INTRODUCTION

In recent years, we have witnessed a large increase of research interest in the area of Vehicular ad hoc networks (VANETs). A number of factors have contributed to the growing interest including serious aim of vehicle manufacturers to incorporate information technology to ensure safety, environmental and comfort issues of their vehicles; and the concern of governments for adoption of innovative technologies to provide road safety. One of the important safety applications in VANETs is Cooperative Collision Warning System (CCWS) that disseminates safety alert messages to prevent potential accidents (Yan et al., 2010). Several messages in this category need to be propagated to vehicles beyond the immediate transmission range, e.g. safety alert messages about hazardous driving situations such as dangerous road surface, unexpected road block, accidents, unexpected fog banks, and so on (Fasolo et al., 2006; Rudack et al., 2003). Dissemination of such messages requires the design of effective propagation algorithms that can provide reliable message delivery to all the relevant vehicles with minimum delay. Propagation of message beyond the immediate transmission range involves multi-hopping in the highly dynamic network. Consequently, the propagation scenario becomes much more complex as multi-hop increases the chances of collision and also causes over consumption of radio resource due to unnecessary retransmissions (Korkmaz and Ekici, 2004). Considerable research has been carried to address the complex routing mechanism in VANETs. In this regard, significant effort is directed on providing feasible solutions using broadcast routing techniques. Broadcast routing accomplishes the critical requirement of VANET safety messages by reliably transmitting the message to all relevant vehicles.
vehicles. Urban Multi-hop Broadcast (UMB) (Korkmaz and Ekici, 2004) BROADCOMM (Durresi et al., 2005) and Smart Broadcast (SB) (Fasolo et al., 2006) are among prominent works using broadcast technique. Most broadcast methods adopt the conventional 802.11 like RTS/CTS handshake before transmitting the actual safety message. RTB/CTB (request to broadcast/clear to broadcast) handshake in VANETs (substitute for RTS/CTS handshake in 802.11) is used to mitigate the hidden node problem. Unlike 802.11, here the safety message initiator exchanges RTB/CTB with only one of the recipients among its neighbors. However, note that due to the small size of VANET safety message payload length of 100 bytes on average(Xu et al., 2004), each safety message transmission occupies the radio channel for a very brief amount of time as opposed to a data stream. Consequently, in case of message transmission without RTB/CTB handshake, the likelihood of message collision due to hidden node is virtually equal to that with the use of RTB/CTB exchange. Also importantly, since vehicular topology has mostly extended distribution of vehicles and multihop transmission, the so called gagged terminal problem and masked terminal problem are acute in VANET scenario. Moreover, the extended distribution of vehicles also has frequent instances of hidden terminals outside the transmission range of receivers i.e. the CTB message from receivers is unheard by those hidden terminals, thus causing handshaking ineffective. Several works in the literature evaluate the efficiency of handshaking mechanism in infrastructure based 802.11 networks (Sobrinho, 2005) and general ad hoc networks (Xu et al., 2002). However, to the best of our knowledge, there does not exist any work in hitherto literature that concerns the evaluation of handshaking mechanism with regards to VANETs. In this paper, the efficiency of safety message dissemination using handshake based broadcast in VANETs is evaluated. Instant broadcast, a simplified version of Smart Broadcast technique, is recommended where safety message is propagated without using handshaking mechanism and related control packets. Analytical model based on Markov chain modeling is also developed for message propagation delaying instant broadcast. Thorough evaluation and comparisons performed in ns-3 simulator show that lower propagation delay can be guaranteed by avoiding handshaking mechanism and at the same ensuring reliability of reception by all the relevant nodes. The main contributions of this work are: evaluating the effectiveness of handshake mechanism in VANETs for the first time, improved end to end propagation speed by 100% each hop through avoiding handshake, theoretical analysis of delay for the instant broadcast method which can be easily extended for delay in any broadcast method in VANETs, and profound simulation results by modeling the communication architecture in ns-3 simulator.

Handshake Based Routing Techniques in VANets

Several handshake based routing techniques have been proposed for VANETs. However, safety message dissemination in VANETs imposes strict constraints of minimized propagation delay and guaranteed delivery to all relevant vehicles. Therefore, we will focus our discussion to two solutions that comply best with these requirements (Li and Wang, 2007; Yang and Chou, 2008). In the following, we detail the functionality of Urban Multi-hop Broadcast and Smart Broadcast routing solutions.

Urban Multi-hop Broadcast (UMB)

In UMB protocol, node that is furthest away from the sender is selected for the message relay and is engaged in RTB/CTB handshake. To select the relay node, the coverage area of the sender is divided into equal size sectors in the direction of dissemination of message. The relay node is selected in the furthest sector. The sender node broadcasts a control packet called Request to Broadcast (RTB) which contains the geographical location of the source and sector size. When the nodes in the direction of dissemination receive this RTB packet, they compute their distance to the source.
Based on this distance they send a channel jamming signal called black burst: the further the distance of the respective sector the longer the burst. Once a node completes its burst it senses the channel. If the channel is busy the node exits the contention phase. However, if the channel is idle the node identifies itself as the next relay node and returns a control packet Clear to Broadcast (CTB) containing its ID. Note that CTB would collide if there were more than one node in the furthest sector. In that case the process will reiterate by dividing the sectors into sub sectors of smaller widths. After successfully receiving a CTB packet the source node sends its broadcast packet that also contains the ID of the node which successfully sent the CTB (the relay node). The relay node will now become the new source and repeat the process for next hop.

**Smart Broadcast (SB)**

Smart broadcast is an extension of UMB protocol that attempts to minimize the excessive delay caused by iterative collision resolution method in UMB. Similar to UMB, SB uses the assumption that coverage area can be partitioned in Adjacent sectors and that node are capable of estimating the sector they belong to. Hence a contention resolution procedure is performed. Source broadcasts the control RTB packet to seek the corresponding CTB packet. The receiving nodes Contend to return the CTB packet based on their corresponding sector. In case of CTB collision, unlike in UMB, the process will not be iterated again but rather the nodes would remain in contention phase and the node with the next minimum back off will send the CTB.

**Instant Broadcast**

In this section a simplified version of Smart Broadcast protocol is suggested that avoids the use of handshake mechanism. Detailed description with analytical model for propagation delay is presented for Instant Broadcast method.

**Motivation**

UMB and SB protocols rely on the exchange of RTB/CTB messages each hop before the transmission of actual safety message. Both the protocols may perform well for the case of non-safety data transfer in VANETs where a typical data transfer carries more than 2312 bytes. However, the small size of VANETs safety message (100 bytes payload on average) may not be adequate to employ RTB/CTB exchange which can incur excessive delay (Li and Wang, 2007). In particular for a multi-hop propagation, the overall end to end delay would severely deteriorate as the delay overhead due to RTB/CTB multiplies each hop.

**Protocol Description**

Instant Broadcast is the simplified extension of Smart Broadcast protocol that avoids the usage of handshake mechanism. The sender (message originator) gains access to the medium by following the 802.11 CSMA/CA policy and broadcasts the entire safety message. Collision for the message originator is dealt by following the exponential back off mechanism. The position, direction of broadcast, and sectoring information is appended in the safety message packet as a small overhead of about 12 bytes. This overhead is not specific to Instant Broadcast protocol as it is also used in both UMB and SB protocols. The position information comprises 4 bytes each for longitude and latitude of the sender (acquired from the on-board GPS device), hop count and intended broadcast distance comprise 2 bytes, direction of broadcast is 2 bits, while sectoring information comprises 1 byte each for sector width (in meters) and number of sectors. Receiving nodes will follow the same SB contention procedure and the relay node will rebroadcast the safety message. In case of collision the vehicle with the next minimum back off value will rebroadcast the message.
The rebroadcast from the relay node is overheard by the sender; this will confirm the successful reception of safety message. In case the rebroadcast message is not heard by the sender within the specified time (timeout), the broadcast is repeated by the sender. Note that the movement of vehicle (50 miles per hour on average) relative to message propagation speed (25 meters per millisecond on average according to simulations in section IV) is negligible to affect the message overhearing mechanism. In the last hop the message is retransmitted twice, once by the actual forwarder and the second time (after the first retransmission is received) by the furthest receiving node for the purpose of acknowledgement.

Figure 1 shows a general sequence of packets in handshake based broadcast and instant broadcast methods. The figure gives an intuitive comparison between the two methods in terms of delay while considering collisions. Here, elimination slots account for the time during which surroundings nodes decide the next forwarder among themselves. It can be observed from the figure that by the time handshake method broadcasts the message in one hop, instant broadcast would have almost completed two hops in case when there is no collision. Interestingly, even while comparing collision case for instant broadcast to successful case for handshake broadcast, the delay of instant broadcast does not exceed drastically and it completes its one hop in almost the same time as handshake based broadcast. The delay gain of instant broadcast in figure 1 may seem improbable; however, we will also show in our simulation analysis in section IV that the delay gain of instant broadcast is effectively twice as the handshake based methods under practical assumptions. UMB, SB and the suggested extension of SB use the concept of equally partitioning the coverage area into adjacent sectors around the sender node, to decide the next relay node. Each receiving node in the range decides its corresponding sector by estimating its distance from the sender node using the location information. Each sector is assigned a contention window containing equal number of time slots:

\[
W_n = t_1; t_2; t_3; \ldots; t_lg + (N - n); n = 1; 2; \ldots; N (1)
\]

Where \(W_n\) denotes the contention window for sector \(n\). The number of time slots \(l\) is equal for all sectors and its value depends on traffic congestion. The more congested the traffic the more the number of time slots. Each window is offset by \(N - n\), where \(N\) is the total number of sectors, thus making sure that nodes in the further sectors always transmit before nodes in the other sectors. The optimization of parameters \(N\) and \(l\) will be shown with the help of simulations in section IV.

**Delay Analysis**

The delay analysis for the vehicular multi-hop scenario using Instant Broadcast method is formulated here. As explained above the sending mechanism in the first hop (message origination) is different from the sending (forwarding) mechanism in the following hops. In the former the sender increases its back off window size in case of collision until successful transmission occurs, while in the latter the sender gives up in case of collision and the node with the next minimum Back off value will forward the message. As a result, in the delay analysis, we deal the delay for the first hop separately from the delay of the following hops. The analysis for the message origination hop is presented first. In this analysis, a Bianchi’s Markov chain is used with the assumption that the traffic distribution is uniform and that there are fixed number of contending nodes (CN) (excluding the sender) and fixed number of hidden nodes (HN) for each sender. In the Bianchi’s Markov chain model (Bianch, 2000), the author defines the probability \(p\) as a probability that a transmitted packet collides and thus increases current window size to
double. The collision, as considered in (Bianchi, 2000), occurs when contending nodes choose a time slot at the same time. However, in our scenario we also consider collisions due to hidden nodes. To incorporate this effect, a modified Markov chain model is depicted in Fig.2. b(t) and s(t) are stochastic processes representing the back off time counter and back off stage, respectively, for a given node at time t. P0 is the packet collision probability at state s(t). Let tr be the transmission time of the packet given by

\[ t_r = \frac{H_{PHY} + H_{MAC} + \text{Payload}}{R_b} + \delta \]  

(2)

Where HPHY and HMAC are the PHY and MAC headers MAC header also includes our protocol overhead. Rb is the data rate while \( \delta \) is the propagation time. Here, we assume the same data rate for payload, PHY and MAC header.Transmission.

We represent the interval, in terms of the number of back off slots, that a hidden node does not transmit a packet during time tr by

\[ k_o = \left[ \frac{t_r}{\text{slot time}} \right] \]  

(3)

Let \( T_c \) be the transmission probability of a contending node and \( T_h \) be the transmission probability of a hidden node. The probability that a hidden node does not transmit during the sender’s transmission is \( (1 - \tau \) \) \( T_h \) . Consequently, by incorporating these collisions, the probability of unsuccessful transmission becomes

\[ P_r = 1 - (1 - T_c) \alpha \cdot T_h \]  

(4)

From (Bianchi, 2003), the probability that a node starts its transmission in a given time slot is given by

\[ \tau = \frac{2(1 - 2^\alpha)}{(1 - 2^\alpha)(W' + 1) + \alpha W'(1 - (2^\alpha)^m)} \]  

(5)

where \( W' \) is the minimum window size and \( m \) is the maximum backoff stage. \( T_c \) and \( T_h \) can be computed from (Bianchi,2003), and equation (4) using numerical analysis. The probability that a transmission occurs among contending nodes in a given time slot is

\[ P_{tr} = 1 - (1 - T_c)^{CN+1} \]  

(6)

The probability that a packet is successfully transmitted given \( P_{tr} \) (probability that transmission occurs among contenders) is given by

\[ P_s = \frac{(CN + 1)T_c(1 - T_c)^{CN}(1 - T_h)^{tr}XH}{P_{tr}} \]  

(7)

From (Chatzimisiou et al., 2003) and the above equations, we can write the average delay for message transmission in the first hop (message origination hop) \( E[D] \) as

\[ E[D] = E[S]E[slf] \]  

(8)

\[ E[S] = \frac{(1 - 2^\alpha)W' + 1 + \alpha W'[1 - (2^\alpha)^m]}{2(1 - 2^\alpha)(1 - P_s)} \]  

(9)

\[ E[slf] = (1 - P_{tr})\alpha + P_{tr}P_sT_s + P_{tr}(1 - P_s)T_c \]  

(10)

\( E[S] \) is the average number of slot times for a successful transmission and \( E[slf] \) is the average length of a slot time; \( \sigma \) is the duration of empty slot, \( T_s \) and \( T_c \) are the average time the medium is sensed busy because of a successful transmission or a collision respectively.

\[ T_s = DIFS + \left( \frac{H_{PHY} + H_{MAC} + \text{Payload}}{R_b} + E[D'] + \delta \right) \]  

(11)

\[ T_c = DIFS + \left( \frac{H_{PHY} + H_{MAC} + \text{Payload}}{R_b} + \text{timeout} + \delta \right) \]  

(12)

As explained in the protocol description, we consider re-transmission in the next hop as acknowledgment for transmission in the previous hop. Therefore, in (11), we include the average next hop delay \( E[D'] \) as the acknowledgement delay in (12), however, we include the acknowledgement timeout of the message originator. Now, we briefly describe the analysis for the average delay \( E[D'] \) of the forwarding hop. Here we assume the transmission probability \( T_h \) of a hidden node is the same as considered above. Also, we assume from our sectoring method that the contention window size \( I \) is fixed for each
sector in the propagation scenario. Since the traffic distribution is assumed as uniform, the number of hidden nodes and the number of contending nodes are assumed to be the same for each sector. Note that unlike in the first hop, here the sender does not use exponential backoff and rather gives up transmission in case of retransmits the message. The probability of transmission in a given slot time is given by $r_c$.

Using (7), we get probability $P_{st}$ that packet is successfully transmitted. The average delay $E[D_r]$ for a forwarding hop can be finally written as

$$E[D_r] = E[d]X$$  \hspace{1cm} (13)

where $E[d]$ is the average delay for a retransmission attempt, which can be computed by using (8), (9) and (10) with $m = 1$, while $X$ is the average number of retransmission attempts in the forwarding hop given by

$$X = \sum_{n=0}^{W-1} (1 - P_{st} P_{tr})^n P_{st} P_{tr} n$$  \hspace{1cm} (14)

Note that while calculating the forwarding hop delay, we include the average next hop delay to account for acknowledgment in (11). Therefore, the average next hop delay will be included in each forwarding hop until the retransmission in the last hop. In the last hop, as explained in the protocol description, there is a retransmission after the initial forwarding that specifically serves as acknowledgment without requiring any further confirmation.

**Simulation setup**

To analyze the comparison of handshake based broadcast method and instant broadcast method, IB is fully implemented along with UMB and SB broadcast schemes in ns-3 simulator, version 3.9 (The NS-3 Network simulation). The traffic mobility is generated using TraNS (Traffic and Network Simulation Environment) (Traffic and Network Simulation Environment). The common simulation parameters are summarized in Table 1. We have used 4 km road length scenario with unidirectional roads having two lanes. Ten different vehicle densities are tested with density from 5 to 50 nodes per 300 meters length of the road (i.e. one hop distance), and having Gaussian randomly assigned speed with mean 50 miles/h and standard deviation 3 miles/h. The minimum safe time headway between vehicles is kept 1.5 seconds. We use Jakes model to estimate Rayleigh fading for the channel (Blaszczyszyn et al., 2009). To best study the performance of algorithms in the existence of hidden nodes, the scenario is tested for different message generation rates of 0.01 to 1 message per vehicle per second, where 1 message per vehicle per second has a high likelihood of hidden nodes existence at almost every broadcast instance. Moreover, to account for randomness each simulation test is run for three runs to acquire thorough results.
RESULTS AND DISCUSSION

Figure 3(a) shows average one hop propagation delay for instant Broadcast using different contention window sizes $l$ and number of sectors $N$. The plot is based on mean delay with variable node densities. From the figure it can be observed that both $l$ and $N$ are influential on the propagation delay. The higher values of each parameter may avoid collisions, however, it would incur higher delay. On the contrary, the smaller values incur excessive delay due to collisions and the resulting retransmission. The parameter setting of $l = 7$ and $N = 8$ seems optimal for minimum propagation delay. Also, since the sectoring approach is identical in all the three protocols under discussion, we keep the optimum values of window size $l = 7$ and number of sectors $N = 8$ in the rest of the simulation experiments. Figure 3(b) gives an explicit comparison between handshake based method and instant broadcast method in the presence of variable number of hidden and contending nodes under saturation condition. Here, average one hop network throughput is reported against variable packet payload size from 100 to 2200 bytes. For the sake of clarity in the plot, we depict Smart Broadcast (being the closer counterpart of IB) in detail, while for UMB, the average throughput curve is shown. Clearly, the IB method achieves higher throughput compared to handshake based broadcast for message sizes up to 1000 bytes. The throughput gain of IB, for the smaller message sizes, is almost constant regardless of the increase of the number of hidden nodes. The throughput gain is understandable for a number of reasons. Firstly, due the fact that handshake based method aims to exploit the small size of RTB to reserve the channel prior to sending the actual message packet. However, for the smaller message size, the message itself has less likelihood of collision like an RTB packet. Thus the handshake serves as an overhead, resulting in lower throughput. Secondly, the extended vehicle distribution (topology) on the road has a high likelihood of gagged station problem. In a gagged station problem the RTB/CTB exchange unnecessarily prevents simultaneous (non-interfering) communication among neighboring nodes, thus effecting the overall network throughput. Thirdly, the extended distribution of vehicles on the road causes the masked station problem in high packet generation rates, where RTB/CTB virtually becomes ineffective and rather incursive delay. For message sizes above 1000 bytes, however, the handshake mechanism can be effective as shown in the plot and can improve the overall throughput. Figure 3(c) shows the success rate of the three protocols. Success rate is the ratio of the number of nodes that receive the safety message to the total number of nodes that are present in the multi-hop coverage range. Here, reception by any node is the final successful reception of message regardless of the Number of retransmission due to collisions. As discussed earlier, the existence of hidden nodes is directly proportional to packet generation rate. Here, we see that IB performs equally well with a very negligible loss (about 0.2% more than handshake based method) over higher packet generation rate. Thus, IB maintains equal reliability as protocols with handshaking overheads, while at the same provides lower propagation delay as we show in the following figures. Figure 4(a) shows mean delay with respect to message generation rate using safety message payload length of 100 bytes. From the figure it is obvious that instant broadcast method provides considerable improvement over SB and UMB protocols in terms of mean one hop delay. The delay gain is consistent with message generation rate until slightly above

<table>
<thead>
<tr>
<th>Simulation parameters</th>
<th>Description</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Transmission range</td>
<td>300 meters</td>
<td></td>
</tr>
<tr>
<td>Data rate</td>
<td>3 Mbps</td>
<td></td>
</tr>
<tr>
<td>Message payload size</td>
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<tr>
<td>Protocol overhead</td>
<td>12 bytes</td>
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<tr>
<td>MAC header size</td>
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<tr>
<td>PHY header size</td>
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<td>Base protocol</td>
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<tr>
<td>RTB, CTB, ACK</td>
<td>20, 14, 12 bytes</td>
<td></td>
</tr>
<tr>
<td>Time slot, DIFS, SIFS</td>
<td>20, 50, 10 $\mu$Sec</td>
<td></td>
</tr>
<tr>
<td>Road length</td>
<td>4 km (2 lanes)</td>
<td></td>
</tr>
<tr>
<td>Vehicle density</td>
<td>5-50 vehicles/300 meters</td>
<td></td>
</tr>
<tr>
<td>Vehicle speed</td>
<td>50 miles/h (mean)</td>
<td></td>
</tr>
<tr>
<td>Message generation rate</td>
<td>0.01-1 message per vehicle/second</td>
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<tr>
<td>Path loss model</td>
<td>Two Ray model</td>
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<tr>
<td>Fading model</td>
<td>Rayleigh fading model</td>
<td></td>
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<tr>
<td>Simulation time</td>
<td>100 seconds (each run)</td>
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0.1 message per second per vehicle where the hidden node problem may be acute, resulting in the handshake methods performing equally well. However, retransmission due to hidden node collisions in the higher message generation case do not significantly affect the IB performance as the delay (even in the higher rates) is close to the handshake based methods. Figure 4(b) depicts mean delay with respect to distance. We observe considerable delay gain of IB again over SB and UMB protocols with respect to distance. Note that the distance interval (300 meters) on x-axis roughly represents one hop communication range. Therefore, we observe that the delay gain of IB over the other two protocols doubles every hop, and it can be seen in the fourth hop that the delay gain of IB is about a significant 12 milliseconds.

Figure 4(c) depicts average load generated by each message in the network against vehicle density. The figure highlights an important achievement of IB protocol over the other two protocols. It provides the total number of bits transmitted in the network in order to disseminate a safety message to related nodes. In other words, it shows the channel reservation per safety event. The average load generated per message increases slightly with increasing vehicle density for all the three protocols due to retransmission triggered by collisions in the high density traffic. However, since IB involves only the actual message in the propagation mechanism, it generates the least amount of load in the network per message. Since the handshake based methods involve RTB and CTB overhead packets, and also, due to their resulting retransmission because of gagged station problems and masked station problems, their overall load generated per message is higher. The evaluation results show that Instant Broadcast offers equal reliability as the methods using handshaking mechanism, and at the same time improves the overall safety message propagation delay by avoiding overhead messages.

**CONCLUSION**

In this paper, we have analyzed the use of handshaking mechanism for safety message dissemination in VANETs. Instant Broadcast routing without using handshaking is asserted to be used for multi-hop safety message dissemination in VANETs. Our extensive simulation results using ns-3 simulator suggest that Instant Broadcast significantly improves the message propagation delay and ensures reliability of reception by all the nodes in the multi-hop range. The evaluation of handshaking mechanism presented in this paper will assist future researchers in considering handshaking while designing VANET communication protocols. Theoretical delay analysis for instant broadcast method is also developed in this paper, which can be extended for delay calculation of any broadcast method in VANETs. Future work can be directed towards further investigation of the contention resolution mechanism and exploit some novel parameters such as vehicle type and lane number with respect to message originator. In this paper, we have presented a new technique for sectoring the broadcast range for safety message routing in VANETs. Rush hour traffic scenario is considered where most of the hitherto mechanisms are severely affected with collisions and consequent high message propagation delays. The hitherto neglected factor of road width is introduced to be used as a second dimension for sectoring the transmission range of the message sender. Collision gain of the proposed technique is evaluated using Marchov chains. Extensive simulation evaluation is performed using ns-3 simulator, and the results suggest that Lane based sectoring significantly improves the message propagation delay by as much as 9 ms for rebroadcast in each hop while at the same time improves reliability of message propagation by reducing rebroadcast collisions by 2% over the existing sectoring technique even in worst traffic scenario. Uncovering the importance of road width for VANETs in this paper will assist future researchers in understanding a more detailed road topology that influences VANET
communication. The idea of segmenting transmission range into manageable units can also be replicated in service channel allocation strategy in VANETs where there is an equally critical concern about effective channel utilization. Theoretical delay analysis for rebroadcast stage developed in this paper can be extended for delay calculation of other broadcast methods in VANETs. Future work can be directed towards investigation sectoring in road intersection scenarios, and further study of the vehicle density and topology learning mechanism on the road.

REFERENCES


ü The ns-3 network simulator http://www.nsnam.org/

ü Traffic and Network Simulation Environment (TraNS) http://lca.epfl.ch/projects/trans
