

Introducing Lane Based Sectoring for Routing in VANETs

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Abstract

Vehicular Ad hoc Networks (VANETs) provide vehicle-to-vehicle and vehicle-to-infrastructure communication using Dedicated Short-Range Communications (DSRC). The core objective of VANETs is to provide safety message communication among vehicles. In dense urban traffic, safety message communication encounters severe packet collisions due to excessive number of nodes contending to access the control channel. In such a complex dense and mobile scenario, an ideal single vehicle per time slot has yet not been achieved. This paper introduces the use of lane level location information to achieve a single vehicle per time slot configuration. The transmission range of a message originator is divided into a grid using distance and lanes as the two variables. Each block within the grid houses a single vehicle at most that is assigned a unique time slot. The contention among nodes for the same time slot is virtually removed. Theory and ns-3 simulation justify the feasibility, and prove that the technique reduces packet collisions by 2%, and improves message dissemination speed by as much as 30% each hop.

Keywords:- VANETs, Road-width, Lanes, Sectoring

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INTRODUCTION

With the exponential increase of vehicles on the road, driving has become increasingly difficult and risky. In order to ensure passenger safety in challenging road scenarios, car manufacturers together with government agencies are in pursuit of a solution called Vehicular Ad hoc Networks (VANETs). VANETs would allow drivers to anticipate hazardous traffic events and approaching bad traffic conditions through inter-vehicle communication. One of the critical design issues in VANETs is the dissemination of safety messages beyond the immediate transmission range of a vehicle. The propagation requires multi-hop forwarding of the message by selected vehicles among a large number of contenders. The problem becomes severe in dense urban traffic where higher number of contending vehicles results in excessive packet collisions. Since these collisions greatly impact reliability of reception and overall message dissemination speed, it remains the core

concern while developing ideas for message routing in VANETs (Yan et al., 2010).

Considerable work has been carried to address the safety message propagation problem in VANETs. One common approach used to provide multi-hop forwarding is to divide the transmission range of message originating vehicle into multiple geographical sectors based on distance (Korkmaz et al., 2004, Fasolo et al., 2006, Khan et al., 2011). Vehicles in each sector pick a random backoff value from a contention window assigned to that sector. Contention windows are assigned in such a way that vehicles in the furthest sector can transmit first. Forwarding task is assigned to vehicle with minimum backoff. Since contention within a sector is random, it is highly probable in dense traffic environments that two vehicles within the same sector pick the same backoff value, thus causing collision. Further narrowing the sector length may minimize the effect to a certain degree. However, even with minimum possible sector length—equal to the length of a

car and necessary safety following distance many potential time slot colliders are still present in adjacent lanes. Considering the effect of lanes in VANETs forms the core of this work.

This paper aims to uncover the role of lanes in VANET communication. With road widths fastly nearing 100 meters (more than ten lanes each direction) (Turnbull 2003), it has become indispensable to consider the effect of road width or more specifically lanes while designing message propagation algorithms for VANETs. This work primarily considers dense urban traffic environment where traffic in each lane behaves like train trails with constant speeds. The proposed technique is suggested to be incorporated with methods for regular traffic using the currently probed vehicle density learning mechanism. To the best of our knowledge, this is the first work that considers the worst case rush hour traffic, whereas the previous works deal normal urban traffic as the extreme case. The use of the prevailing Differential Geographic Positioning System (DGPS) is assumed to determine accurate vehicle location. The aforementioned transmission range of a message originator is finely dissected both length and width-wise using distance and lanes respectively, forming a grid like structure with each block containing a single vehicle at most. Unique backoff values are assigned to each block ensuring only one vehicle in the furthest range forwards the message. Long contention window as a result of fine dissection may suggest high transmission delay, however, in dense traffic there is always a forwarding vehicle present in the furthest range that transmits with minimal backoff (i.e. transmission in the beginning of the window), making the length of the window ineffectual on delay. Additionally, since the overhead delay of message retransmission due to forwarding collisions is reduced, the overall end to end message propagation time is remarkably minimized.

The proposed idea is studied using thorough simulations performed in network simulator-3 (ns-3). Considerable reduction in rebroadcast collisions is achieved by using the grid based technique and the total collision occurrence is contained to below 3% in the worst case, while the message forwarding delay for each hop is improved by 9 ms over the existing sectoring technique. The important contributions

of this work are: reducing packet collisions due to visible (non-hidden) nodes to near zero by using the grid based unique backoff value assignment, improved propagation delay through instant and collision-free forwarding of the furthest node, greater coverage by ensuring the furthest node as the next forwarder, and bringing to light the hitherto disregarded factor of road width to the attention of VANET research community. The remaining of this paper is organized as follows. Section II gives a brief idea of the significance of road width in VANETs in related literature. Section III details the proposed technique with theoretical analysis. Section IV presents the ns-3 simulation environment, results and their discussion. Conclusion with a discussion on future work is given in Section V.

Road Width in Vehicular Communication

Road topology is one of the critical foundation elements considered while designing communication mechanisms for VANETs. Some of the important topology factors considered in hitherto VANET literature include vehicle density, vehicle speed, headway distance, road side clutter (for path loss calculation), while the road geometry is assumed either entirely linear or with the inclusion of intersections (Fesolo et al., 2006, Li et al., 2009, Blaszczyzyn et al., 2009, Korkmaz et al., 2004, Xu et al., 2004) consider road width, however, their consideration is limited to its effect on vehicle density i.e. geographical separation of lanes is not considered and instead parallel vehicles in different lanes are assumed to be at the same location. Road width is also neglected in VANET mobility pattern generator tools (Krajzewicz and Rossel, 2011, Haerri et al., 2006, Traffic & Network simulation, 2011), where multiple lanes only account for density while their geographical separation is still ignored. The exponential increase of vehicles on the road has resulted in the ever increasing road widths to maintain smooth flow of traffic. Consequently, the average width of busy roads in a metropolis has become above six lanes each direction (Bauer et al., 2004). I-10 East downtown Houston is a compelling example of the significance of road width where the road is as

wide as 13 lanes each direction (Turnbull, 2003). In such scenarios vehicles in parallel lanes will exacerbate channel contention, and in addition, may effect physical path for radio propagation on the road. This work, however, thoroughly takes into account road width and attempts to exploit vehicles' lane level location information to avoid channel contention problem in multi-hop routing. The goal is to achieve zero collision (due to visible nodes) in rush hour traffic in dense urban scenario.

Broadcasting Using Lane Based Sectoring

In the following we present an extension to our Instant Broadcast algorithm proposed in (Khan et al., 2011) by introducing lane based sectoring. Here we assume rush hour dense traffic scenario, however, later in our simulations we show that the idea is also applicable in normal highway traffic where linear car spacing is 17 meters. Since our technique characteristically makes use of road lanes, we restrict our scenario to the usual urban road width of four or above lanes (Bauer et al., 2004).

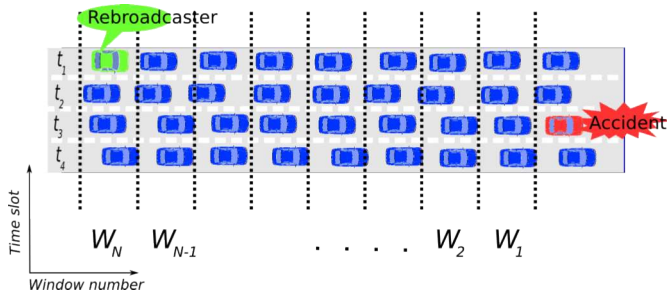


Figure 1. Backoff value assignment using Lane based Sectoring

Broadcasting Algorithm using Lane based Sectoring

The sender node (message originator) gains access to the medium by following the 802.11 CSMA/CA policy and broadcasts the entire safety message (with average VANET safety message size of 300 bytes (Khan et al., 2011)). The safety message is piggy backed with DGPS position of the sender, direction of broadcast and sectoring information for receiving nodes. Sectoring information, in turn, includes sectoring mode (i.e. linear or grid sectoring mode), and road width (at the sending instant). Sectoring mode is decided by considering current road density, which is learned through

periodic beacon messages from surrounding vehicles or through keeping track of packet collision history where more collisions determine higher density and vice versa. Withal sender's road width is considered to cater scenarios where different road widths exist within the multi-hop broadcast range e.g. road widening or narrowing within the multi-hop distance. The piggy backed information adds a minimal overhead of about 11 bytes. Similar size overheads are used in most broadcasting methods including UMB and SB protocols in (Korkmaz et al., 2004, Fasolo et al., 2006). The location information comprises 4 bytes each for longitude and latitude of the sender (acquired from the on-board DGPS device), direction of broadcast is 2 bits, while sectoring information comprises 2 bits for sectoring mode, 1 byte for road width (in number of lanes), and 1 byte for sector length (in meters).

Receiving nodes will enter a contention phase to rebroadcast the safety message and node with the smallest backoff value among the contenders will rebroadcast the safety message to the next hop. Since the receiving node furthest from the sender can provide longest relay, nodes in the furthest sector will have the least backoff values. In grid sectoring, in addition to lengthwise sectoring of the road based on the distance from the sending node, each sector is further subdivided width-wise into cells. Each sector is assigned a contention window with equal number of time slots:

$$W_n = \{t_1, t_2, t_3, \dots, t_l\} + (N - n), \quad n = 1, 2, 3, \dots, N \quad (1)$$

where W_n denotes contention window for sector n . The number of time slots l is equal for all sectors and its value is equal to the number of road lanes. Each window is offset by $N - n$, where N is the total number of sectors, thus ensuring that a node in further sector always rebroadcasts before a node in the nearer sectors.

Fig. 1 shows the sectoring mechanism and back off value assignment in lane based broadcast method. Transmission range of the safety message sender is divided into equal size sectors with increasing distance

from the sender along the road in the message forwarding direction. Each sector is assigned a fixed length contention window W_n as described in equation (1). Within each sector, the road section is further subdivided width-wise into cells with cell width equal to that of one lane. Each cell is then assigned a fixed time slot from the corresponding contention window. Length of a cell (along the horizontal axis in Figure 1) is significant in the proposed mechanism. One cell in our scenario strictly spaces one vehicle in order to completely avoid collision. Therefore, we cautiously assume sector length (or cell length) as 13 meters, although (Bauer et al., 2004) reports that the average vehicle spacing in a city freeway is about 16.8 meters (equal to four car lengths; average car length being 4 meters). Node within each cell backs off for its assigned amount of time. Consequently, in our scenario the node in N^{th} sector (furthest) sector with time slot t_1 will rebroadcast first. All the remaining nodes with higher back off values would overhear the rebroadcast and would subsequently quit their rebroadcast step. The rebroadcast from the relay node is also overheard by the original sender, this will confirm successful reception of the safety message. In case the rebroadcast message is not heard by the original sender within the specified time (timeout), the broadcast is repeated by the original 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 influence the message overhearing mechanism. The same mechanism is repeated in the remaining hops until the message propagates across the intended distance.

Delay Analysis

Since this work focuses on the rebroadcasting stage in VANET multi-hop safety message propagation, we confine our delay analysis to the rebroadcasting step in the message propagation scenario. The rebroadcast delay in a normal sectoring mechanism is formulated first, followed by the rebroadcast delay in lane based sectoring. We assume

the traffic distribution is uniform and that there are fixed number of contending nodes (CN) for each sender. We follow Bianchi's Markov chain model (Bianchi, 2000) to formulate one hop delay for our broadcasting mechanism. Let t_r be the transmission time of the packet given by

$$t_r = \frac{h_{PHY} + h_{MAC} + Payload}{R_b} + \delta \quad (2)$$

where h_{PHY} and h_{MAC} are the PHY and MAC headers (MAC header also includes our protocol overhead). R_b is the data rate and δ is the propagation time. We assume the same data rate for payload, PHY and MAC header transmission. Let τ_c be the transmission probability of a contending node. The probability of unsuccessful transmission becomes

$$P_r = 1 - (1 - \tau_c)^{CN} \quad (3)$$

From (Bianchi, 2000), the probability that a node starts its transmission in a given time slot is given by

$$\tau = \frac{2(1 - 2P')}{(1 - 2P')(N + 1) + P'N(1 - (2P')^l)} \quad (4)$$

where N and l are number of sectors and number of slots from (1). τ_c can be analytically computed from (Bianchi, 2000) and equation (4).

The probability that a transmission occurs among contender nodes in a given time slot is

$$P_{tr} = 1 - (1 - \tau_c)^{CN+1} \quad (5)$$

Probability that a packet is successfully transmitted given

P_{tr} is

$$P_s = \frac{(CN + 1)\tau_c(1 - \tau_c)^{CN}}{P_{tr}} \quad (6)$$

From (Blaszczyszyn et al., 2009) and the above equations, we can write the average delay for message rebroadcast $E[D]$ as

$$E[D] = E[x]E[t] \quad (7)$$

Where

$$E[x] = \frac{(1 - 2P')(N + 1) + P'N(1 - (2P')^l)}{2(1 - 2P')(1 - P')} \quad (8)$$

$$E[t] = (1 - P_{tr})\sigma + P_{tr}P_sT_s + P_{tr}(1 - P_s)T_c \quad (9)$$

$E[x]$ is the average number of time slots for a successful transmission and $E[t]$ is the average length of a time slot; σ is the duration of empty slot, T_S and T_C is the average time the medium is sensed busy because of a successful transmission or a collision respectively.

$$T_S = DIFS + t_r + \delta + ACK \quad (10)$$

$$T_C = DIFS + t_r + timeout + \delta \quad (11)$$

In case of lane based sectoring method, the rebroadcast delay $E[D]$ is strictly dependent on the density of nodes. Rush hour traffic has the lowest rebroadcast delay as the smaller back off value cells, like all other cells, are likely to be occupied, thus causing rebroadcast in the first few time slots of the contention window. Therefore, in rush hour traffic for lane based sectoring method, as P_{tr} becomes equal to P_c , and CN approaches zero, the probability of successful transmission P_s approaches nearly 1.

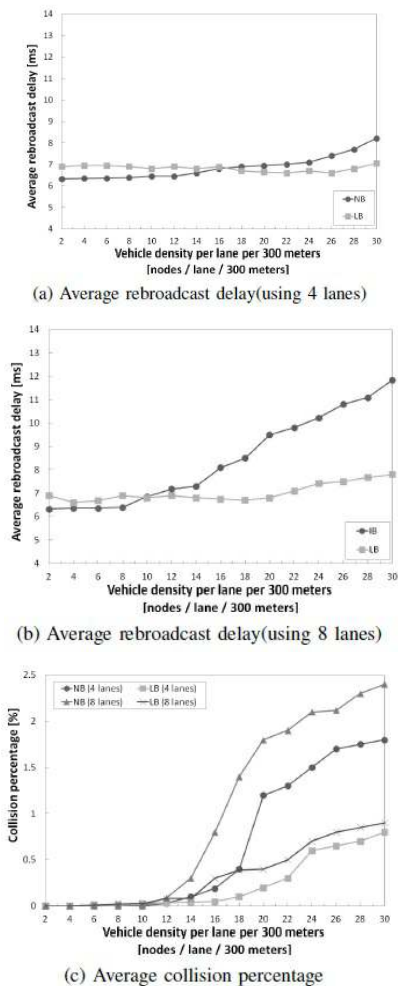


Figure 2. Rebroadcast delay in 4 and 8 lanes, average collision percentage; (message size 300 bytes).

Simulation Analysis

Simulation setup

To analyze the comparison of normal sectoring broadcast and lane based sectoring broadcast, the general broadcast procedure followed by UMB, SB and IB in (Korkmaz et al., 2004, Fasolo et al., 2006, Khan et al., 2011) was fully implemented using both normal sectoring as well as lane based sectoring in ns-3 simulator, version 3.9. The traffic mobility is generated using the tool VanetMobiSim (Haeri et al., 2006).

Simulation parameters are summarized in Table 1. We have used 1 km road length scenario with unidirectional road having four and eight lanes. Fifteen different vehicle densities are tested with density ranging from 2 to 30 nodes per lane per 300 meters length of the road (i.e. one hop distance), and having Gaussian randomly assigned speeds with mean 50 miles/h and standard deviation 3 miles/h. The minimum headway between vehicles is kept as 10 meters to account for worst case scenarios. Jakes model has been used to estimate Rayleigh fading for the channel (Blaszczyszyn et al., 2009). To best study the performance of the proposed technique, the scenario is tested for different message generation rates of 0.01 to 1 message per vehicle per second.

Description	Value
Transmission range	300 meters
Data rate	3 Mbps
Message payload size	300 and 1000 Bytes
Protocol overhead	11 bytes
MAC header size	34 bytes
PHY header size	26 bytes
Base protocol	802.11p
Time slot, DIFS, SIFS	20, 50, 10 μ Sec
Road length	1 km
Vehicle density	2-30 vehicles/lane/300 meters
Vehicle speed	50 miles/h (mean)
Vehicle spacing	10 meters
Message generation rate	0.01-1 message per vehicle/second
Path loss model	Two Ray model
Fading model	Rayleigh fading model

RESULTS AND DISCUSSION

Fig. 2(a) and 2(b) show average rebroadcast delay in 4 and 8 lane road configuration with variable vehicle densities. NB in the figure denotes

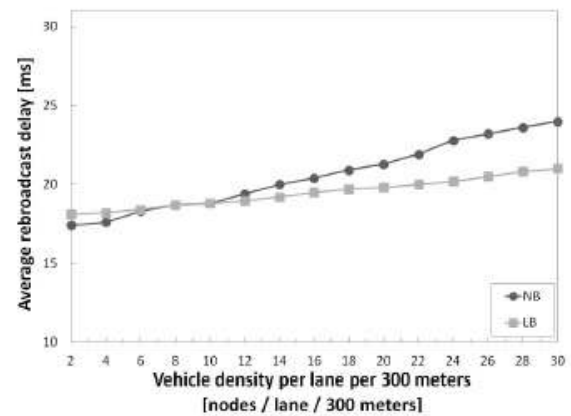
Normal sectoring Broadcast while LB denotes Lane sectoring based Broadcast. We use the average message size of 300 bytes to measure the performance here. In fig. 2(a) the behavior of both the methods remains unaffected in low density scenarios until the vehicle density of 16 nodes per lane per 300 meters. Among the two methods, LB however, slightly falls short in performance in low density range due to the usage of longer back off window than required. Note that the window size for LB has been kept as 120 slots as discussed in the algorithm, albeit it was also mentioned that a density learning technique can alleviate such additional time slot overhead. For the case of NB however, the window size has been varied depending on the density of vehicles. Therefore, NB maintains its advantage in low density scenarios. In fig. 2(a) as the vehicle density increases above 16 nodes per lane per 300 meters, the additional window size of LB pays off and there is a delay gain of about of 2 ms per rebroadcast as the density reaches 30. This effect clearly demonstrates the LB basic principle that as the vehicle density reaches rush hour traffic (i.e. as nearly every cell of the grid is being occupied with vehicles), there is high likelihood that least back off value slots are assigned to vehicles and rebroadcast takes place early in the back off window.

In Fig. 2(b) the delay gain of LB over NB becomes clearly compelling. Using 8 lanes road scenario the NB method sectors the transmission range with narrower sector length, however, the presence of nodes in the parallel lanes is disregarded. Therefore, although the high density of nodes in each sector is considered, the likelihood of back off value collision among nodes grows astonishingly higher, thus resulting in resending attempts from the original sender and causing high delay. LB, on the other hand, is effected minimally with higher density and a near one time slot per node configuration is achieved and the delay gain reaches as high as 5 ms per rebroadcast over the normal broadcast method.

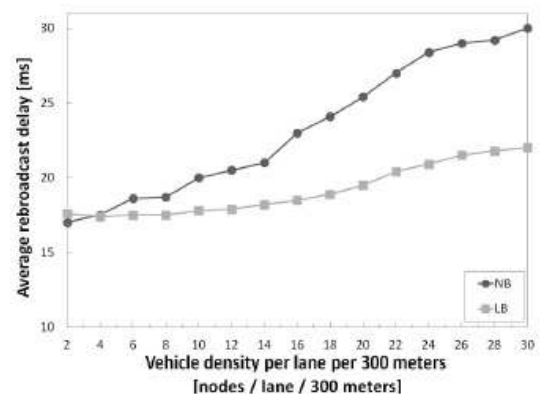
Fig. 2(c) depicts average collision percentage with variable vehicle densities in 4 and 8 lane cases. The figure explicitly depicts the

collision improvement perspective of LB over NB method. Here collision percentage is the measure of the number of retransmission attempts by the sender. It can be discerned from the figure that the performance of normal sectoring method NB is severely degraded in high density road traffic. In rush hour traffic where vehicle density increases above 16, the collision rate steeply rises to as high as 2.4% in 8 lane scenario.

Higher collision directly incurs high retransmission rate, thus effecting overall end to end delay as well as message dissemination reliability. LB, in contrast, even in the worst case of 8 lane with 30 nodes per lane maintains collision percentage below 1, thus promising high reliability as required for safety communication in VANETs.



(a) Average rebroadcast delay(using 4 lanes)



(b) Average rebroadcast delay(using 8 lanes)

Fig. 3 shows performance measure with message size of 1000 bytes. The general behavior of the two methods follow the same trend as in fig. 2 where the message size is 300 bytes. There are, however, two noticeable distinctions with higher message size. First, contention is slightly more sensitive to node density with higher message size; Second, the

overall collision rate is higher for the two methods in both 4 and 8 lane scenarios. The reason being the higher message size means longer medium occupancy by each sender, causing accumulated contenders, thus more collisions and its resultant longer overall delay. Importantly, the gain of LB over NB method remains significant even with higher message size both in terms of delay (by 9 ms in worst case) and collision rate (by 2% in worst case).

CONCLUSION

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 effected 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 of sectoring in road intersection scenarios, and further study of the vehicle density and topology learning mechanism on the road.

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