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Effects of Distance-Based Defer Times and Probabilistic Channel to Time-Stable Geocast

Phuchong Kheawchaoom and Somsak Kittipiyakul

***Abstract*—One popular approach to suppress broadcast storm in vehicular ad-hoc networks is based on distance-based defer time, where nodes further from the transmitter rebroadcast sooner and the closer nodes that hear prior rebroadcasts suppress their own rebroadcasts. In this paper, we study the effects of some previously proposed distance-based defer times in both deterministic and probabilistic (i.e., fading) channels, with a time-stable geocast protocol, called iDTSG, used for emergency message notification. We consider both dense and sparse traffic. The simulation results show trade-offs between reliability and efficiency, especially in the dense scenario where the broadcast storm problem is significant. In addition, since the previously proposed defer times are more suitable for deterministic channels, we propose and evaluate a new defer time which is more appropriate to probabilistic channels. Although our proposed defer time works well, it can still be improved in the future by considering the fact that nodes suppress their own rebroadcasts if they hear prior rebroadcasts.**

***Index Terms*—vehicular ad-hoc networks, time-stable geocast, broadcast storm, emergency notification, distance-based defer time**

I. Introduction

VEHICULAR ad-hoc networks (VANETs) have an important role in safety transport system applications. In these applications, drivers can be informed of important traffic information such as accident incident or road condition. To distribute such emergency information, a reliable and efficient broadcast protocol is needed. There are two major and well-known problems in VANETs: broadcast storm problem and network disconnection problem. A straightforward broadcasting by flooding usually results in serious redundancy, contention, and collision, which is referred to as the broadcast storm problem [1]. On the other hand, the network disconnection problem is due to high mobility caused by fast moving vehicles and sparse traffic densities during off-peak hours and/or during initial deployment [2]. Among the two problems, the broadcast storm problem is more important for dense networks while the network disconnection problem is more important for sparse networks.

In this paper, we consider a highway scenario where the crashed vehicle or the vehicle that has seen an accident wants to inform the other vehicles that are approaching the dangerous area. Since this accident warning message must be directed to a specific geographical region and stay there for some time for the accident to be taken care of, this problem of message multicast to vehicles in a specific region and time duration is called *time-stable geocast* [3].

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P. Kheawchaoom and S. Kittipiyakul are with Sirindhorn International Institute of Technology, Thammasat University, Pathum Thani, Thailand, email: phuchong.k@gmail.com, somsak@siit.tu.ac.th.

We assume that every vehicle participating in this system is equipped with a localization device such as GPS and an IEEE 802.11p transceiver. Hence, each participating vehicle knows its current location and can notify other vehicles of the accident and include its current position in its message rebroadcast as well. Each node does not know the current position and speed of any of its neighbor nodes.

In our previous work [4], we proposed a time-stable geocast protocol, called iDTSG, which has good performance for both dense and sparse traffic. To alleviate the broadcast storm problem, iDTSG uses the same distance-based *defer time* as proposed in [5]. The defer time is used in a general approach to suppress the broadcast storm problem in stateless broadcast protocols, where each node does not know or keep track of the locations of its neighbors [6]. In schemes based on distance-based defer times, when a node receives a message that it has not received before from a source, it waits a defer time before determining whether to retransmit the message. The receiving nodes that are further away from the transmitting nodes use shorter defer times and hence are allowed to rebroadcast first. When the closer nodes hear the rebroadcast(s), they suppress their own rebroadcasts. In this paper, we study in more details than what we have done in [4] on the importance of the distance-based defer time on the performance of the iDTSG protocol in suppressing the broadcast storm problem.

A. Related Work on Distance-Based Defer Times

Several proposed broadcast protocols have used distance-based defer times. Some papers use deterministic defer times (e.g., [7]–[9]), while the other uses stochastic deter times (e.g., [10]). In [11], although the authors use a deterministic defer time, the decision for a vehicle to rebroadcast and hence use the defer time is stochastic and dependent on the local vehicle density. In this paper, for simplicity of comparison, we consider only deterministic defer times.

In [5] and our previous work [4], the distance-based defer time is inversely proportional to the distance d and given as

$$T_{D,I}(d) = \frac{R\ T_N}{d}, \tag{1}$$

where $d > 0$ is the distance between the transmitting node and the receiving node (known by the receiving node from the message which contains the location of the transmitting node), R is the "transmission range" and T_N is called the normal sleeping time defined as

$$T_N = \frac{2R}{s_r + s_{max}} \tag{2}$$

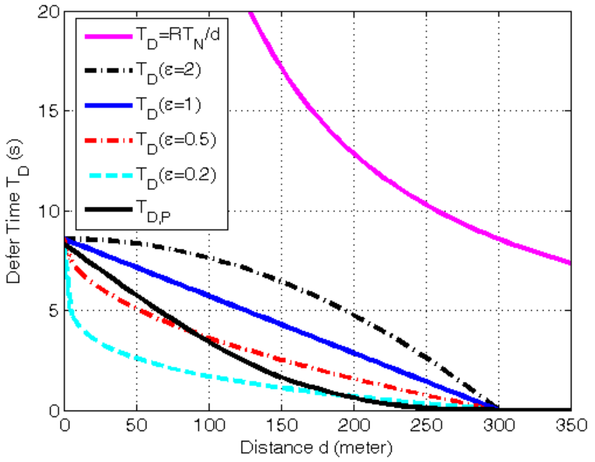

Fig. 1. Different defer times T_D: the inverse defer time $T_{D,I}$ in (1), T_D in (3) with $\epsilon = 2, 1, 0.5$, and 0.2, the probabilistic-channel defer time $T_{D,\text{opt}}$ in (4), for $R = 300$ and $T_{\text{DMAX}} = R/s_{max} = 8.57$ s. For this plot, we assume the receiving node is moving at the maximum speed ($s_r = s_{max}$) and hence from (2) we have $T_N = 2R/2s_{max} = T_{\text{DMAX}}$.

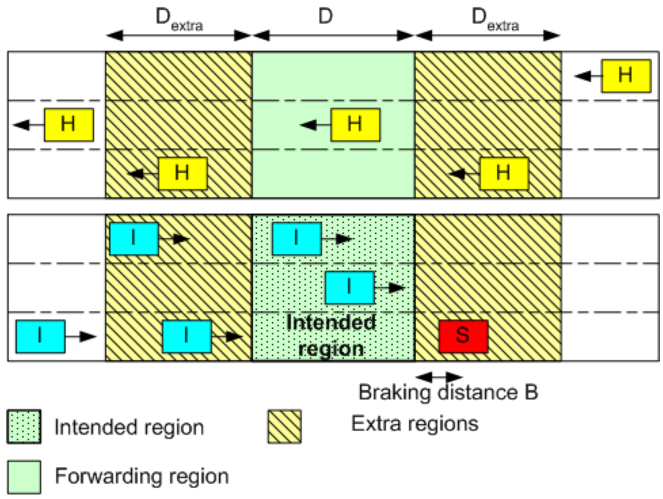

Fig. 2. Problem model and an illustration of the intended, forwarding, and extra regions. For illustration purpose, the figure shows three lanes per direction. However, in our simulation we consider only one lane per direction.

which depends on the current speed s_r of the receiving node and the maximum speed limit s_{max} on the highway. Fig. 1 illustrates an example of this defer time.

A more popular form of defer times has been used in multiple papers, e.g., [7]–[11]. It is given as

$$T_D(d) = \begin{cases} T_{\text{DMAX}} \left[1 - \left(\frac{d}{R}\right)^{\epsilon}\right], & \text{if } 0 \le d \le R, \\ 0, & \text{if } d > R, \end{cases} \tag{3}$$

where $\epsilon > 0$ is a constant, and T_{DMAX} is a given maximum defer time. With such definition of T_D, the farther node from the source waits less and rebroadcasts faster.

Different values of ϵ give different shapes of the defer time. Fig. 1 illustrates T_D's for $\epsilon = 2, 1, 0.5$ and 0.2. Without confusion, we denote $T_D(\epsilon = \epsilon_0)$ for T_D with $\epsilon = \epsilon_0$. It can be shown that T_D is linear, convex, and concave for $\epsilon = 1$, $\epsilon < 1$, and $\epsilon > 1$, respectively. Note that when $\epsilon = 0$ or $T_{\text{DMAX}} = 0$, we have the simple flooding scheme with no broadcast storm suppression since all nodes use the same defer time of zero.

Several values of ϵ have been used in literature. By assuming that nodes are uniformly distributed over a two-dimensional area, the authors in [7], [9], [11] set $\epsilon = 2$ so that T_D is expected to be uniformly distributed over the range $[0, T_{\text{DMAX}}]$. The aim is to have minimum collision, assuming that the vehicles are uniformly distributed on the highway. In [8], the authors used the defer time in (3) with $\epsilon = 1$. Although the authors in [10] used random defer times, they also used (3) with $\epsilon = 1$ as the mean of the defer time. In summary, it seems that a guideline in choosing ϵ is to have a uniform defer time to avoid collisions. We will see that other values of ϵ actually give better performance.

A few notes on the values of R and T_{DMAX}. It seems that the defer time in (3) assumes that the channel is deterministic in the sense that no nodes outside the transmission range R receive the packet transmission, while the nodes inside the range R always does. However, although this channel model is simple, it is not realistic since it ignores multipath fading. For multipath fading channel, which we call "probabilistic channel", the proper value of R is not obvious. For the maximum defer time T_{DMAX}, lowering T_{DMAX} increases the speed that the message is disseminated at the cost of more collisions.

B. Our Contribution

In this paper, we study the effects of the three design parameters ($T_{\text{DMAX}}, \epsilon$, and R) in the popular defer time given in (3) in both deterministic channel and probabilistic (i.e., fading) channel, which we will describe later. We make our evaluation with the iDTSG protocol [4]. With a probabilistic channel, only a fraction of nodes receive the packet transmission and hence we propose a modified defer time that would give the defer time distributed uniformly in $[0, T_{\text{DMAX}}]$, assuming that the vehicles are uniformly distributed on the highway and the channel statistics in the form of the packet reception probability is known. However, we see that this modified defer time does not give the best performance. The reason might be that we have to take into account that the nodes further from the source would rebroadcast sooner and the closer nodes that hear the rebroadcast suppress their own rebroadcasts. This behavior should be included when selecting the defer time function.

The rest of the paper is organized as follows. Section II provides background and a brief description of iDTSG, channel models, our proposed defer time, and performance metrics. Section III gives simulation results showing the effects of different defer time shapes and parameters. The paper is summarized in Section IV.

II. Background and Protocol Description

A. Problem Model and iDTSG Protocol

Consider a portion of a two-way highway illustrated in Fig. 2. There is a source vehicle S that has an accident or has encountered an accident and immediately starts broadcasting the alarm message to the behind vehicles traveling in the same direction, to warn them of the accident. The goal of our time-stable geocast protocol is to disseminate the alarm message within a specific region of D km behind the breaking distance B from the location of the accident, for a duration of T hours. We denote this region of D km as the *intended region*.

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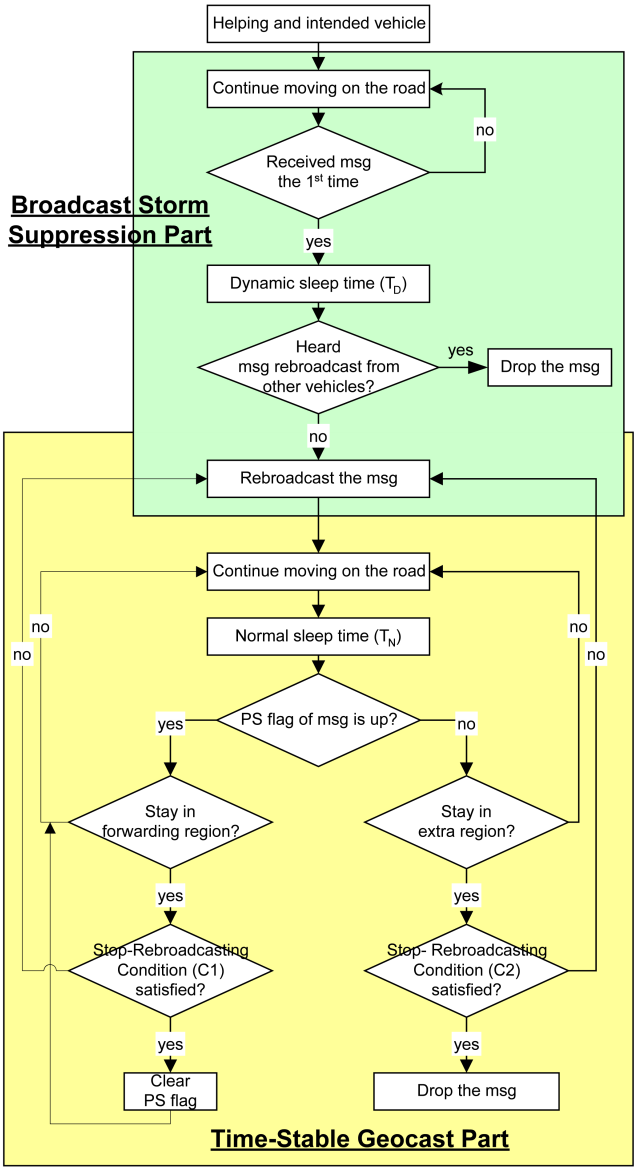

Fig. 3. iDTSG protocol flow chart

We divide all vehicles except the source S into intended and helping vehicles. As illustrated in Fig. 2, the *intended vehicles* (I) are the vehicles that are moving toward the accident. They are the target recipients of the alarm message. The *helping vehicles* (H) are the vehicles that are moving in the opposite direction on the other lanes, with respect to the source. The helping vehicles help relaying the message to the intended vehicles which are likely to be disconnected from each other due to sparsity. To keep the messages within the intended region, we define two additional regions: forwarding and extra regions. The intended region and the opposite region in the opposite lane are together called forwarding region. Both ends of the two forward regions with length D_{extra} are called extra regions.

Due to space constraint, the iDTSG protocol is described via the flowchart shown in Fig. 3. The protocol is mainly composed of two major parts: the first part deals with the broadcast storm suppression and the second part focuses more on how to keep the message alive in the intended region for the given time duration. More details of iDTSG can be found in [4].

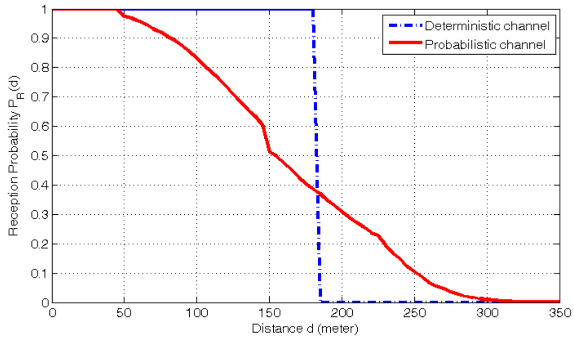

Fig. 4. Packet reception probabilities for the deterministic and probabilistic channels.

B. Deterministic and Probabilistic Channels

In deterministic channel model, every receiving node within a radius R from the source can always receive the broadcast packets. This channel is a result of the Friis propagation model, which considers only a free-space path loss. Hence, the model assumes a line-of-sight propagation and no multipath. However, in real highways the wireless channel is affected by multipath and non-free-space path loss. For this purpose, we use the same Nakagami fading channel and log-distance path loss model which match well with the empirical data, as in our previous work [4].

Using ns-3 simulation and the same transmission power of 5 dBm, Fig. 4 shows the reception probabilities versus distance for the deterministic channel and the probabilistic channel based on the Nakagami and the log-distance path loss. We denote the reception probability under the probabilistic channel as $P_R(\cdot)$.

C. Defer Times for Probabilistic Channel

In addition to the defer times in (1) and (3), to include the effect of the probabilistic channel we propose a new distance-based defer time:

$$T_{D,P}(d) = T_{\text{DMAX}} \left[1 - \frac{\int_0^d P_R(x)\, dx}{\int_0^\infty P_R(x)\, dx} \right] \tag{4}$$

for $d \geq 0$. Specifically, $T_{D,P}$ takes into account the fact that at distance d only a fraction $P_R(d)$ of the nodes receive the packet transmission. An example of $T_{D,P}$ for the above reception probability $P_R(\cdot)$ is shown in Fig. 1. In the figure, since $P_R(d)$ for $d > R = 300$ is very small, for convenience we truncate $T_{D,P}$ such that the $\int_0^\infty$ is replaced with $\int_0^R$ and $T_{D,P}(d) = 0$ for $d > R$. Note that $T_{D,P}$ requires the knowledge of $P_R(\cdot)$ which, in practice, might be difficult to know and depends on time and location.

The reason to define $T_{D,P}$ as in (4) follows the idea in [7], [9] and assumes that the vehicles are distributed uniformly on the highway. The idea is that we should design $T_{D,P}$ such that the defer time is distributed uniformly over its range $[0, T_{\text{DMAX}}]$. This criteria would make sure that the collision rate is minimized.[1] Following this design criteria, it can be shown that, after taken into the account the reception probability P_R, the $T_{D,\text{opt}}$ function gives the uniformly distributed defer time.

[1]However, as we will see from the simulation results, such uniformly-distributed defer time calculation is incomplete. See comments at the end of Section III-C

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D. Performance Metrics

We study the effects of the defer times to the system performance, which we define below. Generally, in broadcast protocols including time-stable geocast protocols, we are interested in reliability and transmission efficiency which can be measured in multiple ways. Here the reliability is measured in term of the packet *loss ratio* while the the efficiency is measured via *overhead* and *collision rate*.

1) Loss Ratio: Assuming the time of the first broadcast of the message as time $t = 0$, the loss ratio at time t is the ratio between i) the number of those intended nodes that have not received the message up to time t and ii) the total number of intended nodes up to time t.

2) Overhead: The overhead at time t is the total number of packet rebroadcasts up to time t. This number includes the collided rebroadcasts.

3) Collision Rate: Due to simulation constraints, we measure the collision rate by counting the number of nodes that detect collisions. Specifically, the collision rate at time t is the ratio between i) the total number of nodes detecting collisions up to time t and ii) the total number of packet transmission up time time t. Although this is not a typical definition of collision rate, it is sufficient for our relative comparison purpose.

III. Simulation Results

Using ns-3, we evaluate the performance of the iDTSG protocol with the defer times in (1) and (3) with different values of the design parameters $\epsilon, T_{\text{DMAX}}$ and R and our proposed defer time $T_{D,P}$ in (4). We consider both the deterministic and probabilistic channels given in Fig. 4 and the "realistic" vehicle mobility model proposed in [12]. We use IEEE 802.11p as in [4] with 5 dBm transmitted power. For the mobility model, we use the same parameters as in our previous work in [4]. Since an emergency notification system must work in any environment, including any traffic density, here we consider two density scenarios: dense and sparse. In the dense scenario, the mean, minimum, and maximum inter-vehicle spacing are 40m, 7m, and 150m, respectively. In the sparse scenario, the mean, minimum and maximum values are 250m, 80m, and 600m, respectively.

Note that, from Fig. 4, the packet reception probability for the probabilistic channel at 40m and 250m are about 100% and 10%, respectively. This means that in the dense scenario, we would expect several vehicles in the same direction of traffic flow to receive the transmission and in the sparse scenario only one vehicle or none. Hence, in the dense scanario, we have a highly connected network, while in the sparse scenario, a highly disconnected network.

In our simulation, we inject the source vehicle to the 10-km straight highway. After moving for 6.5 km, the source starts broadcasting an alarm message periodically until it receives the same message back from another vehicle. The message is required to be within the region $D = 3$ km for duration $T = 30$ minutes. The speed limit is $s_{max} = 35$ m/s ($= 126$ km/h). For each simulation result, we run 10 different runs and calculate the average values.

A. Effect of Transmission Range in Probabilistic Channel

First, we evaluate the effect of varying the value of R in (3) on the protocol performance for the probabilistic channel. One easily sees that the form of T_D (specially on the part that $T_D(d) = 0$ for $d > R$) is suitable for deterministic channels where R is the transmission range. However, for probabilistic channels, the transmission range where the reception probability is not zero is actually unlimited. Hence, for probabilistic channels the nodes further than R would all use zero defer times and hence collide. This might result in many collisions if R is too small.

To make our evaluation, we consider the case where $\epsilon = 1$ and $T_{\text{DMAX}} = R/s_{max}$ and hence, from (3),

$$T_D(d) = \frac{R}{s_{max}}\left(1 - \frac{d}{R}\right) = \frac{R - d}{s_{max}} \tag{5}$$

for $d \in [0, R]$ and 0 otherwise. For this T_D and dense traffic scenario, Fig. 5 shows the loss ratio, overhead, and collision rate respectively, for 3 cases: i) deterministic channel with $R = 180$, ii) and iii) probabilistic channel with $R = 180$ and $R = 300$, respectively. Fig. 5(a) shows that at the same $R = 180$, the probabilistic channel gives a slightly better loss ratio than the other channel. The reason is that under the probabilistic channel nodes further than $R = 180$ can still receive the packet with non-zero probability. For both channels at $R = 180$, all intended nodes receive the message within 5 seconds. However, it is 30 s for the $R = 300$ case. This is because, according to (5), T_D for $R = 300$ is always larger than T_D for $R = 180$ and hence the rebroadcasts happen slower. However, since $T_D(d) = 0$ for $d > R = 180$, as shown in Fig. 5(b) and Fig. 5(c) there is a higher overhead and collision rate in the probabilistic channel with $R = 180$ case.

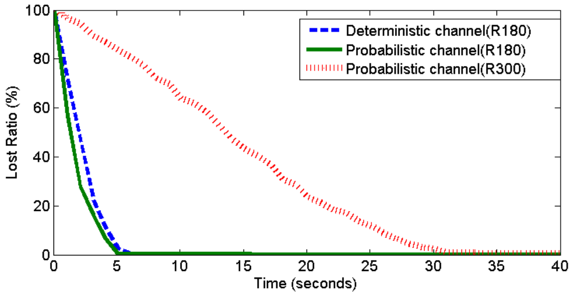
From Fig. 5, it is important to evaluate the performance of the defer time in (3) with realistic channel model. Furthermore, different R gives different performance trade-off. Since the probabilistic channel with $R = 300$ gives similar overhead, lower collision rate, but worse loss ratio than the deterministic channel, from now on we assume $R = 300$ when we use the probabilistic channel.

B. Effect of Maximum Defer Time

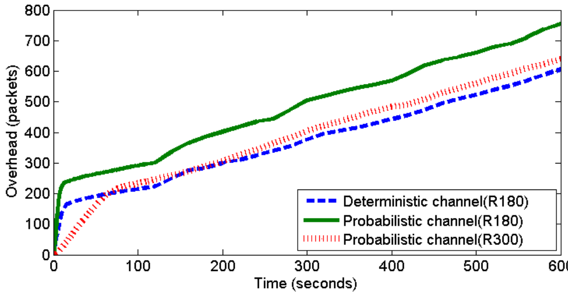
Next we study the effect of the maximum defer time T_{DMAX} in (3) to the performance of iDTSG. We consider here only the linear defer time case ($\epsilon = 1$) and only three values of the maximum defer times: $T_{\text{DMAX}} = 0.25T_{\text{MAX}}, T_{\text{MAX}}$, and $4T_{\text{MAX}}$ where $T_{\text{MAX}} = R/s_{max}$. Here we discuss the deterministic channel only. The results for the probabilistic channel are quite similar to the deterministic channel case and are omitted due to the page limitation.

Fig. 6 and Fig. 7 show the performance of varying the maximum defer times T_{DMAX} for dense and sparse scenarios, respectively, when the channel is deterministic with $R = 180$ (hence, $T_{\text{MAX}} = R/s_{max} = 180/35 = 5.1$ s). In the dense scenario where the average inter-vehicle spacing is 40m, Fig. 6 shows that, as expected, a smaller T_{DMAX} gives a smaller T_D and hence a better loss ratio. Since the network is highly connected, the message can propagate to all of the intended nodes within a few seconds for $T_{\text{DMAX}} = 0.25T_{\text{MAX}} = 1.3$ s. However, we require more than 20 s to disseminate the message if $T_{\text{DMAX}} = 4T_{\text{MAX}} = 20.6$ s.

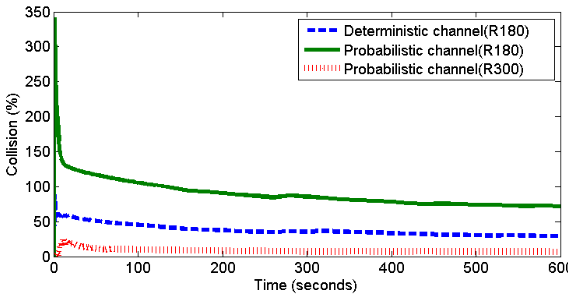
From Fig. 6(a) and Fig. 6(b), the iDTSG protocol contains three phases: Phase 1 is when the message is being disseminated to all intended vehicles in the simulated highway



(a) Loss ratio



(b) Overhead



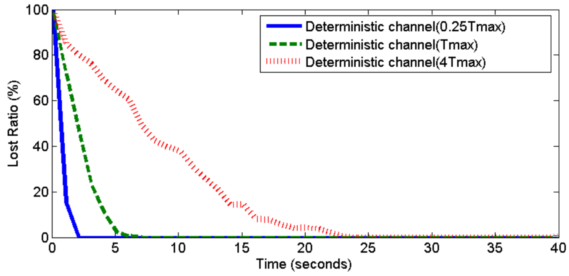
(c) Collision rate

Fig. 5. Loss ratio and overhead for deterministic and probabilistic channels with $R = 180m$ and $300m$, under dense scenario.

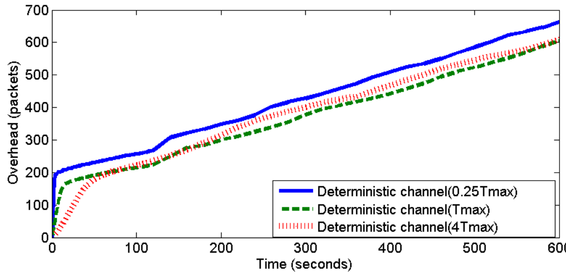
section, Phase 2 is when the message has reached the end of the section but few new cars enter the section, and Phase 3 is the time-stable part when new cars are entering the section and iDTSG needs to inform them of the message. For example, for the $0.25T_{\text{MAX}}$ case in Fig. 6(b), Phase 1 happens for the first few seconds, Phase 2 is after that until about 120 s, and Phase 3 is after 120 s. For dense scenario where nodes are highly connected in both directions, in Phase 1, the rate at which the rebroadcasts happen depends on the defer time T_D. Hence, in this phase the smaller T_{DMAX}, the higher the rate at which the message rebroadcasts happen (this is shown as the overhead). In Phase 2, there is a small number of rebroadcasts since all vehicles have received the message. In Phase 3, the rate at which the rebroadcasts happen depends on the normal sleeping time T_N in (2) which is independent of T_{DMAX}, as shown in Fig. 6(b).

As shown in Fig. 6(c), the collision rate at any time for $T_{\text{DMAX}} = 4T_{\text{MAX}}$ is always smaller than those of $T_{\text{DMAX}} = T_{\text{MAX}}$ and $0.25T_{\text{MAX}}$. It is difficult to explain why the collision rates for the cases of $0.25T_{\text{MAX}}$ and T_{MAX} are similar.

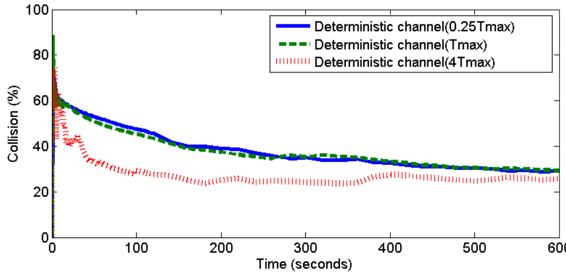
On the other hand, the results for the sparse scenario (Fig. 7) are quite different from the dense scenario. Since the average inter-vehicle spacing is 250m, there are only very few cars or none in the transmission range (recall $R = 180$ here) and hence the network is highly partitioned in either direction. Reducing T_{DMAX} does not help with the loss ratio much since the network is highly disconnected. In fact the loss ratio is reduced via the help from helping vehicles in the opposite direction, carrying the message from one network cluster in the intended direction to another cluster in the same direction. Hence, as shown in Fig. 7(a) the longer T_{DMAX} is actually more beneficial since this allows the helping vehicles to travel further before theirs rebroadcasts. In addition, the loss ratio for the smaller T_{DMAX} does not reach zero even after a long time. For the overhead, the overhead at any time is almost independent of T_{DMAX} as shown in Fig. 7(b). This is also due to the highly partitioned network. For sparse network, there seems to be only two phases (Phase 1 and 3, referred to the dense case), where the phase changing time is around 200 s.



(a) Loss ratio



(b) Overhead



(c) Collision rate

Fig. 6. Performances of varying $T_{\text{DMAX}} = 0.25T_{\text{MAX}}, T_{\text{MAX}}$ and $4T_{\text{MAX}}$ for deterministic channel and dense scenario.

C. Effect of Varying the Shape of Defer Time

Here we consider the effect of different shapes of the defer times, specifically, the inverse $T_D = RT_N/d$ in (1), the popular T_D in (3) with $\epsilon = 2, 1, 0.5, 0.2$ and 0, and the probabilistic channel $T_{D,P}$ in (4).

Fig. 8 shows the performance of the above T_D's in the dense scenario and the probabilistic channel with $R = 300$.

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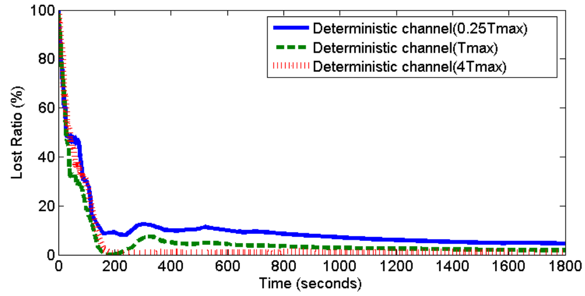
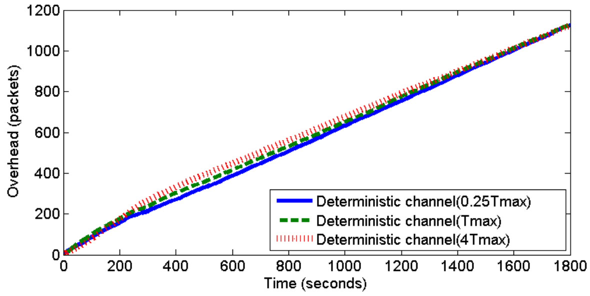
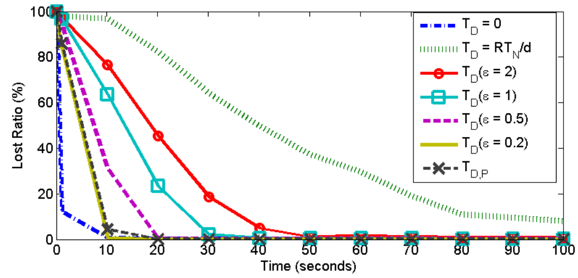


(a) Loss ratio

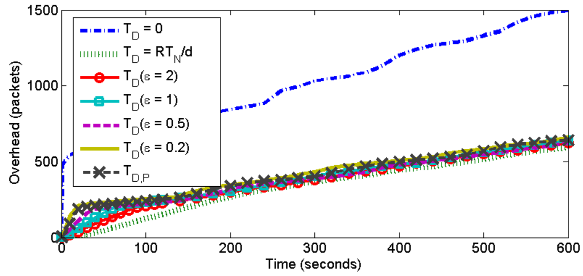


(b) Overhead

Fig. 7. Performances of varying $T_{\text{DMAX}} = 0.25T_{\text{MAX}}, T_{\text{MAX}}$ and $4T_{\text{MAX}}$ for deterministic channel and sparse scenario.



(a) Loss ratio



(b) Overhead

Fig. 8. Performances of varying ϵ and shape of T_D for probabilistic channel and dense scenario.

Fig. 8(a) and Fig. 8(b) show that the smaller the value of ϵ, the better the lost ratio, but at the cost of a higher overhead. The flooding scheme $T_D(\epsilon = 0)$ gives the steepest decrease in the loss ratio but at the cost of high collisions and hence some vehicles did not get the message and the overhead is significantly much larger. The inverse T_D has the slowest decay in the loss ratio but the lowest overhead too. $T_D(\epsilon = 1)$ is worse than our proposed probabilistic-channel $T_{D,P}$ and $T_D(\epsilon = 0.5)$ and $T_D(\epsilon = 0.2)$ since the overhead for all these cases are very similar. Our proposed probabilistic-channel $T_{D,P}$ is also worse than $T_D(\epsilon = 0.2)$ in term of the loss ratio. We believe that to meet the design criteria of uniformly-distributed defer time, we need to also consider the following fact: the closer nodes suppress their rebroadcasts if they hear the rebroadcasts from the further nodes. We will look into this in the future.

IV. Summary and Future Work

We evaluated by simulation the effects of the design parameters (T_{DMAX}, ϵ, and R) for the distance-based defer times and the shapes of the defer times with the iDTSG protocol. We considered both dense and sparse traffic scenarios and both deterministic and probabilistic channels. The simulation results show trade-offs between reliability and efficiency, especially in the dense scenario where the broadcast storm problem is significant. In the dense scenario, reducing the defer time (by reducing T_{DMAX}, R, or ϵ) increases the reliability at the cost of the efficiency.

In addition to the evaluation of the previously proposed defer times, we proposed and evaluated a new defer time which is more appropriate with probabilistic channels. Although it takes into account the different reception probability at different distant and hence performs well, our proposed defer time can still be improved in the future by considering the fact that nodes suppress their rebroadcasts if they hear prior rebroadcasts.

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