Congestion Control in Wireless Networks for Vehicular Safety Applications

Yunpeng Zang, Lothar Stibor, Xi Cheng, Hans-Jürgen Reumerman, Arthur Paruzel and Andre Barroso

Abstract—**The Wireless Access in Vehicular Environments (WAVE) system is developed for enhancing the driving safety and comfort of automotive users. However, owing to the nature of contention based channel access scheme, the WAVE system suffers from Quality of Service (QoS) degradation for safety applications caused by the channel congestion in scenarios with high vehicle. In this paper we study the performance of the Emergency Electronic Brake Light with Forwarding (EEBL-F) application as an example of the safety application in congested scenarios, and propose a congestion control architecture for Vehicular Ad-Hoc Networks (VANET). Concentrated on Medium Access Control (MAC) layer, two concrete congestion control approaches through manipulating MAC transmission queues are introduced. The effectiveness of the proposed congestion control approaches is evaluated through stochastic simulations. Besides, the impact of adaptive transmit power level on congestion control in VANET is also discussed with simulation results.**

Index Terms—**Congestion Control, Contention Window, Quality of Service (QoS), Transmit Power Control (TPC), Vehicular Ad-hoc Networks (VANET), Vehicular Mesh Networks (VMESH).**

I. Introduction

Motivated by reducing the number of vehicle accidents and enhancing the efficiency of the transportation system, the Federal Communications Commission (FCC) of the U.S. approved 75MHz bandwidth at 5.850-5.925GHz band, in year 1999, for Intelligent Transportation System (ITS) wireless communications among vehicles and between vehicles and roadside infrastructures. The frequency channel layout is depicted in Figure 1. One of the seven frequency channels is nominated as the Control Channel (CCH), i.e. CH 178, which can only be used by high priority safety applications and for system management purposes. The other six channels are used as Service Channels (SCHs), mainly for the support of non-safety related applications.

As the primary services of Intelligent Transportation System (ITS), safety oriented applications, safety applications in short, such as cooperative lane change warning and Emergency Electronic Brake Light (EEBL), demand highly reliable inter-vehicle and vehicle-to-roadside communications with very low latency [1]. The Wireless Access in Vehicular Environments (WAVE) system is developed to support such applications on the 5.9GHz ITS frequency band. The WAVE system is based on the IEEE 802.11 Wireless Local Area Networks (WLAN) technology, which is able to provide short to middle range wireless communications among vehicles and between vehicle and roadside with low latency.

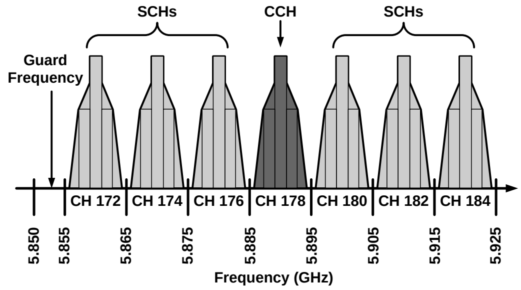

Figure 1. Frequency channel layout of 5.9GHz WAVE system

However, it has been observed that in the WAVE system the performance of the broadcast based safety applications running on CCH drops down seriously in dense scenarios, e.g., a traffic jam with high market penetration rate of WAVE devices. [2] The main reason of the problem is the so called channel congestion, which is caused by the heavy traffic load on CCH.

Within the context of the WILLWARN (Wireless Local Danger Warning) application of the European Research project PREVENT [10], we study the congestion problem in the current WAVE system and propose a cross-layer architecture for congestion control in Vehicular Ad-Hoc Networks (VANET) in favor of safety applications. Particularly, within the proposed architecture we introduce two congestion control approaches based on Medium Access Control (MAC) transmission queue manipulation to solve the congestion problem in the WAVE system.

The rest part of the paper is organized as follows: In section II, the WAVE system is shortly reviewed. Section III states the congestion problem in the current WAVE system using the EEBL with Forwarding (EEBL-F) as an example of safety application. Related previous work on congestion control in VANET is discussed in section IV, which is followed by our proposal of the congestion control architecture in section V. Congestion detection and congestion control approaches developed in this work are presented in the subsections V.B and V.C., respectively. The performance evaluation of the proposed congestion control approaches are given in section VI with simulation results. The impact of transmit power control on congestion control is discussed with simulation results in section VI. Section VII concludes the paper with outlooks on the future work. Throughout this paper all units and abbreviations are defined according to [3].

Y. Zang, L. Stibor and X. Cheng are with the Chair of Communication Networks, RWTH Aachen University, 52074 Aachen, Germany (Phone: +49-241-80-25-829; fax: +49-241-80-22-242; e-mail: {zyp|lsr|bcx}@comnets.rwth-aachen.de).

H.-J. Reumerman, A. Paruzel, and A, Barroso are with Philips Research Aachen, 52066 Aachen, Germany (e-mail: {arthur.paruzel|andre.barroso|hans-j.remerman}@philips.com).

II. WIRELESS ACCESS IN VEHICULAR ENVIRONMENTS (WAVE)

The work presented in this paper is based on the WAVE system. As shown in Figure 2, the protocol stack of WAVE consists of IEEE P1609 standard family, which specifies the upper layers of the system, and IEEE 802.11p describing the basic MAC and Physical layers (PHY).

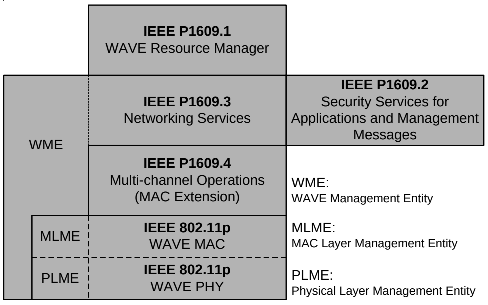

Figure 2. Protocol stack of WAVE system

The IEEE 802.11p PHY is a variant of the IEEE 802.11a PHY, which is based on the OFDM technology. With increased transmit power level, the IEEE 802.11p PHY is able to provide communications within a distance from 100m to 1km in vehicular environments.[1]

The basic MAC and MAC extension layers of WAVE are standardized in IEEE 802.11p and IEEE P1609.4, respectively. The basic MAC is the same as IEEE 802.11 Distributed Coordination Function (DCF), which is based on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) scheme, and the MAC extension layer adopts concepts from Enhanced Distributed Channel Access (EDCA) of IEEE 802.11e, like virtual station, Access Category (AC) and Arbitrary Inter-Frame Space (AIFS), in order to support traffic prioritization.

As shown in Figure 1, WAVE is a multi-channel system with one CCH and multiple SCHs. In order to coordinate the access to CCH and SCHs, IEEE P1609.4 [4] specifies a globally synchronized channel coordination scheme based on the Coordinated Universal Time (UTC)[2]. As show in Figure 3, the channel time is divided into synchronization intervals with a fixed length of 100ms. Every synchronization interval consists of a CCH interval and a SCH interval, 50ms of each. According to the scheme all devices[3] have to tune into CCH during CCH intervals, where high priority frames, e.g. safety messages, are transmitted. During SCH intervals, devices can optionally switch to SCHs for non-safety applications. This scheme allows WAVE devices to perform non-safety applications on SCHs without missing important information on CCH. In this work, we focus on the congestion problem on CCH for safety applications.

[1] The maximum communication distance can only be reached with the highest transmit power and the most robust PHY mode, i.e. BPSK1/2, corresponding to the lowest data rate.

[2] Synchronization to UTC is assumed to be achievable through the time synchronization function of Global Positioning System (GPS).

[3] In this paper the term Vehicle and the term Device are exchangeable, as we assume in our study each vehicle has only one WAVE device equipped.

III. CONGESTION PROBLEMS IN WAVE

The Emergency Electronic Brake Light with Forwarding (EEBL-F), also known as the Cooperative Collision Avoidance studied in [5], is chosen as one example of the safety applications, whose QoS should be guaranteed against channel congestion.

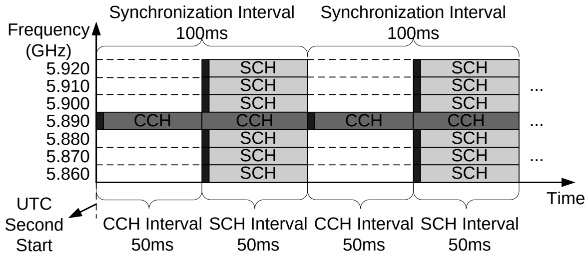

Figure 3. Multi-channel cooperation in WAVE with one CCH and multiple SCH frequency channels using synchronized CCH/SCH intervals

EEBL-F is introduced to avoid or mitigate the chain collision accidents that usually happen on the highway. If drivers approaching to an accident spot start to brake only after they see the rear brake lights in front, then there will be a high probability of having the chain collisions. The EEBL-F messages originated at the accident vehicle and forwarded in the Zone of Relevance (ZoR)[4] can extend the horizon of the endangered drivers and warn them as early as possible, as shown in Figure 4.

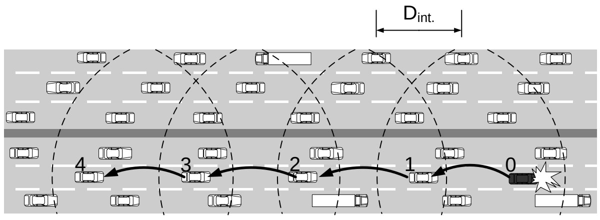

Figure 4. Highway scenario

In addition to the event-driven safety applications like EEBL-F, there are other traffics referred to as the background traffic in this study also transmitted on CCH. Usually, the background traffic on CCH consists of beacons or hello messages, which are periodically broadcast by each device for getting the neighborhood information, and the so called WAVE Service Advertisement (WSA) messages for coordinating the non-safety services on SCHs. It's possible that CCH is congested due to the high background traffic load and the QoS of safety applications, i.e. EEBL-F in this study, is threatened.

The most concerned QoS metrics of EEBL-F application are the reliability and delay, which can be interpreted as the probability of an endangered vehicle being warned by EEBL-F message within a given delay limit. In this paper, we study the delay between the time the first EEBL-F message being sent out by the accident vehicle and the time the message being received for the first time at each concerned vehicle, and we call this delay time as "*warning delay*". As the accident vehicle will periodically generate the EEBL-F messages and each concerned vehicle will forward this message further down in the ZoR, the warning delay is closely related with the suc-

[4] "Zone of Relevance" is defined as the region behind the accident on the side of the highway where the accident happened. All vehicles approaching the position of the accident are part of the ZoR.

cessful reception ratio of the broadcast messages which is seriously affected by the channel congestion level. A scenario is setup to show this problem, as illustrated in Figure 4, where the bidirectional highway consists of six lanes, three for each direction. Vehicles with WAVE devices equipped are located on each lane with the interval distance (D_{int}) of 150m. The EEBL-F message is generated at vehicle 0 and forwarded by vehicle 1, 2, 3 and 4 consequently.

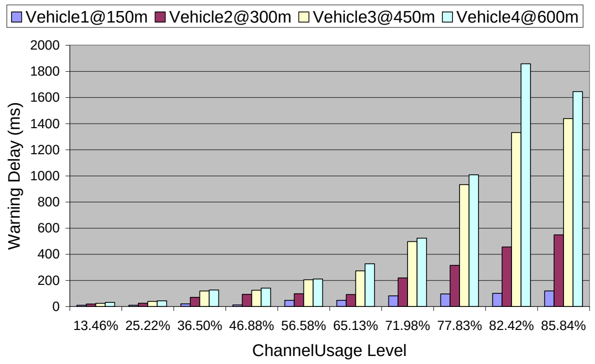

Figure 5. EEBL-F delay vs. channel usage level

Figure 5 shows the growing delay with respect to the increasing background traffic level, which is expressed as the *ChannelUsage* level, as introduced in section V.B. The results in Figure 5 are the average of 50 independent simulation runs. It can be seen that with low background traffic, i.e., when the channel usage is less that 46.88%, the warning delays at all vehicles are below 200µs. However, when the *ChannelUsage* is above 77.83%, the warning delays at the vehicles 3 and 4 increase dramatically. Besides, at the *ChannelUsage* of 82.42% only in 7 simulation runs out of total 50 runs vehicle 4 receives the EEBL-F within 5 second delay. It has to be mentioned, if the difference between warning delays at adjacent vehicles, which we call relative warning delay, is above 500ms, which is the minimum human reaction time, the EEBL-F warning system will be considered defunct, because in this case the optical brake light warning propagates faster than the EEBL-F message. However, it does happen in this example when the *ChannelUsage* is higher than 77.83%.

IV. Related work

There have been several works addressing the congestion problem in VANET. Torrent-Moreno et al. disclosed the relationship between the transmit power and channel load in VANET through an analytical model in [2]. The authors further proposed a power control approach, namely Fair Power Adjustment for Vehicular environments (FPAV), to achieve the fairness and avoid the channel congestion. However, as presented by the authors the implementation of the proposed approach requires tight synchronization among the nodes and a 'global knowledge' on the channel load, which are hard to get in current WAVE system. A utility-based congestion control approach is proposed in [6] for non-safety applications. The main idea is to dynamically assign the bandwidth according to the utility value of the message to be transmitted at each device. Since this approach needs the road to be segmented into sections for calculating the message utility metric, it can not be directly used in context of safety applications.

V. Mechanisms of Congestion Control For Vehicular Communications

In this section, we first propose an architecture for congestion control in VANET and then introduce two concrete congestion control approaches developed within this architecture.

We divide the congestion problems in VANET into two categories, namely uni-priority congestion and multi-priority congestion. As the name suggests, the uni-priority congestion is caused by the traffic of the same priority, typically the warning messages of safety applications from different transmitters. The main solution for this kind of congestion problem is the efficient message dissemination algorithms, as studied in [7] and [8].

In this work we concentrate on the second kind of congestion problem, i.e. multi-priority congestion, where applications of lower priorities, e.g. the back ground traffic in this study, may exhaust the channel resource and impact the QoS of the application with the highest priority, as shown in section III.

A. *Cross-layer congestion control architecture for VANET*

In order to solve these congestion problems, we propose an architecture, as illustrated in Figure 6. A congestion control management entity is introduced to the WAVE Management Entity (WME), which is responsible for detecting the congestion problem and performing the congestion control. Specifically, concrete congestion control approaches are designed at each layer of the communication protocol stack.

--Application layer: application based constrained message rebroadcast, as discussed in [5], can help in reducing the traffic load and congestion.

--Network layer: smart and efficient rebroadcast routing algorithms are helpful for mitigating the congestion problem by limiting the forwarded traffic.

--MAC layers: priority differentiation at MAC layer is the main approach to solve the congestion problem.

--Physical layer: channel sensing and measurement functions, e.g. the Channel Clear Assessment (CCA) from IEEE 802.11, can contribute to the congestion detection.

--Channel: dedicated channel design for different applications, as the CCH/SCH architecture in WAVE, facilitates the priority differentiation between safety and non-safety applications. However, CCH in WAVE is still used by applications of multiple priorities.

In this work we focus on the MAC layer, and present the congestion detection methods as well as two congestion control approaches.

B. *Congestion detection*

Two kinds of congestion detection methods are introduced in this work, namely event-driven detection and measurement-based detection.

1) Event-driven detection

The event-driven detection method monitors the safety applications and decides to start the congestion control whenever a high priority safety message is detected. For example, when a device detects an EEBL-F safety message either generated at its own application layer or received from another device, it will launch the congestion control immediately to guarantee the QoS of safety applications.

2) Measurement based congestion detection

With this method, each device periodically senses the channel usage level, and detects the congestion whenever the measured channel usage level exceeds the predefined threshold.

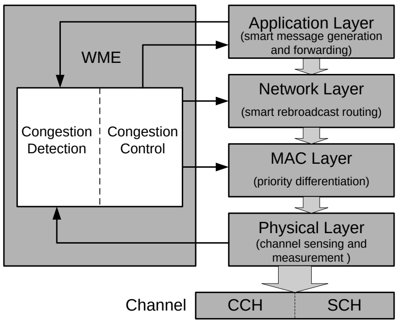

Figure 6. Cross-layer congestion control architecture

The packet transmission process at the WAVE MAC is shown in Figure 7. Besides the channel busy period indicated by the CCA module at PHY, the Arbitration Inter-Fame Space (AIFS) and backoff period are also “virtue busy”, since during this period there is already at least one packet pending for transmission.

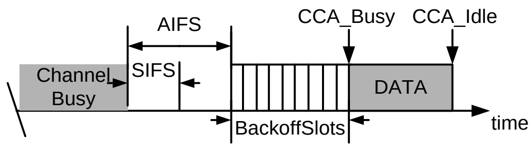

Figure 7. Data transmission process in WAVE

We propose a metric for estimating the channel usage level in favor of safety applications, i.e. EEBL-F in this case. The channel usage level *ChannelUsage* is calculated every CCH interval by the following equation:

$$ChannelUsage = \frac{\sum_{n}\left(D_{BUSY} + D_{AIFS} + \overline{D_{Backoff}}\right)}{D_{CCH}} \times 100\%$$

The numerator in the right side denotes the estimated overall channel busy time of n messages sensed by a device in one CCH interval. D_{BUSY} is the channel busy duration indicated by the CCA module for each message sensed; D_{AIFS} is the AIFS length of the EEBL-F message and $\overline{D_{Backoff}}$ is the mean backoff duration of EEBL-F message, which we take the value of $\frac{1}{2}\cdot CW_{\min}\cdot aSlotTime$ in our study. The $CW_{\min}$ is the minimum contention window size of EEBL-F application and *aSlotTime* is one backoff slot time, as listed in Table 2 and Table 1, respectively. The denominator D_{CCH} is the duration of one CCH interval, i.e. 50ms in the WAVE system. By comparing the calculated *ChannelUsage* with a predefined threshold $Threshold_{Congestion}$ at the end of each CCH interval, the device can detect the congestion if the $Threshold_{Congestion}$ is exceeded.

It has to be explained that the channel usage level in the real scenarios is too complicate to be analyzed because of the different traffic load, varying message size, overlapped backoff process, hidden station problem, etc. The metric *ChannelUsage* proposed here is just an intuitive and approximate estimation of channel busy level, which is related with the overall traffic load on the channel. The effectiveness of this estimation is proved by the simulation results shown in section VI.

C. Congestion control via MAC queue manipulation

The main idea is to provide the safety message absolute priority over other traffic via manipulating the MAC transmission queues of lower prioritized traffics, or to dynamically reserve a fraction of bandwidth for the highest priority traffic with adaptive QoS parameters.

The MAC layer queue architecture of the WAVE device is shown in Figure 8, where transmission queues are mapped to traffics with different priorities, i.e. Access Category (AC) in the figure. The channel access priorities are statically differentiated via the QoS parameters associated with each queue. According to the WAVE MAC scheme, shorter AIFS value and smaller contention window size can statistically provide higher channel access probability for the traffic assigned to them. The QoS parameters of different traffic priorities used in this study are listed in Table 2, where AC=3 corresponds to the highest priority, i.e. EEBL-F.

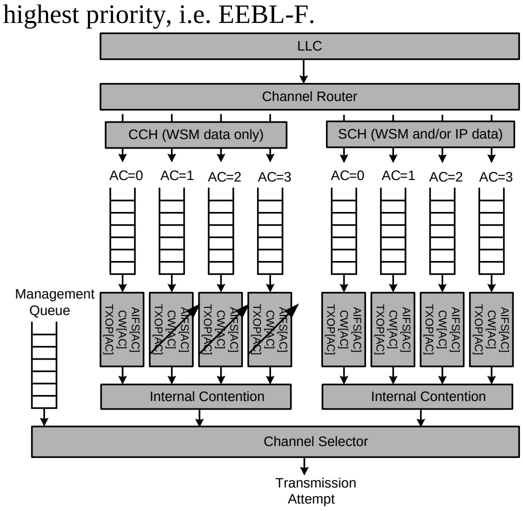

Figure 8. WAVE MAC queue architecture

Two MAC queue manipulation based congestion control approaches are introduced.

1) Queue freezing

Upon the detection of the safety message with the event-driven detection method, each device applies the brute force queue freezing for all MAC transmission queues except for the safety queue with the highest priority.

The algorithm can be expressed with pseudo code as:

```
/* Congestion Control with Queue freezing */
If ((A safety message is locally generated) or (A safety message
is received from another station)) {
    Freeze all MAC queues except for the safety queue;
}
```

In this way, the absolute channel access priority is granted to the EEBL application and the congestion caused by lower priority traffic can be avoided. This approach is trigged only when the EEBL-F message is detected and all background traffics are not allowed.

2) Adaptive QoS parameter

Different from the brute force queue freezing approach, the adaptive QoS parameter approach dynamically reserves fraction of bandwidth for safety applications, even no EEBL-F message is detected. The algorithm is described as:

```
/* Congestion Control with Adaptive QoS */
If (ChannelUsage>Threshold_Queuefreeze){
    Freeze all MAC queues except for the safety queue
}
Else {
     If (ChannelUsage>Threshold_Congestion){
        For (all AC != safety){
        /* for all non-safety queues */
            If (CW(AC)<CW_max(AC)){
                CW(AC) = CW(AC)*2; /* increase the contention
            window size till CW_max */
            }
        }
    Else if (ChannelUsage<Threshold_Sparse){
        For (all AC != safety){
        /*for all non-safety queues*/
            If (CW(AC)>CW_min(AC)){
                CW(AC) = CW(AC)/2; /* decrease the contention
            window size till CW_min*/
            }
        }
      }
    }
}
```

Each device measures the *ChannelUsage* of every CCH interval. We define 3 thresholds for the *ChannelUsage* value, $Threshold_{Queuefreeze}$ stands for 95% of the ChannelUsage, if this threshold has been exceeded, then the queue freezing approach introduced in the previous subsection will be triggered due to quite little bandwidth left for safety application; the $Threshold_{Congestion}$ (70%) and $Threshold_{sparse}$ (30%) are also defined to adjust the contention window size for all transmission queues except for the one for safety messages. When the measured *ChannelUsage* is above the predefined $Threshold_{Congestion}$ the device will double the contention window size *CW(AC)* for all transmission queues except the one for the safety queue till the maximum possible contention window size $CW_{max}(AC)$ is reached, in this way the transmission opportunities of these queues are reduced and the *ChannelUsage* will get lower. Oppositely, in case the measured channel usage is lower than a predefined $Threshold_{sparse}$, the *CW(AC)* of all low priority queues are halved, until the possible minimum contention window size $CW_{min}(AC)$ is reached.

D. Congestion control via dynamic transmit power control

As discussed in [2], the transmit power control of background traffics on CCH, which are usually periodical one-hop broadcast messages, can restrict the channel usage level and dynamically reserve a fraction of bandwidth for the safety application. The original idea from [2] is to control the transmit power of low priority messages and keep the transmit power of the highest priority traffic unchanged. However in the reality the “packet based” transmission power control is very hard to implement with a single radio transceiver. Therefore, in our study we adjust the transmit power for all packet types and study the impacts of transmit power control on the congestion problem in VANET.

VI. Simulative Performance Evaluation

Simulations are carried out with the Wireless Access Radio Protocol II (WARP2) simulation environment developed in the chair of communication networks, RWTH-Aachen University. The WAVE MAC and PHY protocols have been implemented in WARP2. All simulations are performed with the WAVE CCH/SCH multi-channel architecture, as specified in [4]. Our focus in this study is on the CCH during the CCH interval, as illustrated in Figure 3. In the simulations, all devices are assumed to be perfectly synchronized in order to perform the CCH/SCH switching. It has to be mentioned that the CCH interval takes only half of the overall channel time. Thus, the results shown here represent the performance of the half capability of IEEE 802.11p PHY.

A. Simulation setup

WAVE PHY parameters specified in [9], as given in Table 1, are used in our simulations. All results are derived with the PHY mode of BPSK½, which corresponds to the 3Mb/s PHY data rate of IEEE 802.11p. The error model developed in [11] is used for emulating the packet error performance of IEEE 802.11p PHY with inter-vehicle wireless channel.

TABLE 1
WAVE PHY RELATED PARAMETERS

Parameter	Value
OFDM symbol duration	8 µs
PLCL preamble length	32 µs
PLCP header length	8 µs
pSlotTime	16 µs
pSIFS	32 µs
pDIFS	64 µs

MAC layer QoS parameters for different access categories on CCH used in the simulations are given in Table 2. In our simulation EEBL-F application takes AC 3 and the background take AC 0.

TABLE 2
WAVE MAC QOS PARAMETERS ON CCH

AC	CW_{min}	CW_{max}	AIFS
1	15	1023	9
0	7	1023	6
2	3	1023	3
3	3	7	2

Two highway scenarios, corresponding to different vehicle densities, moving speed and WAVE device penetration rates, are set up. The simulated highway structure, as introduced in section III, consists of 3 lanes for each direction and vehicles on each lane with an interval of D_{int}, as show in Figure 4. The width of each lane and the width of the mid separator are 5m and 2m, respectively. Other parameters for the two scenarios are listed in Table 3.

The EEBL-F traffic is artificially triggered at Vehicle

0, which is always located at the right most position of the scenario, at the simulation time 5.0s to emulate the occurring of an accident. The packet size of the EEBL-F message is 100B and the packet is periodically generated with a frequency of 10Hz [1]. Since the background traffic on CCH consists of multiple independent periodical applications, e.g. beacons and WSA messages, we use one Poisson arrival process at each device to model the background traffic. The packet size of the background traffic is set to 200B, which is the same for all devices.

TABLE 3
SCENARIO SETUP PARAMETERS

Scenario	D_{int} (m)	Highway Length (m)	Vehicle speed (km/h)
Middle density	150	1000	130
High density	80, 60,40[5]	1000	160, 120, 80

The *Warning Delay*, as introduced in section III, is used as the metric to evaluate the reliability and delay performance of the EEBL-F application. As we know, the message forwarding algorithm has significant impact on the performance of safety applications, as discussed in [5]. Since in this work we focus on the QoS of EEBL-F in presence of background traffics, we adopt a rather simple rebroadcast algorithm, i.e., only vehicles on the same lane and located behind the accident vehicle will forward the EEBL-F message, and study the Warning Delay of the EEBL-F message at each concerned vehicle. Due to the forwarding algorithm, only the EEBL generator vehicle will rebroadcast EEBL in every CCH interval, all other intermediate vehicles will only forward an EEBL after their successful reception of this EEBL from front vehicles, otherwise the forwarding process will be broken in this lane.

B. Simulation results and discussion

Figure 9 shows the performance of EEBL-F in the middle density scenario without and with congestion control methods. The transmit power for EEBL-F and background traffic is 100mW. The background traffic is defined as number of packets transmitted by each vehicle per second, following a Poisson distribution. It can be seen that through manipulating the MAC queue, the congestion can be controlled and the warning delay of EEBL-F at each station is limited within 550ms. There is no relative warning delay exceeding 500ms when the congestion control methods applied. Furthermore, it can be observed that the adaptive QoS parameter method outperforms the brute force queue freezing method.

Figure 10 presents the *ChannelUsage* curves at vehicle 3 with respect to different background traffic loads in the same scenario before the EEBL-F applications is triggered, for the cases without and with adaptive QoS parameters approach. It can be seen that, with dynamic QoS parameters, there is always a fraction of channel resource reserved for EEBL-F applications even in the heavily loaded channel. This also explains the phenomena the dynamic QoS method outperforms the brute force queue freeing, since the queue freezing relies on the successful reception of the EEBL-F message, whose probability drops down when the *ChannelUsage* level is high.

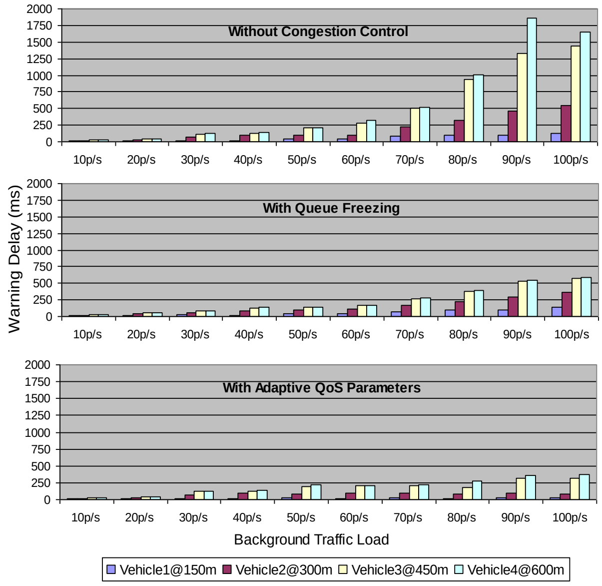

Figure 9. Congestion control in middle density scenario

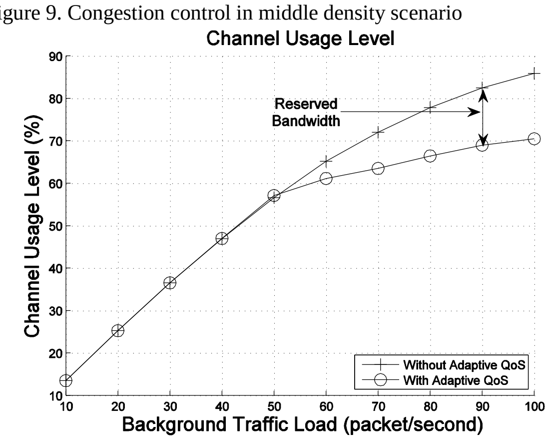

Figure 10. Channel usage level in middle density scenario

The impacts of the congestion control mechanisms on the performance of background traffics are shown in Figure 11. In the figure, the total numbers of the background packets being sent out at device 2 within 10 seconds simulation time are depicted together with the proportion of the packets being successfully received at its neighbor device 3. As expected, the queue freezing approach seriously impacts the performance of background traffic, as the queues are stopped after the detection of EEBL-F message. On the contrary, the adaptive QoS parameter approach keeps a good tradeoff between the QoS requirements of the safety application and the background traffic.

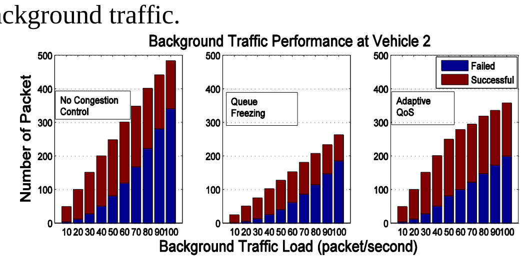

Figure 11. Background traffic performance at vehicle 2

Similar simulations have been carried out for the high density scenario. As show in Figure 12, the adaptive QoS parameter approach still outperforms the queue freezing

[5] The three values are for the left, middle and right lanes of each direction, respectively.

approach and keeps the QoS requirements of EEBL-F being fulfilled.

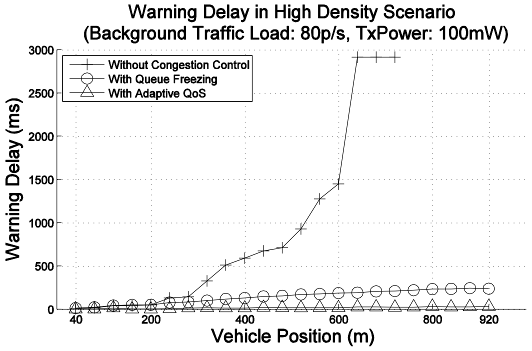

Figure 12. Warning delay in the high density scenario

An interesting observation from the simulation results is that with different transmit power levels, the degree of congestion problem in high density scenario is almost the same. When background traffic is high, e.g. 60p/s, the *Warning Delays* of 1000mw transmission power is almost the same with 50mw, as shown in Figure 13. The reason is as follows. When transmit power increases, as the same transmit power is applied to all devices in our simulations, more neighbor devices can be covered in the communication range which results in higher background traffic load and higher collision probability. On the other hand, higher density also introduces more forwarders of the EEBL-F messages, which can compensate the reliability degradation of each hop. When background traffic is low, e.g. 20p/s, the *Warning Delay* performance gets better with higher transmission power, e.g. 1000mw, because of the larger transmission range results in more receivers in each hop.

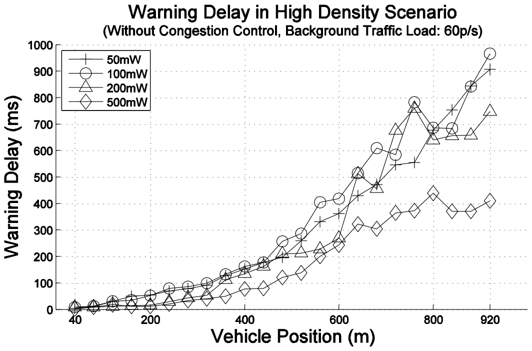

Figure 13. Warning delay with different transmit power level

VII. Conclusion

In this paper, we studied the congestion problem in VANET in favor of safety applications. We proposed an architecture for solving the congestion problem in VANET based on the WAVE system. Particularly, the dynamic QoS parameter approach proposed in our work has been proved to an efficient congestion control method for the safety application. As the next step of this work, we would like to integrate our proposal with the efficient message forwarding algorithms.

Acknowledgment

The authors would like to thank Prof. Dr.-Ing. B. Walke for his friendly advice to this work. The contributions from our colleague Hui Chen are highly appreciated.

References

[1] The CAMP Vehicle Safety Communications Consortium consisting of BMW, F.G.N.T. & VW., Vehicle Safety Communications Project Task 3 Final Report, "Identify Intelligent Vehicle Safety Applications Enabled by DSRC", U.S. Department of Transportation, National Highway Traffic Safety Administration, 2005

[2] Torrent-Moreno, M.; Santi, P. & Hartenstein, H. "Fair Sharing of Bandwidth in VANETs In Proceedings of the second ACM International Workshop on Vehicular Ad Hoc Networks (VANET)", 2005, 49-58

[3] *IEEE Transactions, Journals and Letters – Information for Authors*, IEEE Periodicals Transactions/Journals Department, auinfo03.pdf, IEEE, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA,

[4] IEEE P1609.4, Wireless Access in Vehicular Environments (WAVE) Multi-Channel Operation, Draft Standard, D06, Nov. 2005

[5] Biswas, S.; Tatchikou, R. & Dion, F. "Vehicle-to-vehicle wireless communication protocols for enhancing highway traffic safety", Communications Magazine, IEEE, 2006, 44, 74 – 82

[6] Wischhof, L. & Rohling, H. "Congestion control in vehicular ad hoc networks", Vehicular Electronics and Safety, 2005. IEEE International Conference on, 2005

[7] Yang, X.; Liu, L.; Vaidya, N.H.; Zhao, F., "A Vehicle-to-Vehicle Communication Protocol for Cooperative Collision Warning", Mobile and Ubiquitous Systems: Networking and Services, 2004. MOBIQUITOUS 2004. The First Annual International Conference on 22-26 Aug. 2004 Page(s):114 – 123

[8] H. Füßler, M. Mauve, H. Hartenstein, M. Käsemann, and D. Vollmer, "A Comparison of Routing Strategies for Vehicular Ad Hoc Networks", Department of Computer Science, University of Mannheim, Tech. Rep. TR-02-003, July 2002.

[9] IEEE 802.11 Working Group, "Draft Amendment to Standard for Information Technology – Telecommunications and information exchange between systems – Local and Metropolitan networks – specific requirements – Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Amendment: Wireless Access in Vehicular Environments", IEEE P802.11p Draft Standard, D1.2, Sept. 2006

[10] PREVENT: Preventive and active safety; 6th Framework program integrated project http://www.prevent-ip.org/

[11] Zang, Y.; Stibor, L.; Orfanos, G.; Guo, S. & Reumerman, H. "An Error Model for Inter-Vehicle Communications in Highway Scenarios at 5.9GHz", Proceedings of the Second ACM International Workshop on Performance Evaluation of Wireless Ad Hoc, Sensor, and Ubiquitous Networks, 2005, 49-56