Increasing Broadcast Reliability in Vehicular Ad Hoc Networks

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ABSTRACT

Broadcast transmissions are the predominate form of network traffic in VANETs. However, since there is no MAC-layer recovery on broadcast frames within an 802.11-based VANET, the reception rates of broadcast messages could be very low, especially under saturation conditions. In this paper, we present an adaptive broadcast protocol that significantly improves the reception rates of broadcast messages. We rely on the observation that a node in a VANET is able to detect network congestion by simply analyzing the sequence numbers of packets it has recently received. Based on the percentage of packets that are successfully received in the last few seconds, a node dynamically adjusts the parameters it uses, such as contention window size, transmission rate, and transmission power, to improve the delivery rate of broadcast messages. Our experiments show that the improved protocols reduce the collision rates by over 50% for both high priority and low priority traffics under saturation conditions.

Keywords

ad hoc networks, broadcast, contention window, DSRC, IEEE 802.11, prioritized access

1. INTRODUCTION

Rapid advances in wireless technologies provide opportunities to utilize these technologies in support of advanced vehicle safety applications. In particular, the new Dedicated Short Range Communication (DSRC) [1] offers the potential to effectively support vehicle-to-vehicle and vehicle-to-roadside safety communications, which has become known as Vehicle Safety Communication (VSC) [2] technologies. DSRC enables a new class of communications applications that will increase the overall safety and efficiency of the national transportation system. For instance, systems might monitor traffic in order to adjust the changing of lights. Sensors might use feedback from vehicles to detect traffic jams. Emergency vehicles might use broadcast via wireless to change traffic signals in order to speed themselves along. Cars might talk with one another to drive cooperatively, therefore avoid collisions and improve efficiency.

1.1 Motivation

Broadcast messages will play a larger role than the use of unicast messages in a VANET. A large portion of the messages sent in a vehicular network will be broadcast messages. Some of the uses for broadcast messages are: sending emergency warning messages, periodically broadcasting a vehicles state, etc. The lower layer technology used in VANETs will be a variant of IEEE 802.11a technology [2]. However, the 802.11 technology is known for not being able to manage the medium resources very efficiently, especially in case of broadcast messages. Providing reliable delivery of broadcast messages in a VANET introduces several key technical challenges:

- *No retransmission is possible for failed broadcast transmissions since they cannot be detected.* A failed unicast transmission is usually detected through the acknowledgement (ACK) from the receiver. However, it is not practical to receive an ACK from each node for a broadcast message. If acknowledgments were used a problem known as the "ACK explosion problem" would exist, where each receiving node would at almost the same instance send an ACK back to the transmitter in turn causing a large number of collisions.

- *The contention window size, CW, cannot change because there is no MAC-level recovery on broadcast frames.* In order to control congestion, the contention window size (CW) is exponentially increased each time a failed transmission is detected. Since there is no detection of failed broadcast transmissions, the size of the CW fails to change for broadcast traffic as it does for unicast traffic. This may result in excessive collisions, if a large number of nodes are contending for access.
- *The hidden terminal problem exists because the RTS/CTS exchange cannot be used.* The hidden terminal problem [1] is the main cause of collisions in a wireless network. The IEEE 802.11 protocols use an optional RTS/CTS handshake followed by an acknowledgment to guarantee the delivery of a unicast packet. Broadcast messages, on the other hand, cannot use the RTS/CTS exchange because it would flood the network with traffic.
- *The vehicular network should support the ability to prioritize messages.* When emergency warning messages are broadcast, they should be given a higher access priority than regular data messages.

1.2 Contributions

The goal of this paper is to develop an adaptive broadcast protocol that improves the reliability of delivering broadcast messages in a VANET. *We rely on the observation that a node in a VANET is able to detect collisions and congestion by simply analyzing the sequence numbers of packets it has recently received. In a VANET, each node will broadcast its status to its neighbors at least 10 times every second. While a node does not know if the packets it sent are correctly delivered or not, it knows the exact percentage of packets sent to him from neighboring nodes are successfully received.* Based on the percentage of packets that are successfully received in the last few seconds, a node is able to determine the current local conditions of the network and roughly estimate the number of neighbors in its communication range. Therefore, a node is able to dynamically adjust the parameters it uses, such as contention window size, transmission rate, and transmission power, to improve the delivery rate of broadcast messages.

The novelty of this approach is that no communication control overhead is involved. In addition, the proposed technique doe not require changing the existing 802.11 standard instead it focuses on optimizing the parameters used by 802.11. For that reason, we believe that this approach will have very good chances to be commercially deployed.

The remainder of this paper is organized as follows. In Section 2, we present some related work. We discuss the classification of broadcast messages and prioritized access protocols in Section 3. Section 4 describes the adaptive adjustment of contention window protocols. Performance evaluation is presented in Section 5. Section 6 provides our conclusions and some further research directions.

2. RELATED WORK

A number of authors have addressed the problem of sending broadcast messages in MANETs and VANETs. Torrent-Moreno, Jiang, and Hartenstein show that the probability of reception of a broadcast message decreases as the distance from the sender increases and under saturation conditions the probability of reception messages can be as low as 20% at distances of 100 meters to the sender and even lower for larger distance [10]. The primary reason that the reception rate decreases is because of the hidden terminal problem. They implement a priority access mechanism which improves the reception rate of broadcast messages, but still fails to achieve reliability anywhere near 100%. In all likelihood, it may be unrealistic to expect every node in an 802.11 based network to successfully receive a broadcast because of the hidden terminal problem.

Xu et al [13] propose a single-hop broadcast protocol that increases the probability of a message's reception by sending the message multiple times. The problem with this scheme is it will not scale well when used for multi-hop relaying. Yang et al [5] propose the VCWC protocol to transmit emergency warning messages (EWM), which is based on a state machine and a multiplicative rate decrease algorithm. When an accident first occurs, the vehicle starts transmitting EMWs at the maximum rate and over time decreases the rate at which EMWs are sent.

Both [13] and [5] aim at increasing the probability of reception by broadcasting a message multiple times, which increases the load on the network. Other solutions aim at assigning time slots to nodes for them to transmit during, these solution are likely inapplicable to VANETs because it requires the synchronization of nodes which is hard to achieve because of the high mobility of nodes. Also, many of the algorithms that need to maintain sets or clusters may not perform well in VANETs because of the high mobility and the large amount of overhead that is necessary to maintain the sets.

3. PRIORITIZED ACCESS

The emphasis of a VANET is to support safety related applications. The DSRC standard will provide one Control Channel and six service channels [2]. The Control Channel will be used primarily for the exchange of public safety related information and service announcement. Since a number of different types of traffic are present on the Control Channel, the packets should be prioritized based on their class of traffic. We classify broadcast messages in the control channel as follows:

TABLE 1: Traffic Classes

Traffic Class	Message Type
0	Emergency Warning Message (EWM)
1	Emergency Vehicle Approaching Warning Message (EVAWM)
2	Periodic Broadcast Message (PBM)
3	Service Advertisement Message (SAM)

Collision warning in a VANET is achieved by either an active or passive approach. First, the active approach is event driven and messages are only exchanged when an emergency event occurs. When an abnormal event occurs, Emergency Warning Messages (EWM) are transmitted to warn surrounding vehicles of the condition. For instance, EMWs are transmitted if a vehicle decelerates abruptly and a threshold is reached. EWMs are the highest priority class in the VANET. Second, Emergency Vehicle Approaching Warning Messages (EVAWM) could be issued by emergency vehicles such as fire trucks, ambulance, or police cars, when responding emergency. Third, each vehicle periodical broadcasts its state (e.g. location, speed, and acceleration), in the form of PBMs, to its neighbors so that vehicles will be able to avoid emergency or unsafe situations even before they appear. Fourth, a service advertisement message is a periodic broadcast message that announces the availability of a value-added service to the vehicles. If a vehicle finds a service of interest it switches to one of the service channels to use the service.

In 802.11, a vehicle wanting to access the channel has to wait for the channel to be idle for an “interframe space” (IFS) duration. After that, a backoff procedure is invoked and a backoff counter is randomly chosen from the range of [0, CW), where CW represents the contention window size. This backoff counter corresponds to the number of idle slots the sender has to wait before accessing the channel. Collisions are avoided by nodes selecting different values for their *backoff timers*.

Prioritized access is achieved by a *priority scheme* similar to the one proposed in IEEE 802.11e [3]. Different levels of channel access priorities are provided through different choices of IFS and contention window size. In particular, messages with higher priority can enjoy the channel access privilege over lower priority messages by using a smaller IFS and a smaller contention window. A scheme similar to the Sliding Contention Window (SCW) [4] is used to dynamically adjust the CW. Each traffic class TC[i] has a $CW[i]_{min}$ and $CW[i]_{max}$ which are the minimum and maximum possible values of the contention window for a traffic class. For example, TC[0] could have the parameters $CW[0]_{min} = 8$ and $CW[0]_{max} = 127$, while

TC[3] could have the parameters $CW[3]_{min} = 64$ and $CW[3]_{max} = 1023$. SF[i] is the scaling factor for the traffic class, which determines how much the window are slid up or slid down. SCW[*i*] is the size of the contention window for a specific traffic class. Nafaa, Ksentini, and Mehaoua suggest setting the size of the contention window SCW[i] = 2 * SF[i]. The CW[i] will also contain a $CW[i]_{LB}$ and $CW[i]_{UB}$ which are the lower bound and upper bounds of the window at any instance time. The backoff that a node uses for transmission is randomly selected in the range of $CW[i]_{LB}$ and $CW[i]_{UB}$.

$$\text{Backoff} = \text{random}() \,\%\, (CW[i]_{UB} - CW[i]_{LB} + 1) + CW[i]_{LB}$$

Through message differentiation, not only higher priority messages can access channel faster than lower priority messages, but also collision between higher and lower priority messages are avoided to a large extent.

4. ADAPTIVE ADJUSTMENT OF CONTENTION WINDOW

As a result of using differential IFS, collisions are more likely between flows of the same traffic class. If the number of contending flows of equal priority is substantial, then the chance of a collision occurring is increased. On a crowded highway the number of vehicles contending to access the wireless medium can be high. For instance, in a gridlocked 4 lane highway with vehicles placed 15m apart, approximately 300 or more cars would be attempting to transmit a PBM (e.g., 600m diameter / (15m between vehicles * 4 lanes * 2 directions) 320 vehicles). Because a large number of nodes in a jam-packed highway are contending for access to the medium, it is also necessary to vary the size of the contention window to reduce the likelihood of a collision. Vehicles could also benefit from the opposing situation where the contention window is decreased to account for light traffic.

The probability of collisions can be reduced and probability of reception can be improved if the size of the CW used to send broadcast messages is able to adapt based on the network conditions. Choosing the correct size of the CW can be difficult. If the number of contending nodes is large and the CW is small, excessive collisions will occur. On the other hand, if the number of contending nodes is small and the CW is large, then unnecessary idle periods will occur and thus result in unnecessary delay. Increasing the size of the CW decreases the probability of a collision but at the same time increases the delay. For these reasons it is crucial that the algorithm chooses the values of the CW effectively.

In 802.11, the contention window size, CW, has a minimum value CW_{min} and is exponentially increased by a factor of 2 each time a packet collision occurs, until it reaches the maximum value, denoted as CW_{max}. Unicast transmissions in a VANET are able to adjust the contention window size to adapt to the changing conditions of the network, but this is not the case for broadcast transmissions. Because broadcast transmissions suffer from the problem known as the "ACK explosion problem", it is not possible to determine if a frame is successfully received or not.

Some form of feedback is needed to improve the reliability of broadcast transmissions. If a node is able to observe its local conditions of the network, it will be able to modify the MAC level parameters to improve the probability that a frame is successfully received.

While it is not possible to detect the collisions of frames, it is possible to record the successful delivery of frames. In a VANET each node will periodically broadcast status packets to its neighbors every 100ms. By simply analyzing the packets it has received recently, a node is able to detect collisions and congestion, and thus determine the network conditions. For example, a node will be able to calculate the exact percentage of packets sent to him from neighboring nodes that are successfully received and roughly estimate the number of neighbors in its communication range at present.

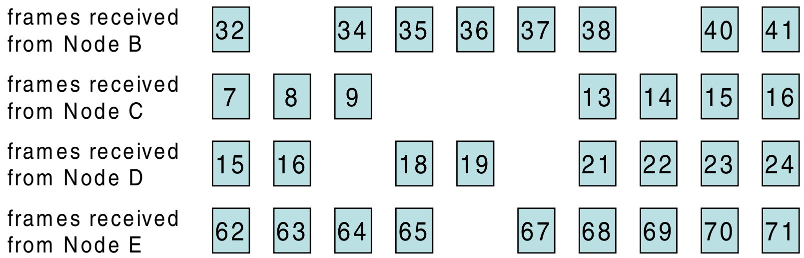

Fig. 1 Frames that node A received in the last second

In our modified implementation of 802.11, when a node sends a packet, a sequence number is assigned. The sequence number is incremented by 1 each time a node sends a frame. Each node then records the overheard sequence numbers coming from a specific node. As shown in Fig.1, node A records that it has overheard the frames coming from node B with the sequence numbers 32, 34, 35, 36, 37, 38, 40, 41. Based on the observed sequence numbers node A could conclude that frame 33 and frame 39 were corrupted or lost. Similarly, node A could conclude that three frames from node C, two frames from node D, and 1 frame from node E were corrupted or lost in the last second. Therefore, the percentage of packets sent to him from neighboring nodes that were corrupted in the last second is 20% (8 out of 40), and four nodes are currently in its communication range.

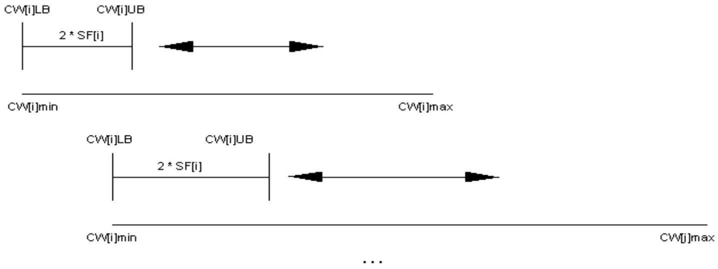

Fig. 2 Sliding Contention Window

The collision rate can be used as an indication of contention in a distributed network. The number of collisions experienced and the number of nodes contending to access the medium determine if the current value of the contention window needs to be maintained. If a large number of collisions have occurred, SF[i] should be used to slide SCW[i] towards $CW[i]_{max,}$ as shown in Fig. 2. On the other hand, if the number of collisions detected is below a threshold then SCW[i] is slid toward $CW[i]_{min}$.

3.1 Moving Average of Collision Rate

In order to adjust to the dynamic conditions of the network each node in the network monitors the network traffic. Each node has a hash table, which it uses to record the overheard broadcast messages coming from the neighboring nodes. For each overheard message, a node will update the table entry for the specific source address. A dynamic hash table is used so that an entry is updated in near constant time. The MAC address is used as the key to the hash function. The entries maintained in the hash table are given in Table 2.

TABLE 2: Broadcast Table

MAC Address	Sequence Number	Average Reception Rate	Timestamp

The sequence number is the decisive factor in determining the reception rate. To determine the reception rate the difference between the sequence numbers is examined. If for instance, the last heard sequence number was 132 and the node just received sequence number 135 the difference between the sequence numbers is three, so it would indicate that two messages were lost.

A weighted moving average is used to calculate the average reception rate. In a highly dynamic network such as a VANET, the emphasis should be placed on the most recent conditions of the network. To calculate the weighted average, we use an approach similar to the TCP round trip time estimation [].

$$\text{EstReceptionRate} = \alpha * \text{EstReceptionRate} + (1 - \alpha) * \text{SampledReceptionRate}$$

The sampled reception rate will contain the value of a 1 or 0. If the gap between the sequence numbers is larger than 1, the average reception rate is calculated multiple times. For example, if the difference in sequence is three the average would be calculate twice using a value of zero for the sampled reception rate and then a final time using one for the sampled reception rate. The value of α controls how quickly the average reacts to changing conditions. For instance, if $\alpha = 0.85$ and the previously recorded average reception rate = 0.91 and there is a gap of two between the sequence numbers the new average reception rate = 0.807475.

Periodically (e.g. every 0.5 second), a node will scan through the table it maintains to determine the local conditions of the network. Based on the information collected in the table, the node can adjust theparameters it uses for transmission. A node uses the local reception rate to predict the network condition. The local reception rate is the average of the estimated reception rates.

$$\text{LocalReceptionRate} = \sum \text{EstRecptionRate} / \text{NumberofNodes}$$

Once a node has determined the local reception rate it compares the value against the previous stored local reception rate to adjust the CW that the node uses.

```
IF (average – previous average >= sliding threshold)
    Slide the window down
ELSE IF (-(average – previous average) >= sliding threshold)
    Slide the window up
ELSE
    Maintain the current window
```

Each table entry has a timestamp associated with it. In order to prevent stale data from affecting the calculation of the local network conditions entries are removed from the table when calculating the local reception rate. If a broadcast has not been received from a node within the timeout threshold, the entry is removed from the table under the assumption that the node is no longer within the transmission range. The timeout threshold should be carefully selected so that nodes that are still within the transmission range but are suffering from a high collision rate are not prematurely invalidated from the table. On the other hand, the timeout value should be short enough so that old data is not maintained in the table.

5. PERFORMANCE EVALUATION

To simulate the proposed broadcast control protocols and compare its performance with existing algorithms, we use the ns-2 network simulator [8, 9]. We use quantitative metric, packet collision rate to evaluate performance of the proposed message broadcast algorithms. In this section, we present the mobility model, the traffic model, and the performance evaluation results.

5.1 Mobility Model

The majority of mobile ad hoc simulations use the random waypoint mobility model. In this model each node in the network randomly chooses a location and a speed to travel at. The node then moves toward its destination and periodically the node will pause and chose another destination to travel towards. The use of the random waypoint model is inappropriate for modeling a VANET, since a vehicles movement is constrained by the road. For this reason, an alternative is used to model the mobility of a VANET.

The mobility model used in the simulations is Freeway Mobility Model, which uses the USC Mobility Generator [11] to create the mobility of the mobile nodes. The simulations model a 3000m stretch of freeway, with a total of four lanes, consisting of two lanes for each direction. Each vehicle's velocity is in the range of 15m/s to 25m/s. We set the acceleration of the vehicles to of the 10% the maximum velocity.

The difference between the freeway model and the random waypoint are as follows:

- Each node in the simulation is restricted to only travel within its lane.
- The velocity of each node is temporally restricted based on the nodes previous velocity.
- A safety distance is maintained so that a node cannot exceed the velocity of the node in front of it if they are within the safety distance.

In order to determine how well the proposed algorithm performs under various conditions, eight different mobility scenarios were generated. In each scenario increased the number of vehicles that are contained in the network by a multiple of 50 vehicles. The number of vehicles in the network ranged from 50 nodes representing a light traffic to 400 nodes representing moderate highway traffic. The duration of the simulations was 300 seconds.

5.2 Traffic Model

Two set of simulations were used to determine the significance of the new algorithm. The first set of simulations use the 802.11e extension to ns-2 [12] developed by Wiethölter and Hoene. The second set of simulations use the modified CW adjustment algorithm.

Broadcast messages are the predominate form of traffic on the control channel of DSRC. The simulations model the control channel by using three traffic classes for the broadcast traffic. Three classes were used to determine the effect that the adaptive adjustment of the CW has on the different classes of traffic versus the inter-frame spacing. Table 3 contains the parameters for the baseline set of simulations. One observation that can be made from the table is that there is no MAC-level recovery of broadcast frames; the CW will always be selected in the range of 0 to CW_{min}.

TABLE 3: 802.11e Parameters

TC	AIFS[i]	$CW[i]_{min}$	$CW[i]_{max}$
TC0	DIFS	7	15
TC1	DIFS	15	31
TC2	DIFS + 1 Slot	31	1023

The second set of simulations use the modified sliding window algorithm which is controlled by observing the network conditions. Most of the proposed algorithms in literature that dynamically adjust the CW do so only for unicast flows. In the case of the control channel of DSRC, a majority of the traffic is broadcast in nature. Since it is not possible to determine the success of an individual flow, the sliding window algorithm is modified so that when the CW is adjusted, it does so simultaneously for all of the traffic classes' windows. For example, when the threshold is reached and the window must be slid up, all off the classes windows are increased by the scaling factor, SF[i], until the $CW[i]_{max}$ is reached or in the case of sliding the windows down until $CW[i]_{min}$ is reached. The parameters used for the sliding contention window algorithm are contained in table 4.

TABLE 4: Sliding Window Parameters

TC	AIFS[i]	CW[i]min	CW[i]max	SF[i]	SCW[i]
0	DIFS	0	20	2	4
1	DIFS	8	72	4	8
2	DIFS + 1 Slot	16	272	32	64

The broadcast traffic for the simulation was generated by a program written in C++ which functions similarly to the cbrgen program provided by ns-2. First, the largest percentage of traffic in the network consists of TC[2]'s periodic broadcast messages (PBM), which roughly account for 95% of the traffic. Such a large percentage of the traffic was generated of this type because in VANET, the largest percentage of traffic is this type. Every 0.1s each vehicle will send a PBM, if it is not sending one of the other classes of traffic. The start time is varied slightly for each transmission period, so that two nodes do not randomly select the same start time and continue to send messages that collide. Next, TC[1] models the EVAWM traffic; in this case nodes are randomly selected to generate a higher priority of traffic for a short duration. Finally, the highest priority traffic TC[0] is used to send EWM that are used in situations such as warning other vehicles of dangerous road conditions. When an EWM is randomly selected to occur, the vehicle transmits messages every 0.1s for 2.5s

5.3 Results

Two sets of simulations were run to compare performance of the broadcast methods. The first set of simulations examined the effect a small CW has on the collision rate of the network. The second set of simulations examines what improvement can be made in the collision rate by dynamically varying the CW.

The initial set of simulations compared the performance of the 802.11e protocol for broadcast traffic. Fig. 3 shows a comparison of the collision rates for different classes of traffic. One surprising finding is that TC[2]'s collision rate reached over 70% for the simulation containing 400 vehicles. On the other hand, the percent of TC[0] and TC[1] packets that collided were approximately half of TC[2] and they remained roughly equal throughout the simulations. One of the reasons for the poor performance of TC[2] is no attempt is made to adjust the rate that packets are sent based on the network condition. The large improvement in the collision rate of the high priority traffic is attributed to the fact that the IFS of these classes is one time slot shorter for TC[0] and TC[1].

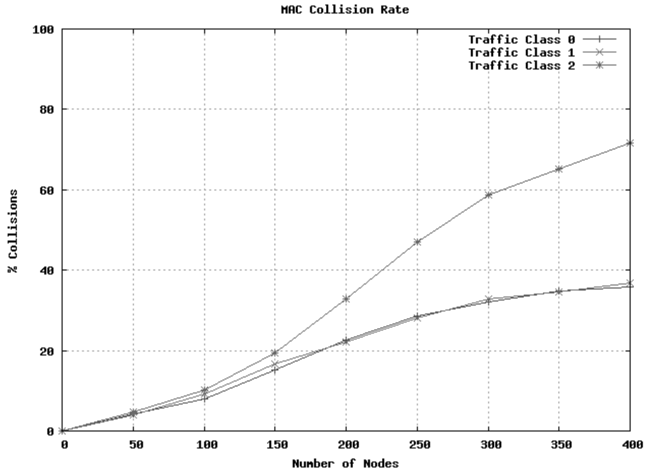

Fig. 3 802.11e Packet Collision Rate

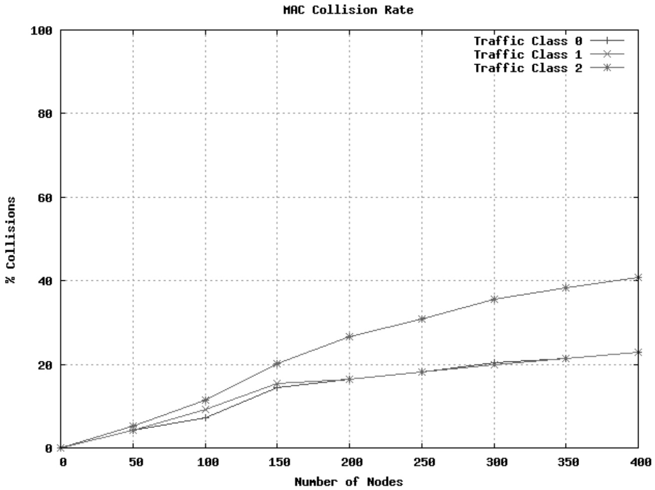

Fig. 4 Modified 802.11e Packet Collision Rate

The next set of simulations examines the effect that vary the size of the CW has on the probability that a message is received. One can see in Fig. 4, by adaptively adjusting the size of the CW, the collision rate is greatly reduced. In the cause of our modified 802.11e broadcast algorithm, the collision for the most densely populated network is considerably reduced from 71.7% to 40.8%. The collision rate also decreased significantly for the high priority traffic classes, reducing from 34.6% to 21.2%.

There was a slight increase in the end-to-end delay for the modified algorithm that adjusts the CW, as could be expected. One of the reasons why the original 802.11e protocol has shorter end-to-end delay is the size of the CW is never adjusted and nodes transmit promptly without regard for the collision rate. The largest possible backoff that is selected in the 802.11e simulation is by TC[2] with the a maximum value of 31 slots. On the other hand, our improved algorithm greatly increases the reliability of the broadcast traffic but at slight expense of an increase end-to-end delay.

6. CONCLUSIONS AND FUTURE WORK

By adaptively adjusting the contention window size, the improved 802.11e protocol reduces the probability of a collision of broadcast traffic by over 50%. The presented solution consumes no additional network resource and little additional complexity for the mobile nodes. Based on the experiment results, the dynamic CW adjustment algorithm shows tremendous promise. Our future work will focus on adaptive control of transmission rate and transmission power based on the network conditions.

6.1 Adaptive Transmission Rate Control

Due to the hidden terminal problem and other interference, it is unrealistic to achieve 100% delivery rate without retransmission in a wireless network. Safety messages typically need to be repeatedly transmitted at a certain rate to ensure reliable delivery. For example, in the event of emergency, the Emergency Warning Messages are repeatedly broadcasted every 100 ms. Similarly, a vehicle broadcasts its state information every 100 ms. Broadcasting a message multiple times increases the probability of reception, but also increases the load on the network.

If the network is highly loaded, increasing the contention window alone will not be effective and may result in very high delivery latency. In this case, a node will have to decrease its transmission rate. The authors of [5] propose the VCWC protocol to transmit emergency warning messages, which is only based on application-specific properties to help controlling channel congestion. When an accident first occurs, the vehicle starts transmitting emergency warning messages at the maximum rate and over time decreases the rate. This approach focuses only on the delivery of emergency messages, while ignoring other public safety and private messages. We will utilize the aforementioned channel feedback, packet collision rate and number of nodes within transmission range, to effectively adjust the transmission rates for all traffic classes. For example, when the packet loss rate is bigger than some threshold, we then first minimize the transmission rate of all traffic classes. If this is not enough, we will further drop all non-safety related messages and reduce the transmission rate of low priority safety messages, and so on.

6.2 **Dynamic Transmission Power Control**

Controlling the communication range by adjusting the transmission power can be used to mitigate the adverse effects of high density network condition. The choice of the communication range has a direct impact on a fundamental property of an ad-hoc network, the connectivity. In a VANET, a static transmission range cannot maintain the network's connectivity due to the non-homogeneous conditions. It is shown in [6, 7] that a dynamic transmission range is needed to maintain connectivity in non-homogeneous networks to take advantage of power saving and increased capacity.

In [6], a dynamic transmission range based on estimation of vehicle density is proposed. Their approach assumes that each vehicle has a wireless device. However, this is very implausible. The Vehicle Safety Communication technology will likely be initially deployed on a small percentage of vehicles. Moreover, the deployment is also likely to be unbalanced. It is very possible that some areas may have a much higher deployment rate than others. With the same high vehicle density, it is possible that the VANET is highly congested in one area and mostly idle in another area. In the later case, if we mistakenly reduce the transmission power, the VANET might not be able to maintain basic connectivity. Thus, we propose to dynamically adjust transmission power based on the actual network condition instead of vehicle density.

We will adjust the transmission range of all nodes using power control in order to keep the load in the medium below a certain threshold. By adjusting the transmission range once the packet generation rate is fixed to the minimum requirement of the safety applications, the load on the channel can be reduced while at the same time high accurate information of neighboring vehicles is still available.

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