Effects of Stochastic and Deterministic Defer Times on Time-Stable Geocast in VANETs

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***Abstract*—A contention-based forwarding is a popular approach for forwarder selection in wireless vehicular ad hoc networks. Requiring no information of neighbors, the selection depends on distance-based defer time where the furthest node rebroadcasts first while the others suppress their rebroadcasting after receiving duplicate message within their defer times. In this paper, we study the effects of some previously proposed distance-based defer times in both deterministic and stochastic versions, with our previously proposed time-stable geocast protocol (called iDTSG). The simulation results show that the stochastic defer times are better than the deterministic defer times in dissemination time while having similar overhead. In addition, we also propose a method to determine deterministic distance-based defer time to avoid collision. Our proposed criteria works well to prevent packet collision in highly connected networks.**

***Index Terms*—stochastic defer time, time-stable geocast, deterministic distance-based defer time, VANETs, contention-based forwarding**

I. Introduction

VEHICLE-TO-VEHICLE vehicular ad-hoc networks (VANETs) operate in a self-organized manner without any infrastructure. They 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, we need a reliable and efficient broadcast protocol, which must take care of the two major and well-known problems in VANETs: broadcast storm problem and network disconnection problem. The broadcast storm problem happens especially when flooding is used to perform broadcast in multihop relay networks [1]. The broadcast storm results in high packet loss due to collisions. On the other hand, the network partitioning problem is due to the high mobility caused by fast moving vehicles or sparse traffic densities during off-peak hours and/or during initial deployment. Among the two problems, the broadcast storm problem is more important for networks with many nodes (dense networks) while the network disconnection problem is more important for networks with very few nodes (sparse networks).

Many articles use contention-based forwarding protocols (e.g., [2]) for forwarder selection in VANETs. The contention-based forwarding protocol requires no information of neighboring vehicles. In this protocol, receiver waits for a time duration, called defer time, before deciding to broadcast the received message. If the receiver does not receive any duplicate messages during its defer time, the receiver broadcasts the received message after the end of its defer time, otherwise it drops the message. The defer time is a crucial factor of contention-based forwarding protocols for broadcast storm suppression in dense networks.

Several proposed defer times (e.g., [3], [4], and [5]) depend deterministically on distance. Hence, they are called distance-based defer times. The distance-based defer time is inversely proportional to the distance between sender and receiver. The further the distance from sender, the smaller the defer time of the receiver. If there are more than two receivers at the same distance from the sender, the receiver will broadcast with the same defer time and hence a collision occurs. There are other defer times that depend not only on distance, but also angle [6] and link probabilistic [7]. In addition, stochastic defer times have been proposed such as uniform and Gaussian random defer times [8], and bi-zone random defer time [9] to decrease the dissemination time in non-line-of-sight transmission or probabilistic channel.

In this paper, we apply stochastic defer times to suppress broadcast storm in our previously proposed time-stable geocast protocol (called iDTSG [10]) which is used for emergency message notification. iDTSG uses contention-based forwarding process. Some effects of some existing deterministic distance-based defer times in both deterministic and probabilistic (i.e., fading and shadowing) channels were studied in our previous work [11]. It was shown in that contention-based forwarding protocols are better than position-based forwarding protocols in probabilistic channel [12]. However, an influence of the undesirable shadowing attenuation becomes more significant when the traffic becomes dense since the progress of transmission is reduced by the shadowing problem [13]. With the shadowing effect, the message dissemination time may be longer than desired for an emergency notification in VANETs. Here, we show by simulation that stochastic defer times are better than the deterministic ones when the protocol is used in real world and faces with probabilistic channels. Furthermore, for deterministic defer time, we show that for a highway of a single lane in each direction, we can determine the minimum defer time such that no collision occurs.

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.

A. Related Works

1) Deterministic defer times: A popular form of defer time has been used in multiple papers, e.g., [3], [4], [5],

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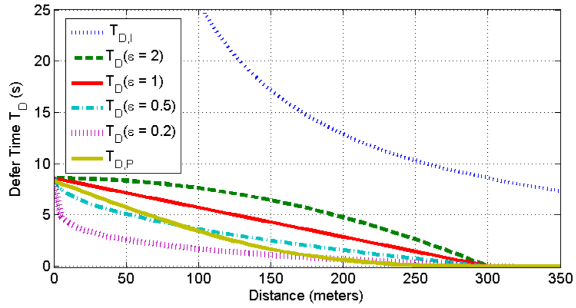


Fig. 1. Different defer times T_D: the inverse defer time $T_{D,I}$ in (2), T_D in (1) with $\epsilon = 2, 1, 0.5$, and 0.2, the probabilistic-channel defer time $T_{D,P}$ in (3)

[8], [14]. It is given as

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

where $\epsilon \ge 0$ is a constant, and T_{max} is the maximum defer time. Due to the definition of T_D, the farther node from source waits less and rebroadcasts faster.

Other forms of defer times have also been used. For example, in [15] and the original version of our iDTSG protocol [10], the distance-based defer time is inversely proportional to distance, and given as

$$T_{D,I} = \frac{K}{d}, \quad d > 0 \tag{2}$$

for a constant K.

In [11], we proposed a defer time which takes into account the fact that in probabilistic channels, the further the distance, the lower the packet reception probability.

$$T_{D,P} = T_{MAX}\left[1 - \frac{\int_0^d P_R(x)\,\mathrm{d}x}{\int_0^\infty P_R(x)\,\mathrm{d}x}\right] \tag{3}$$

where $P_R(x)$ is the probability that a node at distance x from the transmitter receives the transmission.

Fig. 1 shows the defer times given in (1)-(3) with $R = 300$, $T_{MAX} = R/smax = 8.57$ s, $s_{max} = 35$ m/s, and $K = R^2/s_{max}$ for different values of ϵ in (1). Without confusion, we denote $T_D(\epsilon = \epsilon_0)$ for T_D with $\epsilon = \epsilon_0$. T_D is linear, convex, and concave for $\epsilon = 1$, $\epsilon < 1$, and $\epsilon > 1$, respectively. Note that when $\epsilon = 0$ or $T_D = 0$, we have the simple flooding scheme with no broadcast storm suppression since all nodes use the same defer time of zero.

2) Stochastic Defer Times: To include the effect of probabilistic channel (caused by e.g., shadowing effect of cars and trucks), the authors in [9] proposed a stochastic defer time which is selected uniformly between T_{lower} and T_{upper} where:

$$T_{upper}(d) = \begin{cases} T_{max}(1 - \frac{d}{R}), & d > D_{th}, \\ T_{max}, & d \le D_{th}, \end{cases} \tag{4}$$

$$T_{lower}(d) = \begin{cases} 0, & d > D_{th}, \\ T_{max}(1 - \frac{D_{th}}{R}), & d \le D_{th}, \end{cases} \tag{5}$$

where D_{th} is a threshold distance.

Other uniform and Gaussian defer times were proposed in [8] as:

$$T_U(d) \in T_{max}[1 - \frac{d}{R}] \times UniformRV(0, 1), \tag{6}$$

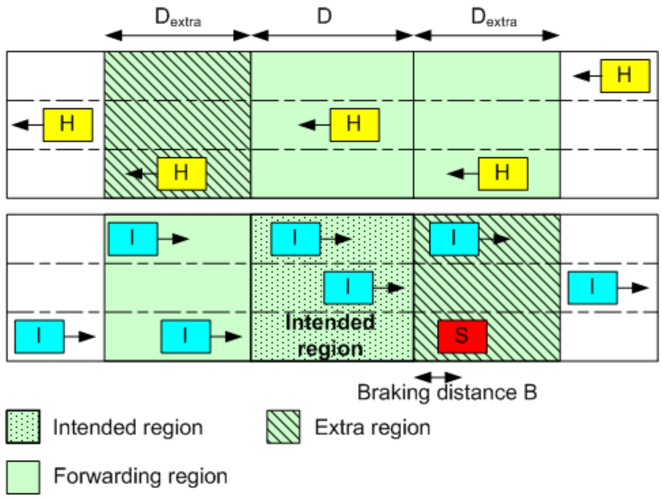


Fig. 2. Problem model and an illustration of the intended, forwarding, and extra regions.

and

$$T_G(d) \in T_{max} \times GaussianRV((1 - \frac{d}{R}), 0.3). \tag{7}$$

B. Our Contribution

In this paper, we study the effects of the popular deterministic distance-based defer time given in (1) and the stochastic defer times in probabilistic channel with fading and shadowing. We base our evaluation on our previously proposed iDTSG protocol [10]. This study extends our preliminary work in [11] which studied the effects of the deterministic distance-based defer times in deterministic channel and probabilistic channel. Some results from [11] are included in this paper for convenience. Our main contribution are as following:

(1) For deterministic defer times in bi-directional single-lane highway, we analyze and show that there is an optimal parameter design to avoid packet collisions and achieve the best message dissemination time.

(2) We show that the stochastic defer times can give a better performance, comparing to the deterministic ones. The reason is that the randomness in the defer times introduce possibility of a closer receiver to broadcast the received packet sooner than another further receiver which may not receive the packet due to signal blocking by other vehicles. 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, bound on minimum defer time, channel models, our proposed defer time, and performance metrics. Section III gives simulation results showing the effects of both stochastic and deterministic 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 with L lanes per direction illustrated in Fig. 2 for $L = 3$[1]. There is a

[1]For illustration purpose, the figure shows three lanes per direction. However, in our simulation we consider only one lane per direction.

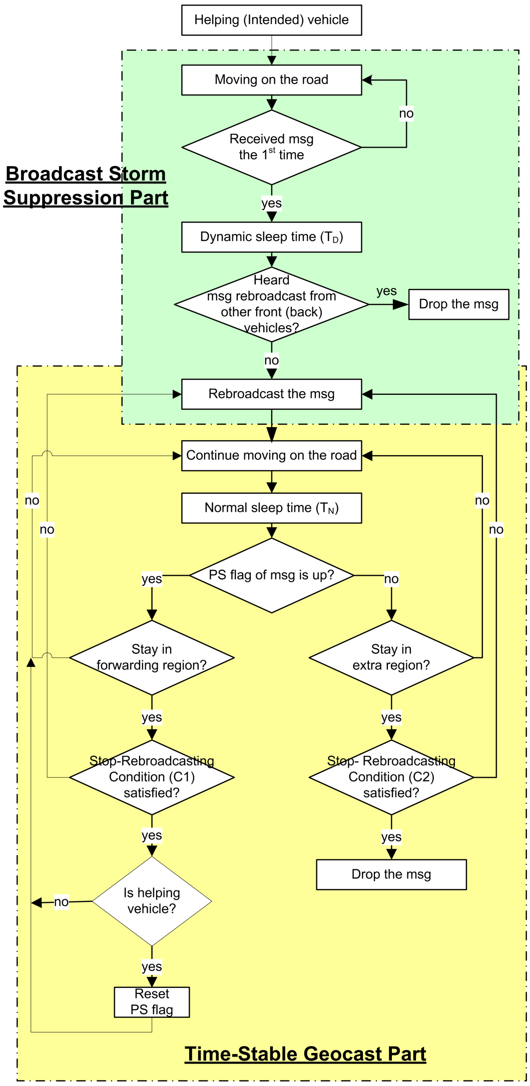


Fig. 3. iDTSG protocol flow chart

source vehicle S that after having an accident or having encountered an accident, 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 geocasting 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 call this region of D km as the *intended region*. 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 from the opposite direction help relaying the message to the intended vehicles which are may 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 are extra regions.

In this paper, we are interested in evaluating the effects of deterministic and stochastic defer times in the broadcast

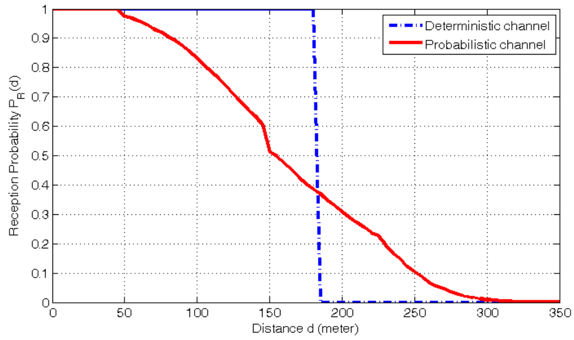


Fig. 4. Packet reception probabilities for the deterministic and probabilistic channels.

storm suppression part of iDTSG. For brevity of the paper, the iDTSG protocol is described via the flowchart in Fig. 3, which is an updated chart of the one given in [10]. In summary, 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 [10].

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 deterministic channel model assumes a line-of-sight propagation and no multipath. However, in real highways the wireless channel is affected by multipath, shadowing (signal blocking), and non-free-space path loss. As in our previous work [10], to model these effects we use the Nakagami fading channel and log-distance path loss model which agrees with the empirical data in [16].

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. 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. In our work, the reliability is measured in term of the packet *loss ratio* while the the efficiency is measured via *overhead*.

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. In emergency notification scenario, we are also interested in the *dissemination time*, which is the shortest time that the loss ratio reaches almost 0%.

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

D. Bound on Minimum Deterministic Defer Times

In our earlier work [11], we studied the relation between ϵ in the popular defer time $T_D(d)$ given in (1) and the performance of iDTSG with probabilistic channel. Via simulation, we observed that $\epsilon = 0.2$ gave better loss ratio, while having similar overhead, than other higher ϵ. Although $\epsilon = 0$ (corresponding to the flooding scheme) gave the worst performance among all considered ϵ's, the loss ratio for $\epsilon \geq 0.2$ monotonically increases with decreasing ϵ, while having similar overhead. Hence, there must be a minimum ϵ, denoted by ϵ_{min}, that gives the best dissemination time while keeping the overhead as small as possible (i.e., negligible collision). While this ϵ_{min} can be found via repeated simulations, it is better to find at least its approximate bound.

To understand the bound of ϵ_{min}, we observe that in our system no cars that are potential relays in the same direction use the same defer times. This is because (i) the considered highways have a single lane per direction, and hence only two receiving cars at the same distance but opposite from a transmitter wait the same defer time, and (ii) in the same direction as the source car, the message should propagate to the back of the transmitter; hence, only the cars in the back of the transmitter are potential relays.

Hence, if any two neighbor nodes use defer times that differ more than the time (called t_p) to send the message, no collisions occur during the message multihopping, i.e., for any defer time function T_D we need the defer time difference between any neighbors greater than t_p, i.e.,

$$T_D(d - \Delta) - T_D(d) \geq t_p, \tag{8}$$

for any distance d from a transmitter and any inter-car spacing Δ. Note that the packet transmission time t_p must include the time due to multiple access protocol as well as the link protocol. Although there is no collision in our situation, there may be time for multiple access protocol such as channel sensing. The defer time difference $T_D(d-\Delta)-T_D$ for d closer to R is an increasing function with ϵ. That is, the best T_D is when (8) holds with equality. Taking the popular defer time given in (1), no collisions happen when

$$T_{max}\left[\left(\frac{d}{R}\right)^{\epsilon} - \left(\frac{d-\Delta}{R}\right)^{\epsilon}\right] \geq t_p \tag{9}$$

In this equation the left term increases with ϵ, as can be observed from Fig. 1.

Hence, we are interested in finding the minimum ϵ, ϵ_{min}, given T_{MAX} and R.[2] A physical constraint is that neighboring cars do not get too close, i.e., $\Delta \geq \Delta_{min}$ for some Δ_{min} which may depends on road condition as well as car density. Although d can take almost any value within R, it should be the farthest distance of the node which can still receive the packet transmission with high enough reception probability $P_R(d)$. This node is the typical one which makes a successful rebroadcast. As shown in Section III-C, specific to the parameters in our simulation, ϵ_{min} is between 0.00095 and 0.007.

[2]A simpler protocol parameter design might be based on the linear defer time where $\epsilon = 1$. In this case, (9) becomes $T_{max}\Delta/R \geq t_p$, which is independent of d.

E. Stochastic Distance-Based Defer Times

Since the car positions as well as the channels are stochastic, it might be suboptimal to use deterministic defer times. Consider a simple example where the inter-car spacings are fixed for all cars on the highway. Due to the probabilistic channels, cars further from the transmitters have less chance to receive the packet transmission and hence it is sometimes a waste of time for when there are no the closer nodes to wait a long defer time further nodes to rebroadcast. It is better if the closer nodes can randomly pick their defer times, which might happen to be smaller than those of further nodes. Stochastic defer times allow a breakdown of the deterministic dependence of defer times on distance, to combat against randomness in the locations and channels, possibly at the cost of higher collisions.

In particular, we consider the following version of stochastic defer times: At each reception of a packet, a node at distance d randomly and independently picks a stochastic defer time, denoted by $T_S(d)$, which is uniformly distributed between 0 and $T_D(d)$ where $T_D(d)$ is the popular deterministic defer time in (1), i.e.,

$$T_S(d) \in Uniform[0, T_D(d)]. \tag{10}$$

III. Simulation Results

Using ns-3, we evaluate the performance of iDTSG protocol with the defer times in (1) and (2) with different values of the design parameters ϵ and our proposed defer time $T_{D,P}$ in (3), with the probabilistic channels given in Fig. 4 and with the ”realistic” vehicle mobility model proposed in [17]. For the mobility model and channel parameter, we use the same parameters as in our previous work in [11].

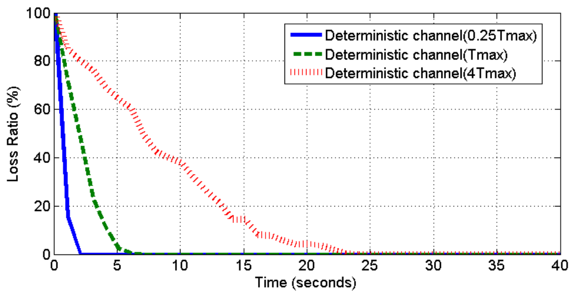
In our simulation, we inject the source vehicle to the 10-km straight highway. After moving for 6.5 km, the source stops moving and starts broadcasting an alarm message until it receives the same message back from another vehicle. The message is required to be within the region $D = 3$ km from the braking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

A. Effect of Maximum Deterministic Defer Time

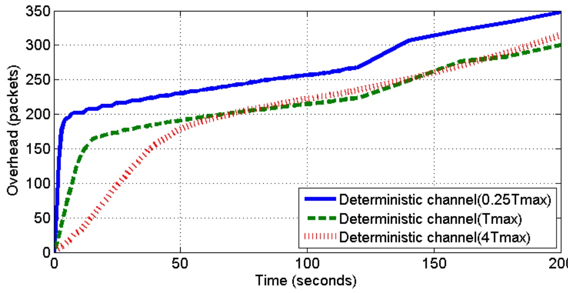
First, we study the effect of the maximum defer time, denoted by $T_{Dmax} = T_D(0)$, in (1) to the performance of iDTSG. We consider here only the linear defer time case ($\epsilon = 1$) and only three values of the maximum defer times: $T_{Dmax} = 0.25T_{max}, T_{max}$, and $4T_{max}$ where $T_{max} = R/s_{max}$. Here we discuss the deterministic channel only. The results for the probabilistic channel are quite similar to the deterministic channel case.

Fig. 5 shows the performance of varying the maximum defer times T_{max} for dense scenario when the channel is deterministic with $R = 180$ (hence, $T_{max} = R/s_{max} = 180/35 = 5.1$ s.

In the dense scenario where the average inter-vehicle spacing is 40m, Fig. 5 shows that, as expected, a smaller

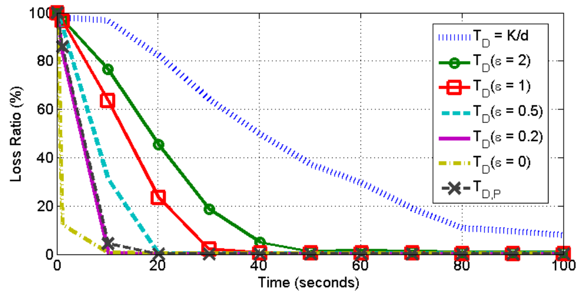


(a) Loss ratio

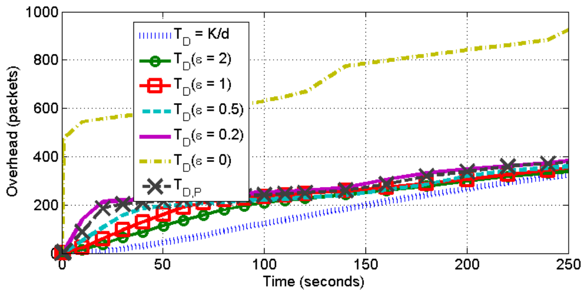


(b) Overhead

Fig. 5. Performances of varying $T_{max} = 0.25T_{max}, T_{max}$ and $4T_{max}$ for deterministic channel and dense scenario.



(a) Lost Ratio for deterministic defer time



(b) Overhead for deterministic defer time

Fig. 6. Performance of varying ϵ and shape of T_D for probabilistic channel and dense scenario

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 $T_{Dmax} = 0.25T_{max} = 1.3$ s. However, we require more than 20 s to disseminate the message for the $T_{Dmax} = 4T_{max} = 20.6$ s case.

From Fig. 5(a) and Fig. 5(b), the iDTSG protocol contain three phases: Phase 1 is when the message is being disseminated to all intended vehicles in the simulated highway 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 many new cars are entering the section and iDTSG needs to keep informing the newly-arrived vehicles of the message. For example, for the $0.25T_{max}$ case in Fig. 5(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 of iDTSG.

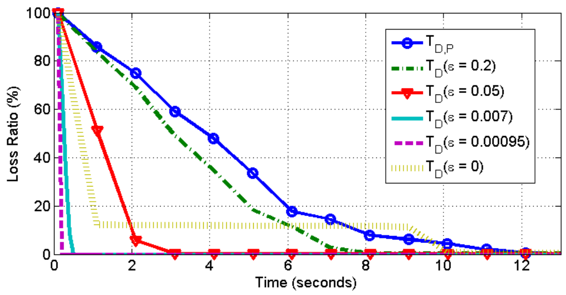
B. Effect of Varying the Shape of Deterministic Defer Time

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

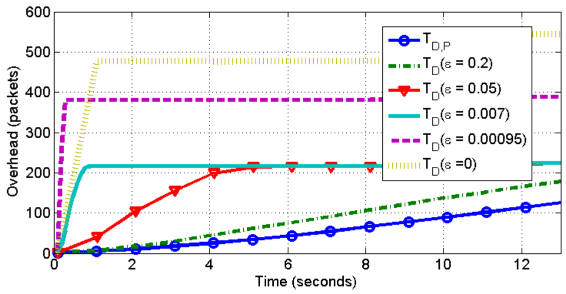
Fig. 6 shows the performances of above T_D's in the dense scenario and under the probabilistic channel with $R = 300$. Fig. 6(a) and Fig. 6(b) show that the smaller the value of ϵ, the better the lost ratio, but at the cost of a higher overhead. The flooding scheme ($T_D(\epsilon = 0)$) gives the steepest 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.

C. Minimum Deterministic Defer Times

Here we evaluate our proposed method in (9) to find the deterministic defer time. To avoid packet collision as discussed in Section II-D, we consider the minimal inter-vehicle spacing (Δ_{min}) to be 6 m, which gives ϵ_{min} to be 0.007 which is the minimum value to prevent flooding behavior. However, if Δ_{min} is changed to 40 m (i.e., the average inter-vehicle spacing in our simulation), the value of ϵ_{min} becomes 0.00095 which leads to flooding, as shown in Fig. 7(b). Since vehicles sometime get closer than the average spacing of 40 m, a vehicle may not be able to hear its neighbor's rebroadcast within its defer time and hence starts its own rebroadcast which results in collision. However, in probabilistic channel, each transmission range is not exactly the same; the packet collisions occur only in the overlap transmission ranges. This is why the lost ratio of $T_D(\epsilon = 0.00095)$ rapidly decreases to 0% within 0.1 s. Since the disparity of defer times between two closest vehicles in $T_D(\epsilon = 0.007)$ and $T_D(\epsilon = 0.05)$ exceeds the minimum packet transmission time, the lost ratio of $\epsilon = 0.007$ rapidly decreases in 0.2 s which it is faster than the $\epsilon = 0.05$ while the overhead is similar as shown in Fig. 7(a). For $T_{D,P}$ and $T_D(\epsilon = 0.2)$, the longer the defer times, the smaller the

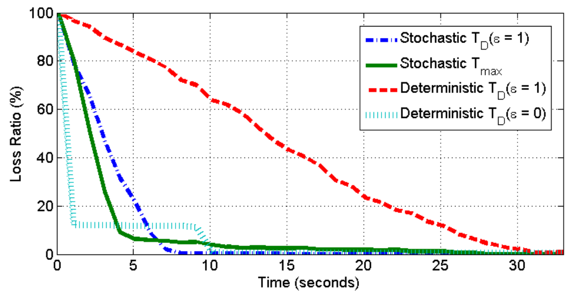


(a) Lost Ratio for deterministic defer time

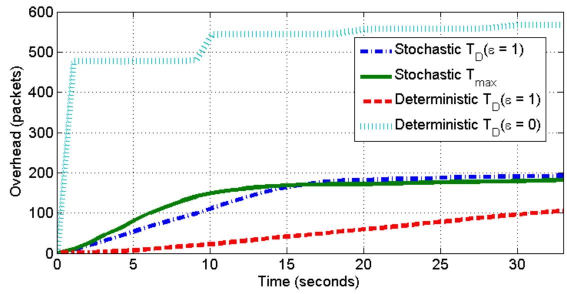


(b) Overhead for deterministic defer time

Fig. 7. Performance of critical deterministic defer time T_D for probabilistic channel and dense scenario



(a) Lost Ratio for stochastic defer time



(b) Overhead for stochastic defer time

Fig. 8. Performance of stochastic defer time T_S and deterministic defer time T_D for probabilistic channel and dense scenario

overhead and hence the slower the decline rate of the lost ratio.

For the purpose of choosing the value of Δ, we see that if the value of Δ greater than the minimal inter-vehicle spacing is selected, there are many vehicles in this range and the defer time of each vehicle in this range is less than t_p which leads to the packet collisions. The parameter ϵ is inversely proportional to Δ. The distance d is proportional to ϵ. This criteria can be applied to calculate other design parameters (e.g., T_{max}, R) while ϵ is fixed. T_{max} can decrease until the slope or the disparity between defer times of two closest neighbors is equal to t_p.

D. Effect of Stochastic Defer Time

Finally, we compare the performance of stochastic defer times and deterministic defer times. We select deterministic $T_D(\epsilon = 1)$ and $T_D = 0$ to compare with stochastic $T_D(\epsilon = 1)$ and $T_S = T_{max}$, respectively. As shown in Fig. 8(a), the stochastic defer times outperform the deterministic defer times in reliability. The lost ratio of the stochastic defer time $T_D(\epsilon = 1)$ decreases faster than the deterministic defer time $T_D(\epsilon = 1)$. The overhead of the stochastic T_{max} is less than the deterministic $T_D = 0$ and is similar to the others. The dissemination time of T_{max} is quite longer than the stochastic $T_D(\epsilon = 1)$ because the variance of the defer times for stochastic T_{max} is much higher. Note that the shown plot is a result of averaging 10 independent runs. It happens that in some runs, many nodes pick small defer times and hence the dissemination time is small, while in other runs, larger defer times are picked more often and hence the dissemination time is larger. Hence as shown in Fig. 8(a), the average of lost ratio of stochastic T_{max} does not sharply decrease to 0%.

In the flooding scheme ($\epsilon = 0$), the packet collisions occur in the first broadcast and all nodes rebroadcast again after expiring of the normal sleep time of iDTSG which depends on the speed of senders. Since speed of senders is usually different, the second retransmission packet is likely to succeed. This is why the lost ratio drops to 18% but stable afterward for a long duration. The lost ratio of $T_D(\epsilon = 0)$ becomes 0% after 10 sec. However, the overhead of $T_D(\epsilon = 0)$ is the highest.

Hence, we have seen that the stochastic defer times increase reliability while they barely incur any extra overhead. Hence, applying the stochastic defer time is beneficial in our iDTSG protocol. A caution is that the stochastic defer times increase the reliability if only T_{max} is much longer than the minimum defer time. If the disparity of defer times between two closest neighbors is close to the packet transmission time, the stochastic defer times actually can be worse than the deterministic defer times. Due to the fact that all vehicles have a chance to rebroadcast when nodes receive a broadcasting packet, we believe that only simple suppression mechanism (i.e, the vehicles stop rebroadcast when they receive duplicate messages) is not sufficient for broadcast storm suppression in the first stage of iDTSG protocol. We will look into combining this mechanism with geo-broadcast or limiting the maximum number of hops to enhance broadcast storm suppression in the future.

IV. Conclusion

By simulation, we evaluated the effects of stochastic and deterministic distance-based defer times in probabilistic channel with iDTSG protocol. We only considered dense scenarios which focused on broadcast storm suppression since this is the scenario different defer time functions matter. The simulation results show the following: 1) trade-offs between reliability and efficiency; 2) reducing the deterministic defer time (by reducing T_{Dmax} or ϵ) increases the reliability at the cost of the efficiency; 3) the deterministic distance-based defer time has a optimal design value of ϵ to avoid collision. We also proposed the method for calculating the defer time to avoid collisions for a bi-directional single lane highway. Furthermore, the stochastic distance-based defer time is more appropriate than the deterministic distance-based defer time in case of increasing reliability if the parameter T_{max} is larger than necessary. Additionally, efficiency can still be improved in the future by considering the fact that all vehicles have a chance to broadcast if they hear the first message in broadcast storm suppression part of iDTSG protocol.

REFERENCES

[1] S.-Y. Ni, Y.-C. Tseng, Y.-S. Chen, and J.-P. Sheu, "The broadcast storm problem in a mobile ad hoc network," in *Proceedings of the 5th annual ACM/IEEE international conference on Mobile computing and networking*, ser. MobiCom '99. New York, NY, USA: ACM, 1999, pp. 151–162. [Online]. Available: http://doi.acm.org/10.1145/313451.313525

[2] H. Füßler, J. Widmer, M. Käsemann, M. Mauve, and H. Hartenstein, "Contention-based forwarding for mobile ad hoc networks," *Ad Hoc Networks*, vol. 1, no. 4, pp. 351–369, 2003.

[3] L. Briesemeister and G. Hommel, "Role-based multicast in highly mobile but sparsely connected ad hoc networks," in *Mobile and Ad Hoc Networking and Computing, 2000. MobiHOC. 2000 First Annual Workshop on*, 2000, pp. 45 –50.

[4] M.-T. Sun, W. Feng, and T.-H. Lai, "Location aided broadcast in wireless ad hoc networks," in *Global Telecommunications Conference, 2001. GLOBECOM '01. IEEE*, vol. 5, 2001, pp. 2842 –2846 vol.5.

[5] A. Bachir and A. Benslimane, "A multicast protocol in ad hoc networks inter-vehicle geocast," in *Vehicular Technology Conference, 2003. VTC 2003-Spring. The 57th IEEE Semiannual*, vol. 4, april 2003, pp. 2456 – 2460 vol.4.

[6] H. Sadeghian, A. Farahani, and M. Abbaspour, "Dynamic forwarding delay in contention-based forwarding protocols," in *Computational Problem-Solving (ICCP), 2011 International Conference on*, oct. 2011, pp. 688 –691.

[7] Q. Yang and L. Shen, "A multi-hop broadcast scheme for propagation of emergency messages in vanet," in *Communication Technology (ICCT), 2010 12th IEEE International Conference on*, nov. 2010, pp. 1072 –1075.

[8] S. Oh, J. Kang, and M. Gruteser, "Location-based flooding techniques for vehicular emergency messaging," in *Mobile and Ubiquitous Systems: Networking Services, 2006 Third Annual International Conference on*, july 2006, pp. 1 –9.

[9] F. Hrizi, C. Bonnet, J. Härri, and F. Filali, "Adapting contention-based forwarding to urban vehicular topologies for active safety applications," *Annals of Telecommunications*, pp. 1–19, 2012. [Online]. Available: http://dx.doi.org/10.1007/s12243-012-0320-0

[10] P. Kheawchaoom, S. Kittipiyakul, and K. Ayutayay, "idtsg time-stable geocast for post crash notification in vehicular highway networks," in *Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON), 2012 9th International Conference on*, Phetchaburi, Thailand, may 2012, pp. 1 –4.

[11] P. Kheawchaoom and S. Kittipiyakul, "Effects of distance-based defer times and probabilistic channel to time-stable geocast," in *Lecture Notes in Engineering and Computer Science: Proceedings of The World Congress on Engineering and Computer Science 2012, WCECS 2012*, 24-26 October,2012, San Francisco, USA, pp. 895–900.

[12] M. Torrent-Moreno, F. Schmidt-Eisenlohr, H. Fubler, and H. Hartenstein, "Effects of a realistic channel model on packet forwarding in vehicular ad hoc networks," in *Wireless Communications and Networking Conference, 2006. WCNC 2006. IEEE*, vol. 1, april 2006, pp. 385 –391.

[13] P.-J. Wang, C.-M. Li, and H.-J. Li, "Influence of the shadowing on the information transmission distance in inter-vehicle communications," in *Personal, Indoor and Mobile Radio Communications, 2009 IEEE 20th International Symposium on*, sept. 2009, pp. 3015 –3019.

[14] K. Ibrahim, M. Weigle, and M. Abuelela, "p-ivg: Probabilistic inter-vehicle geocast for dense vehicular networks," in *Vehicular Technology Conference, 2009. VTC Spring 2009. IEEE 69th*, april 2009, pp. 1 –5.

[15] H. Rahbar, K. Naik, and A. Nayak, "Dtsg: Dynamic time-stable geocast routing in vehicular ad hoc networks," in *Ad Hoc Networking Workshop (Med-Hoc-Net), 2010 The 9th IFIP Annual Mediterranean*, june 2010, pp. 1 –7.

[16] N. Wisitpongphan, F. Bai, P. Mudalige, V. Sadekar, and O. Tonguz, "Routing in sparse vehicular ad hoc wireless networks," *IEEE Journal on Selected Areas in Communications*, vol. 25, no. 8, pp. 1538 –1556, Oct. 2007.

[17] H. Arbabi and M. Weigle, "Highway mobility and vehicular ad-hoc networks in ns-3," in *Simulation Conference (WSC), Proceedings of the 2010 Winter*, dec. 2010, pp. 2991 –3003.

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