Wireless Local Danger Warning Using Inter-Vehicle Communications in Highway Scenarios

Yunpeng Zang, *Member, IEEE,* Lothar Stibor, *Member, IEEE,* Hans-Jürgen Reumerman, *Member, IEEE,* and Hui Chen

***Abstract*— Emergency Electronic Brake Light (EEBL) is one of the most promising applications using Vehicular Ad-hoc Network (VANET) technologies to enhance the driving safety of automotive users. In this paper, based on the previous work in [1], we develop a novel self-organized message dissemination scheme, namely Cluster-based Broadcast (CB), for the EEBL application. The proposed CB broadcast scheme transforms the EEBL message dissemination pattern from multi-hop broadcast forwarding to multiple single-hop broadcast clusters, which can offer higher reliability, lower channel usage and shorter message propagation delay in comparison with the Directional Flooding (DF). The proposed CB scheme uses a distributed ad-hoc cluster organization algorithm based on the location information at each node, and therefore can avoid the cluster maintenance overhead. Furthermore, we study the impact of the market penetration ratio on the performance of EEBL application and propose an innovative idea of enhancing VANET system with receive-only nomadic VANET devices.**

***Index Terms*—Communication systems, Intelligent transportation systems, Inter-vehicular communication, Wireless LAN**

I. Introduction

INTER-VEHICLE Communication (IVC) is essential to the Intelligent Transportation System (ITS), which aims at enhancing the public and private safety as well as increasing the efficiency of the transportation system. The Dedicated Short Range Communications (DSRC) system is developed based on IEEE 802.11 WLAN technologies for the purpose of exchanging information among vehicles in a range up to one kilometer. By providing drivers information about danger situations in advance, IVC can greatly improve the driving safety and avoid vehicle accidents [2]. In the U.S., a 75 MHz frequency band at 5.9 GHz has been allocated for DSRC system. As shown in Fig. 1, one Control Channel (CCH) and six Service Channels (SCHs) are assigned with dedicated frequency bands, each of 10 MHz, for safety and non-safety relevant applications respectively. In Europe, the spectrum regulation on IVC system is currently ongoing, and a similar spectrum layout as in the U.S. with possible usage of combined 20MHz band for non safety applications is foreseen [9].

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In this work, we concentrate on the safety applications in Vehicular Ad-Hoc Networks (VANET), in particularly the Emergency Electronic Brake Light (EEBL), which can avoid or mitigate vehicle chain collision accidents on highways by informing the endangered drivers about the critical situations in early advance. The contributions of this work are two-folder. First of all, we evaluate the performance of EEBL in highway scenarios with our proposed Cluster-based Broadcast (CB) scheme. The CB scheme is based on the previous work from Biswas et al. [1], and can reduce channel resource usage and message propagation delay. Secondly, we reveal the impact of market penetration ratio of IVC devices on the performance of wireless danger warning applications. Based on the analysis we propose an innovative idea of combining the VANET system with nomadic navigation devices, which are only capable of receiving the warning messages, in order to speed up the market rolling-out process.

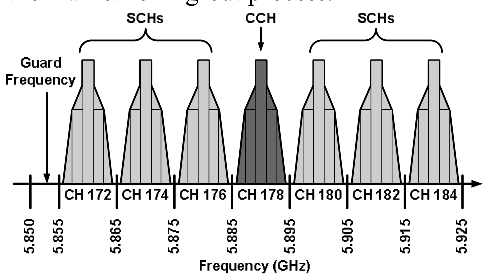

Fig. 1. Layout of the U.S. 5.9GHz ITS frequency band

This paper is organized as follows: Section II briefly introduces the Wireless Access in Vehicular Environments (WAVE) technology standardized by IEEE 802.11p/IEEE 1609, which service as the basis of our study. The EEBL application is formulated in section III, along with the simple Directional Forwarding (DF) scheme. In section V, we propose the novel CB message dissemination scheme for EEBL. Simulative evaluation of EEBL using the simple DF scheme and the proposed CB scheme are presented and compared in section V. Section VI analyzes the EEBL performance with respect to market penetration ratio of IVC devices and discusses the idea of using receive-only nomadic devices to speed up the market rolling-out process of VANET technology. Section VII concludes the paper with some remarks on the future works. Throughout this work we assume single radio unit at each vehicle. Therefore, the term device, node and vehicle are used interchangeably in this paper.

II. Wireless Access in Vehicular Environments (WAVE)

The system architecture of WAVE is illustrated in Fig. 2, where the Physical (PHY) and the basic Medium Access Control (MAC) layers are specified in IEEE 802.11p standards and all above layers are regulated by the IEEE 1609 standard family.

The basic WAVE MAC is identical to IEEE 802.11 Distributed Coordination Function (DCF), as specified in IEEE 802.11p. The WAVE MAC extension layer, as specified in IEEE 1609.4, adopts some concepts from Enhanced Distributed Channel Access (EDCA) of 802.11e, like Access Category (AC) and Arbitrary Inter-Frame Space (AIFS) for differentiating multiple user priorities. DCF/EDCA channel access mechanisms are applied to both CCH and SCHs in context of the multi-channel coordination.

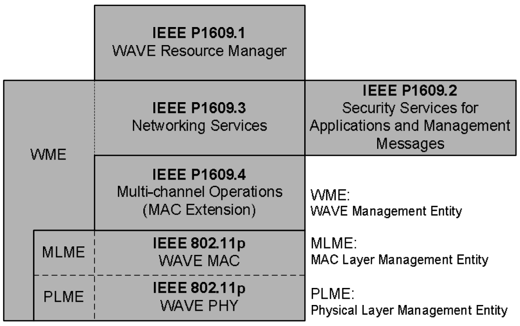

Fig. 2. WAVE protocol stack

DCF is based on CSMA/CA, according to which each station determines individually when to access the medium. Collision Avoidance (AC) scheme based on a random backoff procedure is employed to reduce the probability of collision. The EDCA specified in IEEE 802.11e standard is meant for the distributed QoS support in IEEE 802.11 WLAN [7]. By mapping the traffic of different priorities to different virtual stations and assigning different channel access parameters to each virtual station, EDCA can statistically differentiate multiple levels of QoS.

III. Emergency Electronic Brake Light (EEBL)

Usually on highways, a driver is warned about an emerging danger by the tail brake lights of its preceding car. However, a vehicle can still move quite a distance before it starts to decelerate, because of the driver reaction time. The driver reaction time is defined as the duration between the time the warning signal is observed and the time an action is taken by the driver, and its value varies from 0.4 s to 2.7 s with the average value of 1.0 s [8]. The effect of cumulated reaction times at the following up vehicles could further worsen the situation and result in chain collision accidents [1]. Besides, the Optical Brake Light (OBL) may fail when the drivers' visibility is limited, e.g., because of bad weather conditions, or when the drivers' attention is disturbed.

Emergency Electronic Brake Lights (EEBL) is developed for the above introduced problem. EEBL "enhances" the driver visibility by disseminating the warning messages via wireless links among vehicles to give the warning notification to the endangered drivers with the minimum latency. The EEBL application might not only enhance the warning range of a hard braking message but also might provide important information such as acceleration/deceleration rate.[2] Fig. 3 visualizes the EEBL scenario; Vehicle 0 is the accident vehicle, namely the original EEBL source. A hard brake action or an abnormal situation detected at Vehicle 0 triggers the EEBL application to broadcast the warning messages to other vehicles in the Zone of Relevance (ZoR). In this work, the ZoR is defined as a section of highway that is of the same driving direction as the accident vehicle and starts from the accident vehicle covering all vehicles following it. In other words, the ZoR consists of the set of vehicles that are directly endangered or affected by the accident at Vehicle 0.

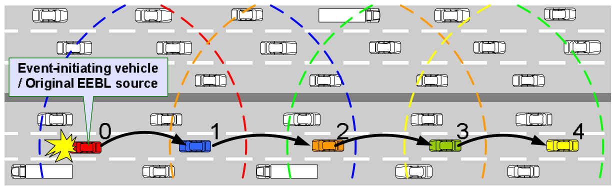

Fig. 3. Emergency Electronic Brake Light (EEBL) in highway scenarios

The message dissemination scheme has great influence on the performance of EEBL danger warning application. The most straightforward scheme is Directional Flooding (DF). According to the DF scheme, unnecessary rebroadcast is avoided at an un-relevant vehicle by comparing the geographic information of the accident derived from the EEBL message to the local geographic information as well as the moving status of the vehicle. As shown in Fig. 4, the vehicle forwards only messages received from transmitters running towards the same direction and located in front of it.

The main drawbacks of the DF scheme are, on the one hand, there is possibility to have broadcast storm even the filter is used, especially in densely populated scenarios. On the other hand, for vehicles located far away from the accident spot, the EEBL messages have to travel through multiple hops before it can be finally received, and the reliability gets lower when the number of hops increases, especially when the network is sparse.

IV. Cluster-based Broadcast (CB) Message Dissemination Scheme

To address the problems of the DF scheme, Biswas et al. [1] proposed a solution, namely Intelligent Broadcast with Implicit Acknowledge (I-BIA). I-BIA scheme improves the reliability of the multi-hop route by using implicit acknowledgement. However, in I-BIA scheme a node stops broadcasting the message once its transmission has been implicitly acknowledged by any of its followers. In high mobility VANET environments, this may induces a broken forwarding route, as the follower responsible for broadcasting may overtakes the preceding vehicle and leave no one responsible for further broadcasting the message down to the end of ZoR.

The main idea of the Cluster-based Broadcast (CB) scheme developed in this work is to transform the multi-hop broadcast propagation into multiple signal hop broadcast clusters in the ZoR, in order to solved the problem of I-BIA in dealing with the dynamic VANET topology and improved the warning reliability without increasing the channel usage.

Similar to the I-BIA scheme proposed in [1], according to the CB scheme when a vehicle receives the first EEBL message from its preceding vehicles driving in the same direction, instead of simply forwarding the message, the vehicle initiates a periodic EEBL source, which generates the EEBL message periodically with a frequency of 10 Hz, which is the same frequency as the original EEBL source does. This source does not stop until it receives an EEBL message from its following vehicles. A message from a follower implies that a new vehicle has started a new EEBL source and would take over the responsibility of broadcasting the EEBL message in its vicinity. Different from the I-BIA scheme, CB requires each vehicle to persistently sense the channel for warning messages coming from its followers even it has already handed over the broadcasting responsibility to one of its followers. In case the vehicle does not receive any message from its followers for a predefined period of time, either because the responsibility of broadcasting has been further handed over down the stream or because the responsible follower has left the ZoR due to mobility reason, it has to restart the EEBL source and broadcast the message again, as long as the vehicle itself is in the ZoR and the life time of the message is not expired. The state machine of the CB algorithm is illustrated in Fig. 45.

In this way, the responsibility of propagating EEBL information in the ZoR is handed over from the EEBL event initiating vehicle, i.e. the original EEBL source, down to the last vehicle in ZoR. Due to the proposed self-restart logic in CB, the message dissemination pattern is no longer a multi-hop broadcast route from the accident vehicle to the border of ZoR, but multiple of cooperatively working single hop broadcast clusters in the ZoR.

The formation of CB clusters follows a totally distributed and anonymous way. Each vehicle makes the decision by sensing the channel for message from its followers and by comparing the location information of the transmitter, which is contained in the received messages, to its own location. There is no overhead and delay required for maintaining the clusters architecture, as all required information is contained in the warning message itself and clusters are formed in the process of warning message propagation. As a result, the warning information is not simply propagated from the original vehicle to the end of ZoR, but kept "alive" with the required refresh frequency in the whole ZoR, since multiple of broadcast clusters can work simultaneously and cooperatively in the ZoR. This also ensures the CB scheme to be scalable in either a large or small scenario.

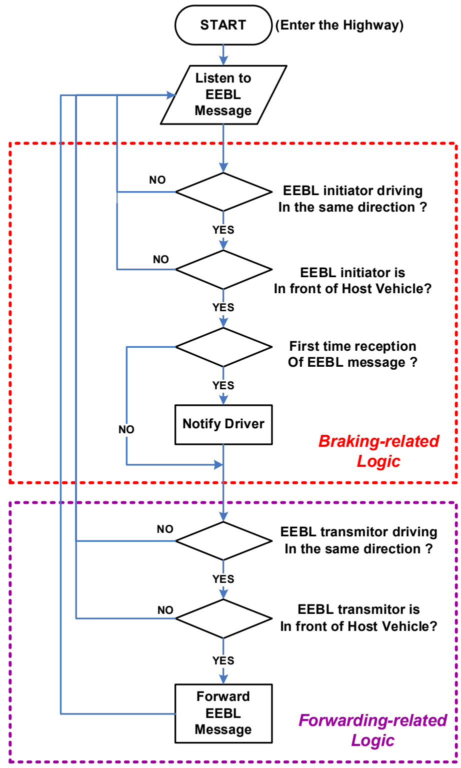

Fig. 4. Directional Flooding Logic

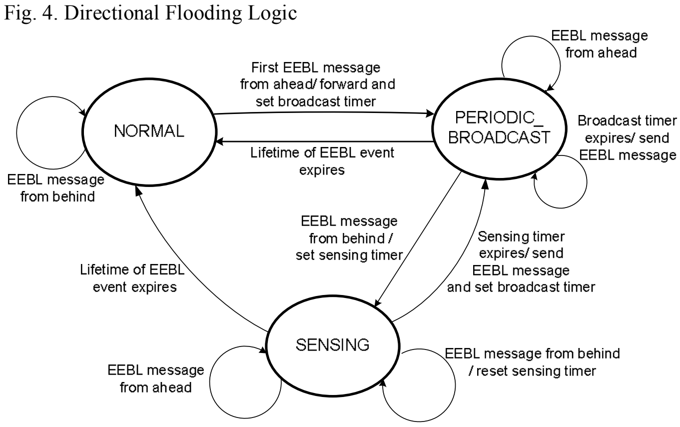

Fig. 5. State machine of the CB scheme

V. SIMULATIVE PERFORMANCE EVALUATION OF EEBL

A. *WARP2 Simulation Environment*

We use the Wireless Access Radio Protocol II (WARP2) simulation environment developed in Chair of Communication Networks (ComNets), RWTH Aachen University [4], for the simulative study. WARP2 is a stochastic simulation environment constructed with Specification and Description Language (SDL). For the purposes of studying the vehicular communication system, the WARP2 environment has been extended with regarding the following aspects.

1) *EEBL Application*

The danger warning related logic and message dissemination schemes, as introduced in section III, have been implemented in WARP2.

2) Communication Protocol Stack

The communication protocol stack used for the evaluation is implemented according to IEEE 802.11p and IEEE 1609.3/.4 protocols, including the synchronized CCH/SCH architecture, DCF channel access, EDCA Quality of Service (QoS) supports, and WAVE Short Message Protocol (WAMP).

3) Vehicular Mobility Model

A microscope mobility model is implemented to model the behavior of drivers. According to the mobility model each driver has his own expected speed, acceleration/deceleration rate, safety distance, and reaction time. Each driver observes both the OBL of the vehicle he follows and the danger alert provided by the EEBL application, if applicable. The driver may change lane or accelerate depending on the distance to vehicles in its vicinity. A vehicle collision is detected when the distance between two vehicles is less than the vehicle size, i.e. 7 meters in this study.

4) Wireless Channel Model for Highway Environment

As studied in [3], the two-ray ground model is employed for determining the signal power attenuation and the Packet Error Ratio (PER) table based error model is adopted for emulating the IEEE 802.11p PHY performance in vehicular environments.

B. Scenario Description

A section of straight highway with 3 lanes of each direction is set up for the EEBL simulation, as shown in Fig. 6. Each lane is 5000 m long and 5m wide. Initially, 161 vehicles are moving with an average[1] speed of 120 km/h. The average inter-vehicle distance is *d* for the middle lane and *2d* for the side lanes. The average deceleration rate of hard brake is 8 m/s^2. We simulate the situation when an accident happens at the first vehicle on the middle lane, i.e. Vehicle 0 in Fig. 6, which may cause rear end chain collisions between the following vehicles. The packet size of EEBL messages is equal to 100 B [2]. The one hop communication range is about 215 m with the transmission power of 100 mW at each vehicle and the PHY mode is BPSK1/2, i.e. 3 Mb/s data rate in IEEE 802.11p. In order to study the EEBL performance under interfering channel, we define background traffic to be the one-hop broadcast traffic at each vehicle following Poisson arrival process. Whenever used, the market penetration rate is defined as the percentage of vehicles equipped with the WAVE device out of overall vehicles in the scenario.

C. Evaluation metrics:

Vehicle *Collision Percentage (CP)* is defined as the percentage of vehicles crashed out of the total number of vehicles in the scenario.

Absolute Delay denotes the latency at each vehicle between the time that event happens and the time this vehicle receives the message for the first time.

Average Relative Delay (ARD) counts the average differentiation latency at consecutive vehicles.

[1] The speed values of vehicles follow the normal distribution with standard deviation of 1.

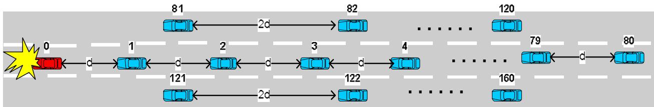

Fig. 6. Simulation scenario for EEBL evaluation

D. Performance of EEBL in Emergency Highway Situation

With the parameters setting given in Table 1, we got the results on the effectiveness of EEBL in reducing highway accident with various emergency situation, as shown in Fig. 7 and Fig. 8.

TABLE 1
PARAMETER SETTING FOR EEBL EVALUATION

Parameter	Value (mean)	Distribution [a]
Inter-vehicle Distance	6m~56m	Normal (σ=1)
Driver Reaction Time	0.5s~1.5s	Normal (σ=0.25)
Background Traffic	0kb/s/vehicle	Poisson
Market Penetration Rate	0% and 100%	N/A

Simulation results without EEBL, i.e. all drivers rely on the OBL of their preceding vehicles, is shown in Fig. 7. First of all, the color varying trend in Fig. 7 confirms the common sense that larger inter-vehicle distance and shorter driver reaction time are beneficial for mitigating vehicle chain collisions. Given the same average inter-vehicle distance, the earlier the drivers could start brake, the lower the collision percentage of vehicles. On the other hand, when the average reaction time is fixed, a larger distance offers more room for the vehicle to decelerate, and thus safer. Secondly, to achieve collision-free safe driving, the inter-vehicle distance must be kept lager than 60 m, which also conforms the rule of thumb that the safety distance should be 1/2 speed meter reading.

In contract, the results in Fig. 8 show the effectiveness of EEBL: The vehicle collision probability is almost independent from the driver reaction time. This is because, with EEBL danger warning, all drivers in the ZoR are informed about the danger situation with very low latency, i.e. less than 100 ms in this simulation. Therefore drivers could be careful and react to the event very early. The minimum required safety distance is decreased to 36 m even when the driver reaction time is as high as 1.5 s. With the same inter-vehicle distance and driver reaction time the vehicle collision probability is greatly reduced by EEBL in comparison with OBL. The simulation results indicate that EEBL is really effective in reducing rear end chain collision.

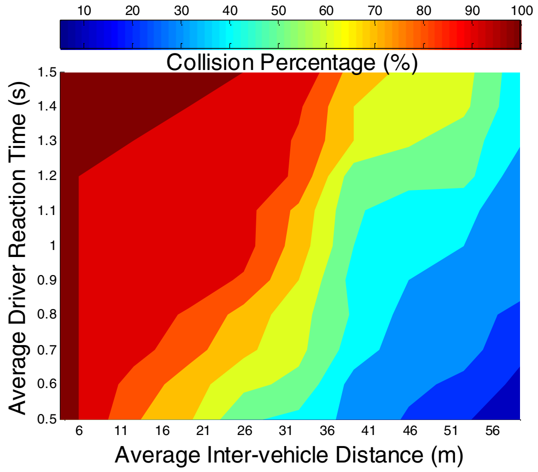

Fig. 7. Accident Avoidance performance of OBL (no EEBL is used, and from blue to red, the situation gets worse)

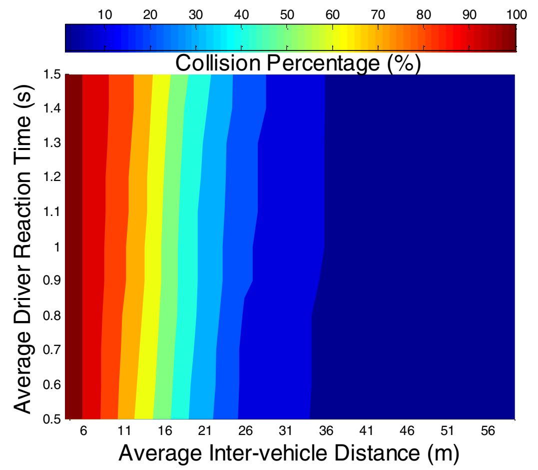

Fig. 8. Accident avoidance performance with EEBL (all vehicle have WAVE devices for EEBL application, i.e. mark penetration rate 100%)

E. *Robustness of Message Dissemination Algorithms against Background Traffic*

The two forwarding algorithms for the EEBL message dissemination introduced in sections III and IV are evaluated in this subsection. The simulation parameter settings are given in Table 2.

TABLE 2
PARAMETER SETTING FOR FORWARDING ALGORITHM EVALUATION

Parameter	Value (mean)	Distribution [a]
Inter-vehicle Distance	46m	Normal (σ=1)
Driver Reaction Time	1s	Normal (σ=0.25)
Background Traffic	0~240kb/s/vehicle	Poisson
Market Penetration Rate	100%	N/A

Fig. 9 reveals the relationship between the offered background traffic load at each vehicle and the channel busy time in this scenario. It can be observed in this scenario the channel gets saturated when the offered background traffic load is higher than 240kb/s/vehicle.

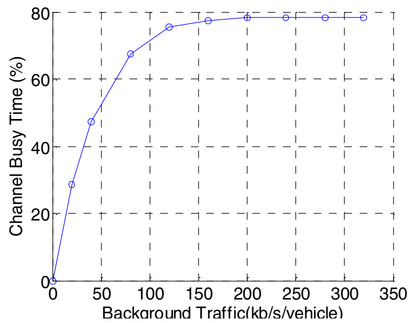

Fig. 9. Channel busy time of CCH with varying background traffic load

Fig. 9 reveals the relationship between the offered background traffic load at each vehicle and the channel busy time in this scenario. Fig. 10 exhibits the impacts of background traffic on the vehicle collision percentage. Directional Flooding and Cluster-based Broadcast give the same collision performance with low interference. The advantage of CB over DF becomes obvious when the background traffic is beyond 80 kb/s/vehicle. With the increase of background traffic, the collision percentage using DF witnesses a ten-fold increase, while the collision percentage using Cluster-based Broadcast remained under 5%.

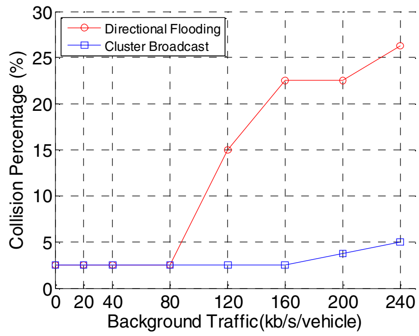

Fig. 10. Vehicle collision percentage versus background traffic load

The same trend applies to the average relative latency versus background traffic, as shown in Fig. 11. It is self-explanatory: The average relative latency increases due to packet collision caused by background traffic. A higher relative latency implies that the EEBL warning is delivered slower, and thus the vehicle collision is more likely to happen due to the lack of time to decelerate.

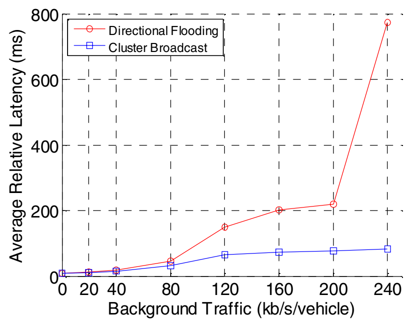

Fig. 11. Average relative latency versus background traffic

A further look at the relationship between the vehicle collision percentage and the relative latency, as shown in Fig. 12, suggests that the collision percentage can be controlled below 5% if we keep the average relative latency smaller than 100ms.

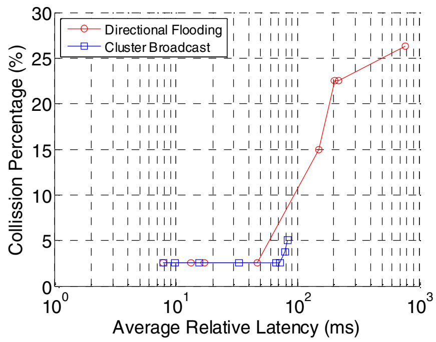

Fig. 12. Relationship between the vehicle collision percentage and the average relative latency

VI. Impacts of Market Penetration Ratio on the EEBL Performance

So far all simulations are conducted with the assumption of 100 percent market penetration rate, i.e., every vehicle has the EEBL device equipped. In this subsection we drop the assumption of full market penetration and perform simulations with more realistic market penetration rates.

A. Simulative Study on EEBL with Realistic Market Penetration Ratio

We set the mean reaction time to 1s, the mean inter-vehicle distance to 51 m and no background traffic. According to the simulation presented above, the collision percentage without EEBL (using OBL only) is 33.75% and the EEBL application (with full penetration rate) reduces it to 1.25%. Fig. 13 shows the vehicle collision percentage as a function of the penetration ratio: The 0.05 penetration rate gives the same collision percentage as OBL. The vehicle collision percentage decreases slowly from penetration ratio of 0.1 to 0.2, while a steep drop occurs when the penetration ratio reaches 0.25 and the collision percentage keeps decreasing sharply to 14% corresponding to the penetration ratio of 0.3. Finally, all the following up collisions are successfully avoided for this scenario when the penetration rate is larger than 0.7. In this simulation vehicles with EEBL device equipped are uniformly distributed in the scenario.

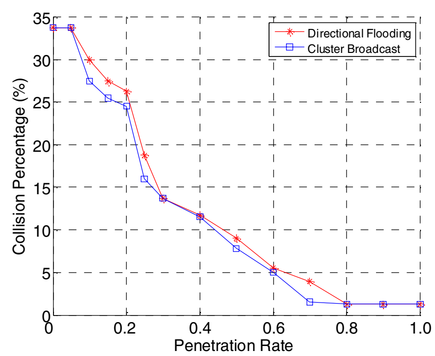

Fig. 13. Vehicle collision percentage as a function of EEBL market penetration rate

The market penetration rate simulation results suggest that to achieve effective collision avoidance with IVC, the market penetration ratio of the WAVE devices should be fairly high, 70% to 80% in this case. However, for an emerging technology, such a high market penetration may take really a long time to achieve, especially considering that the licensed WAVE devices are usually shipped only with new top-level luxury cars in the early market introducing phase.

B. The Role of Nomadic Device in Wireless Local Danger Warning

A straightforward solution of speeding up the market penetration rate is to introduce the nomadic devices, e.g. the portable navigation devices, which are cheap and able to provide the danger warning application using the WAVE radio interface. However, there are many objection arguments on introducing the nomadic WAVE devices, such as:

- The WAVE device has to be integrated into the vehicle and able to access to the car bus for getting the information, e.g. ESP and airbag status, for generating danger warning messages.
- Devices transmitting on the 5.8 GHz ITS frequency band must be licensed, and all messages transmitted on CCH have to be authenticated, which may need authentication scheme involving the vehicle identity in order to prevent malicious attacks.

Nevertheless, the simulation results reveal that the performance of EEBL collision avoidance depends more on the number of drivers that can receive the warning messages in time than on the number of WAVE device that can disseminate the messages, as far as there is already enough WAVE devices disseminating the messages in the ZoR. This leads us to propose the idea of integrating the VANET system and nomadic EEBL warning devices for safety applications.

The idea of the nomadic EEBL danger warning devices are actually a combination of the portable navigation device and a WAVE communication unit with reduced functionality, i.e. without transmission function of WAVE radio unit. The system block diagram of nomadic device is shown in Fig. 14.

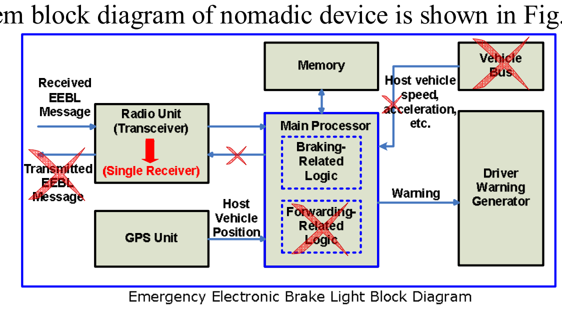

Fig. 14. System block diagram of semi-functional EEBL device (SFED)

The considerations behind the nomadic EEBL danger warning devices are: The device is cheap and easy to manufacture. The prohibition of transmission on 5.8 GHz could avoid the security and authentication problems.

Simulations with the parameter settings in Table 3 are set up for verifying the concept of nomadic EEBL warning devices with different percentage nomadic and standard devices. The same scenario as introduced in section V.B is used here.

TABLE 3
PARAMETER SETTINGS FOR SFED SIMULATIONS

Parameter	Value (mean)	Distribution [a]
Inter-vehicle Distance	51m	Normal (σ=1)
Driver Reaction Time	1.0s	Normal (σ=0.25)
Background Traffic	0kb/s/vehicle	Poisson
Market Penetration Rate	0% and 100%	N/A
Penetration Rate (Overall)	0~100%	N/A
Penetration Rate (SFED)	10%, 20%, 30%	N/A

Fig. 15 plots the vehicle collision percentage with 10%, 20% and 30% Nomadic EEBL Device Ratio (NDR), defined as the percentage of vehicles with nomadic devices out of all vehicles in the scenario, versus various penetration ratio of standard WAVE devices, or *penetration ratio* in short for Fig. 15. The reference is the vehicle collision percentage purely using standard WAVE devices, i.e., NDR is 0%.

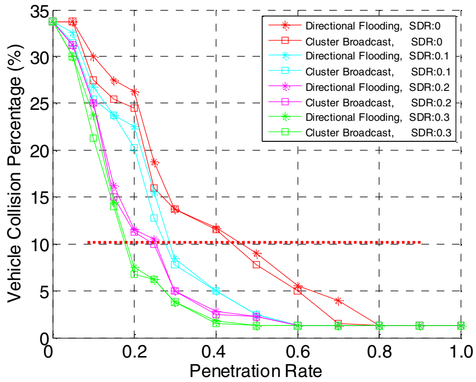

Fig. 15. Vehicle Collision Percentage with nomadic and standard WAVE devices

It is observed that with the same percentage of standard WAVE devices, the introduction of nomadic device can significantly improve the performance of vehicle collision avoidance. As shown in Fig. 15, the combination of 30% standard WAVE devices and 20% nomadic devices can reach the same vehicle collision avoidance performance as with pure standard device of 60% penetration rate. And the combination of 30% standard devices and 30% nomadic devices even outperforms the pure 60% standard devices. This can be explained by the role of nomadic devices, which can improve the accident avoidance performance without increasing the message collision probability.

In summary, the nomadic devices are efficient in improving the vehicle collision avoidance performance when there is already initial market penetration ratio of standard WAVE devices. The nomadic device can not replace the standard devices but it can work as complementary solution and efficiently speed up the market penetration rate.

VII. CONCLUSION

In this paper, we evaluated the performance of the WAVE system with respect to wireless local danger warning applications, i.e. Emergency Electronic Brake Light (EEBL), in highway scenarios. With the proposed Cluster-based Broadcast message dissemination scheme, the reliability of EEBL application is increased with reduced channel resource usage. Additionally, the dependent of the wireless local danger warning application on the market penetration ratio of WAVE devices is analyzed. And a novel idea of using integrated VANET with nomadic WAVE devices is proposed to enhance the EEBL performance and speed up the market penetration rate. In the future, we would like to study the performance of VANET safety applications involving the road side units and vehicles of reverse direction.

VIII. ACKNOWLEDGEMENT

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REFERENCES

[1] S. Biswas, R. Tatchikou and F. Dion, *Vehicle-to-vehicle Wireless Communication Protocols for Enhancing Highway Traffic Safety*. Communications Magazine, IEEE Publication Date: Jan. 2006 Volume: 44, Issue: 1 page(s): 74- 82.

[2] U.S. Department of Transportation, National Highway Traffic Safety Administration. *Vehicle Safety Communications Project Task 3 Final Report - Identify Intelligent Vehicle Safety Applications Enabled by DSRC*. National Technical Information Service, Springfield, Virginia 22161. March 2005.

[3] 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

[4] Chair of Communication Networks, RWTH Aachen University, Kopernikusstraße 16, 52074 Aachen, Federal Republic of Germany, [Online]. Available: http://www.comnets.rwth-aachen.de

[5] Draft P802.11p/D2.0, November 2006 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

[6] IEEE, IEEE Std P1609.4. Wireless Access in Vehicular Environments (WAVE) Multi-Channel Operation. November 2005.

[7] Mangold, S.; Choi, S.; Hiertz, G.; Klein, O. and Walke, B. Analysis of IEEE 802.11e for QoS support in wireless LANs, Wireless Communications Magazine, IEEE, 2003, Volume 10, Page 40 – 50

[8] G. Johansson and K. Rummer. Drivers' brake reaction time. Human Factors, 13(1):23, February 1971.

[9] ETSI Technical Committee Electromagnetic compatibility and Radio spectrum Matters (ERM), "Technical Characteristics for Pan-European Harmonized Communication Equipment Operating in the 5 GHz Frequency Range and Intended for Critical Road-Safety Applications," ETSI, Tech. Rep. ETSI TR 102 492-1/2, 2005