>
<td>PLCP Header Length</td>
<td>8 (\mu s)</td>
</tr>
<tr>
<td>CWM</td>
<td>15–1024</td>
</tr>
</tbody>
</table>
Numerical results prove the effectiveness of the proposed model, and reveal the characteristics of the performance and reliability for DSRC safety-related services, which can be useful in the design of such systems. From the numerical results, we observe that from the perspective of communication, the situation at intersection brings bigger challenge than that in 1-D highway for meeting QoS requirements of safety message broadcast. Based on the basic model, the future work would introduce more realistic factors into the analytic model, such as impact of fading channel, mobility of nodes, intersection with traffic light at urban intersection, etc.

REFERENCES


Fig. 6 Packet reception probabilities of communicating nodes at different locations of the intersection with network parameters $E[PA]=200$ bytes, $\lambda=10$ packets/s, $R_s=24$ Mbit/s, $R_e=500$ m, $W_1=15$.

Fig. 6 shows packet reception probabilities (PRPs) for communicating nodes at different locations of the intersection. Generally, the farther the distance between two communicating nodes, the smaller is the PRP. The differences are getting more significant as the density of vehicles becomes bigger.

V. CONCLUSIONS

In this paper, we propose an analytical model to evaluate the performance and reliability of IEEE 802.11 based broadcast 2-D VANETs for safety message dissemination at rural intersection. The derived performance and reliability expressions take the impact of intersection geometry, the hidden terminal problem, variable message arrival rate, concurrent transmissions of IEEE 802.11 MAC, and DCF backoff process into account. The analytical model is applied to DSRC VANET for broadcast of safety-related messages. Numerical results prove the effectiveness of the proposed model, and reveal the characteristics of the performance and reliability for DSRC safety-related services, which can be useful in the design of such systems. From the numerical results, we observe that from the perspective of communication, the situation at intersection brings bigger challenge than that in 1-D highway for meeting QoS requirements of safety message broadcast. Based on the basic model, the future work would introduce more realistic factors into the analytic model, such as impact of fading channel, mobility of nodes, intersection with traffic light at urban intersection, etc.