Improved Multi-Channel Operation for Safety Messages Dissemination in Vehicular Networks

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ABSTRACT

In this paper we discuss the performance of IEEE 1609.4 multi-channel operation over the 5.9 GHz DSRC spectrum, and we propose an improved multi-channel switching in which the whole Sync interval can be used for the control channel when vehicles are not interested to use service channels. Based on intensive simulations conducted in ns-2, we demonstrate that significant improvements in terms of safety packet received within a Sync interval can be obtained with a negligible degradation of the service provisioning.

Categories and Subject Descriptors

C.2.1 [**Network Architecture and Design**]: Wireless Communication.

Keywords

Multi-channel switching; vehicular networks; safety message; dissemination.

1. INTRODUCTION

Dedicated Short Range Communication (DSRC) is made up of seven 10 MHz channels, a control channel (CCH) for safety messages exchange applications, and six service channels (SCH) dedicated for both safety and non-safety messages. Multi-channel operations of IEEE 802.11p [6] radios is covered by the 1609.4 standard [7]. Both standards describe the functionality of the control channel, the service channels, and the switching between channels. IEEE 802.11p specifies a synchronization interval of 100 ms with a guard interval of 4-6 ms. The guard interval is used for synchronization between vehicles based on the Coordinated Universal Time (UTC) which can be acquired using the Global Positioning System (GPS). During, the synchronization interval, switching between the CCH and SCH channels occurs letting vehicles use either a service channel or the control channel in the corresponding sub-intervals. As per the standard, there is no indication on how to effectively use the synchronization (Sync) interval to dedicate more or less time either to using SCH or CCH channels depending on vehicle density, type of services, etc. Furthermore, if a vehicle, or all vehicles in area do not use service channels, part of the synchronization interval becomes unused.

To address such an issue, several techniques have been proposed and discussed in the literature. In [2], the authors provide a detailed discussion of the main features of the IEEE 1609.4 standard [7]. They focus on issues such as no channel switching, naive channel switching, type of applications requiring channel switching, and optimized scheduling policies that do not allow the transmission of safety messages during Guard Intervals (GI) and SCH periods.

In [1], the authors proposed a mechanism to improve the MAC protocol such that the CCH interval and the SCH interval are adjusted dynamically with respect to the network load and the vehicle density. In their paper, the CCH interval length depends on the reception probability within the CCH channel.

The authors in [4] analyzed the performance of IEEE 1609.4 when only one (CCH or SCH) is used while the other channel is not used. They proposed a Wave Basic Service Set (WBSS) mechanism which exploits free channels, and in which new vehicles are informed about the availability of the empty channels.

In [10], the authors studied the channel wastage and shortage problem with variable traffic density, and they proposed an adaptive autonomous channel switching procedure to have beneficial usage of channel resources.

In [5], the problem of channel switching time according to network characteristics which cause effect on channel usage efficiency over CCH is discussed. The authors proposed an adaptive channel switching method based on density of network.

Other approaches to improve the dissemination of safety messages in vehicular networks have been proposed in the literature. For example, in [9], the authors proposed a mechanism and an intelligent communication platform, called WiSafeCar, for vehicles equipped with on-board vehicle computers which exploits the offered services to improve safety applications in vehicular networks.

In [8], the authors proposed a mechanism called Transmit Power Adaptation (TPA) based on a cross-layer approach in which information from both the PHY layer and the network layer is used to address the problem of the fast changes occurring in the vehicular network topology and which can affect the performance of messages dissemination.

DIVANet'14, September 21–26, 2014, Montreal, QC, Canada.

http://dx.doi.org/10.1145/2656346.2656410 .

In this paper, we address the problem of improving safety messages dissemination in vehicular networks. We propose a simple multi-channel switching mechanism in which only vehicles which successfully receive service advertisement messages, and which are willing to take part to the service offering, switch to the SCH channel during the Sync interval. Other vehicles not interested to use the service stay continuously on the CCH channel for the whole Sync interval. The policy proposed is such that, for vehicles using the entire Sync interval for transmitting in the CCH channel, they can only transmit routine (bacon) safety messages during the sub-interval which is normally dedicated to SCH channel use. This is to avoid the transmission of important messages such as emergency alert, etc., when vehicles using the SCH channels cannot listen.

Our contribution can be summarized as follows: We propose a service-based multi-channel operation in which vehicles that do not need to use the service channels can stay on the CCH during the Sync interval. We evaluate the scheme with a simulation-based analysis of safety messages dissemination in vehicular networks for several realistic scenarios.

The rest of the paper is organized as follows: In Section 2, we formulate the problem addressed in this paper, and we present the system model used to study the performance of the safety message dissemination based on our proposed multi-channel switching scheme. In Section 3, we describe the multi-channel switching policy proposed, and we present in Section 4 a brief derivation of the estimated reception probability. Section 5 presents the setup used for the simulations and discusses the results obtained. Finally, we conclude the present work in Section 6 while proposing some future works.

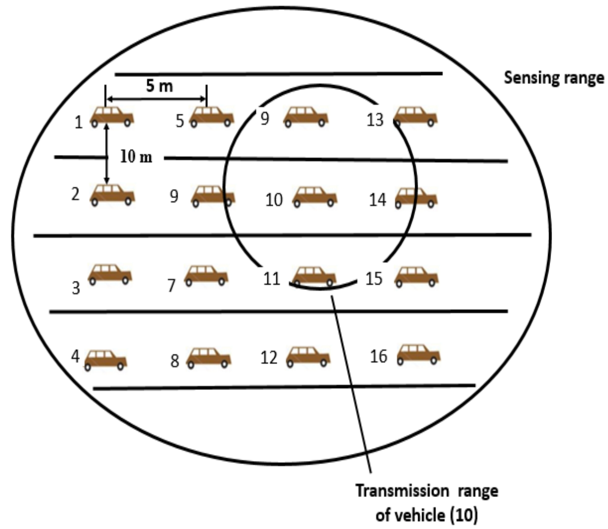

Figure 1: Grid-based Vehicular Network considered.

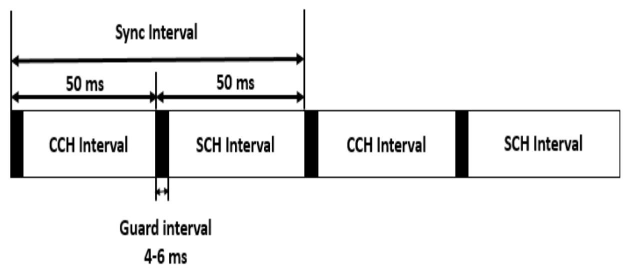

Figure 2: Ordinary multi-channel switching.

2. SYSTEM MODEL AND PROBLEM STATEMENT

In this paper, we address the problem of multi-channel switching for safety message dissemination within a Sync interval. We consider the following network model: we assume N vehicles within the sensing range of each other. Each vehicle periodically generates at a frequency of 10 Hz routine messages to be sent using the 802.11p CSMA/CA protocol without acknowledgement within the CCH interval of a Sync interval of 100 ms of duration. We assume that only $N_{\text{SCH}} \leq N$ vehicles are interested to take part in the service provisioning. For simplicity, without loss of generality, we assume that one vehicle advertises service to the other vehicles rather than a Road-Side-Unit (RSU). We also assume that the vehicles are distributed within the network based on a simple grid-based as shown in Figure 1. We consider a four-lane street in which each lane has to be filled with a vehicle before filling another lane, and we repeat this process until all the N vehicles are arranged within the network. Within a lane, the distance between two consecutive vehicles is 5 m, and the distance between two consecutive lanes is 10 m. We assume that the N_{SCH} vehicles including the service provider vehicle are randomly chosen among the N vehicles. Further, we assume that the number N of vehicles does not change during the performance study.

Given the above system description, we may consider, for any given vehicle within the service coverage area, two possible IEEE 1609.4 channel switching schedules depending each on the vehicle interest with regard to the offered service.

According to the scheduling policy in 1609.4 standard, a vehicle will schedule its control messages according to the CCH interval in order to accommodate other vehicles participating in a service. This is done independently on its interest to the offered service. That is, even if the vehicle is not taking part to the service, it will avoid transmitting during the SCH interval.

In this paper, the problem that we address is to demonstrate the following hypothesis:

"it would be more beneficial for vehicles not involved in the service provisioning to keep disseminating their routine messages, but not any critical message, during the SCH interval in order to improve the overall performance of the control messages dissemination."

3. PROPOSED MULTI-CHANNEL OPERATION

The specificity of our policy is that only vehicles willing to take part in the service provisioning, and which successfully receive the service advertisement message switch to the SCH channel in the next Sync interval. We consider that the whole Sync interval is assigned to CCH operations for vehi-

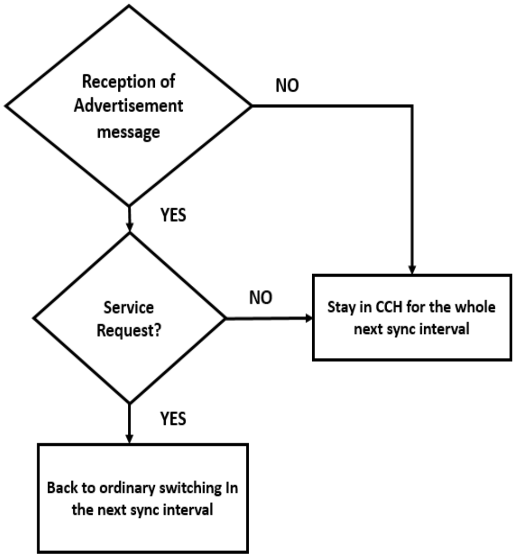

Figure 3: Flowchart of the proposed multi-channel switching.

cles that do not wish to participate in service provisioning despite the use of the SCH channel by some vehicles during that interval. During the time that the SCH is used by some vehicles, the others can still send routine (bacon) safety messages in the CCH. The rationale behind this is that it is more beneficial for vehicles in an area to have a longer period during which they can transmit their routine messages, thus lowering contention on the channel.

When there is an ongoing service provisioning, our channel switching policy states that vehicles participating in the service provisioning will be in the CCH channel for safety messages exchange for a duration of 46 ms, and in the SCH channel also for a duration of 46 ms, after using a guard interval of 4 ms for synchronization purpose. Conversely, vehicles that do not participate in the service provisioning are allowed to use the entire Sync interval (96 ms) for CCH messages exchange. For these vehicles, there is no need to have the guard interval after the default CCH period (46 ms); only the guard interval required for synchronizing the vehicles at the beginning of each Synch interval is used. Note that vehicles not participating in a service provisioning are not allowed to transmit critical messages (such as emergency messages) during the SCH interval. Only routine (beacon) messages are allowed during this interval. In Figure 2, we illustrate how the channel switching is performed for the ordinary switching policy. The description of our proposed policy is shown in Figure 3 and Figure 4.

4. ESTIMATE RECEPTION PROBABILITY

The performance of the channel switching policy proposed relies on the probability of receiving the advertisement message. Given the system model considered in this work, it is not an easy task to derive an exact and closed-form of the probability of successfully receiving the advertisement message. However, vehicles can estimate the reception probability of the advertisement message based on the reception probability of the transmitted beacons within a CCH period. Indeed, by using sequence information in the beacon pack-

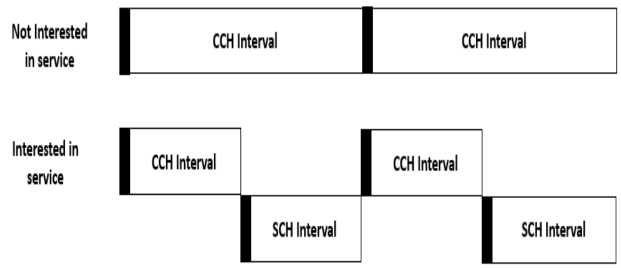

Figure 4: Proposed multi-channel switching.

ets as in [1], each vehicle determines the lost packets. Let $P_{\text{rx}}(i,j)$ be the expected reception probability at the vehicle j during the i-th CCH channel. According to [1], we have

$$P_{\text{rx}}(i,j) = \frac{n_{i,j}}{N_i}, \tag{1}$$

where $n_{i,j}$ is the number of packets received by the vehicle j during the i-th CCH interval, and N_i is the total number of packets expected to be have sent during the i-th CCH interval. Considering N the total number of vehicles within the network, the average expected reception probability, $P_{\text{rx}}(i)$, in the i-th CCH interval is given by

$$P_{\text{rx}}(i) = \frac{\sum_{k=1}^{N} P_{\text{rx}}(i,k)}{N}. \tag{2}$$

Therefore, the probability P_{ad} that a vehicle receives the advertisement message in the i-th CCH interval, assuming there is no ongoing service provisioning, is simply given by

$$P_{\text{ad}} = p_t P_{\text{rx}}(i), \tag{3}$$

where, p_t is the probability that the advertisement provider vehicle transmits its advertisement message during the i-th CCH interval. The derivation of p_t can be found in the literature, for example in [3].

5. NUMERICAL RESULTS AND DISCUSSION

In this section we conduct, for several scenarios, a simulation study using ns-2 to evaluate and compare the performance of our proposed scheme with ordinary multi-channel switching in IEEE 1609.4 based on the evaluation of the number of safety packet received during a Sync interval. The simulation setup is given below.

5.1 Simulation Setup

We consider a vehicular network with several vehicle densities varying from 20 vehicles to 55 vehicles in the area defined in the system model in Section 2. The distribution of the vehicles within the network is based on the grid policy shown in Figure 1. We set the transmission range to 260 m, and the sensing range to 550 m. Other main parameters are listed in Table 1. For the simulations, we assume that, if service advertising is necessary, vehicle which plays the role of service provider advertises the service within its

Table 1: Settings of some parameters used for simulation

Parameter	Value
Sensing range	550 m
CCH interval for service participating vehicles	46 ms
CCH interval for non service participating vehicles	96 ms
SCH interval for service participating vehicles	46 ms
SCH interval for non service participating vehicles	0 ms
Guard interval	4 ms
SIFS	16 μs
Slot time	9 μs
Safety message frequency	10 Hz
Safety message payload	500 Bytes
CW_{min}	15
CW_{max}	1023
Data Rate	6 Mbps
Propagation Model	Nakagami
Modulation	BPSK
Coding Rate	1/2

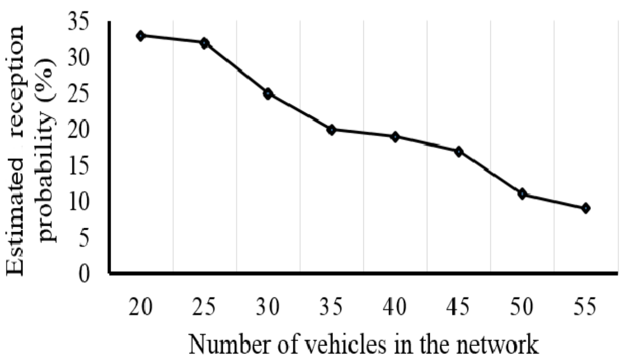

Figure 5: Estimated Reception Probability with respect to the number of vehicles within the network.

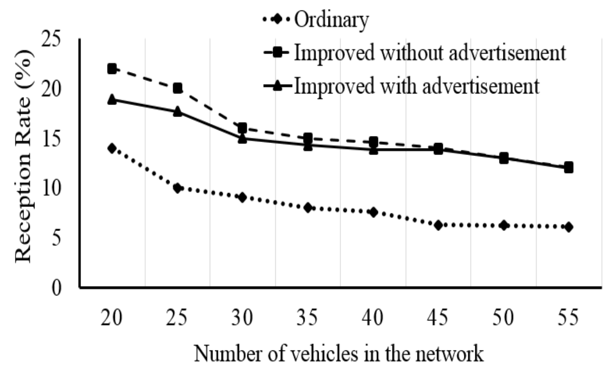

Figure 6: Reception rates of the proposed scheme vs. standard.

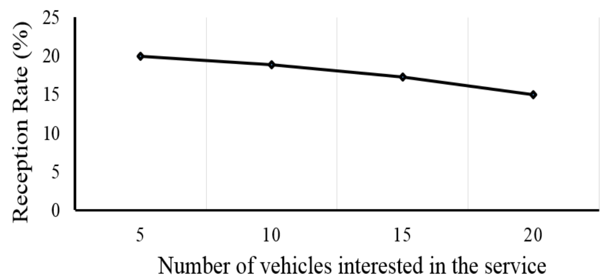

Figure 7: Reception rate within a Sync interval with respect to the number of vehicles interested in the service. Case where the number of vehicles $N = 20$.

neighborhood during the CCH interval. We want to capture the effect of SCH channel switching on the performance of safety message dissemination. When there is no ongoing service scheduled, all vehicles keep transmitting their routine message for the duration of all the Sync interval.

5.2 Discussion

In order to evaluate the estimated reception probability, for different number of vehicles within the vehicular network ($N = 20, 25, 30, ..., 55$), we determine the estimated reception probability based on the derivation in Equation (2). The results are shown in Figure 5. We observe that once the number of vehicles increases, the estimated reception probability decreases. This is because the vehicles use CSMA/CA to access the channel, and the number of collisions increases as the number of contending vehicles increases. Also, with this probability we can estimate the percentage of vehicles receiving the service advertisement message.

For different number of vehicles $N = 20, 25, ..., 55$ within the vehicular network, we determine the reception rate, that is, the total number of safety messages received during the Sync interval vs. those transmitted, and we compare our policy with the ordinary (normal) case. In these simulations, we consider one vehicle providing the service, and 10 vehicles interested in the service.

We notice, in Figure 6, that when the vehicle density increases, the rate of safety message reception for our scheme is much higher than that given by the ordinary switching of the standard. Also, since the probability of getting the service advertisements at the requesting vehicles decreases when the number of vehicles increases, for our scheme the rate of safety messages received is almost the same for both cases where there is, and there is not any service advertisement. When the number of vehicles using the SCH channel is low, all vehicles in the CCH channel use almost the whole Sync interval to transmit their control messages. Another factor that adds to the improvement is the fact that there is no guard interval after 46 ms for vehicles not switching to the SCH channel.

In order to analyze how the number of vehicles interested in the service provisioning affects the performance of the dissemination of safety messages within a Sync interval, we consider three other simulation scenarios. In the first (resp. second, and third) scenario, the number of vehicles in the network is $N = 20$ (resp. $N = 30$, and $N = 40$), we vary the number of vehicles interested in the service provisioning from

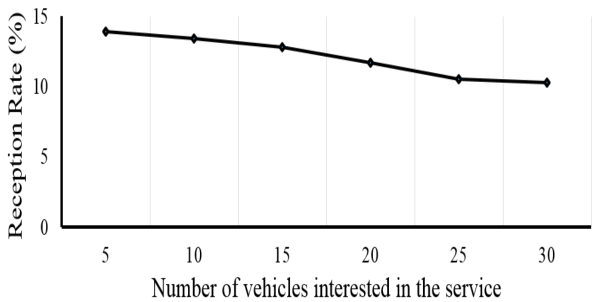

Figure 8: Reception rate within a Sync interval with respect to the number of vehicles interested in the service. Case where the number of vehicles $N = 30$.

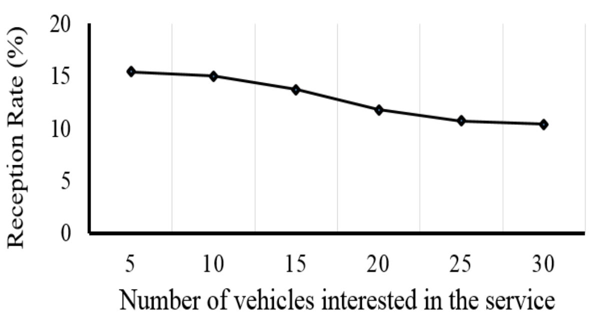

Figure 9: Reception rate within a Sync interval with respect to the number of vehicles interested in the service. Case where the number of vehicles $N = 40$.

$N_{\text{SCH}} = 5, 10, 15, 20$ (resp. $N_{\text{SCH}} = 5, 10, 15, 20, 25, 30$, and $N_{\text{SCH}} = 5, 10, 15, 20, 25, 30$), and we determine the reception rate during the Sync interval. The results are respectively shown in Figure 7, 8, and 9. We observe a similar behavior for the three scenarios; as the number of vehicles interested in the service provisioning increases, the reception rate of safety messages during the Sync interval decreases. The reason is that the number of vehicles effectively switching to the SCH channel increases as the number of vehicles interested in the service provisioning increases. Therefore, the system behavior tends to the one of an ordinary switching mechanism.

6. CONCLUSION AND FUTURE WORK

In this paper we have discussed performance of IEEE 1609.4 multi-channel operation, and we proposed an improved multi-channel switching which assigns to nodes the whole Sync interval for their CCH transmissions while they are not interested in any service application. For vehicles interested in an available service, they use the ordinary multi-channel switching. Based on intensive simulations conducted in ns-2, we demonstrated our hypothesis and showed that significant improvements in terms of safety packet received within a Sync interval can be obtained.

In this work, we have assumed only single hop communications without aknowledgement. As future directions, it may be interesting to consider information relaying, and see how our proposed scheme performs in a multihop scenario vehicular network.

7. REFERENCES

[1] A. Akbarifar, J. Bagherzadeh, and S. Yousefi. An extension to ieee 1609.4 for dynamic multichannel interval adjustment in wave architecture. In *Computer and Knowledge Engineering (ICCKE), 2012 2nd International eConference on*, pages 272–277, Oct 2012.

[2] Q. Chen, D. Jiang, and L. Delgrossi. Ieee 1609.4 dsrc multi-channel operations and its implications on vehicle safety communications. In *Vehicular Networking Conference (VNC), 2009 IEEE*, pages 1–8, Oct 2009.

[3] K. Hafeez, L. Zhao, Z. Liao, and B. Ma. Performance analysis of broadcast messages in vanets safety applications. In *Global Telecommunications Conference (GLOBECOM 2010), 2010 IEEE*, pages 1–5, Dec 2010.

[4] C.-M. Huang, C.-C. Yang, and H.-D. Huang. An effective channel utilization scheme for ieee 1609.4 protocol. In *Ubiquitous Information Technologies Applications, 2009. ICUT '09. Proceedings of the 4th International Conference on*, pages 1–6, Dec 2009.

[5] Y. Huo, J. Guo, R. Zou, H. Zhang, Y. Liu, and L. Zhang. A dynamic channel switching mechanism based on vehicle density. In *Wireless Personal Multimedia Communications (WPMC), 2012 15th International Symposium on*, pages 212–216, Sept 2012.

[6] D. Jiang and L. Delgrossi. Ieee 802.11p: Towards an international standard for wireless access in vehicular environments. In *Vehicular Technology Conference, 2008. VTC Spring 2008. IEEE*, pages 2036–2040, May 2008.

[7] J. Kenney. Dedicated short-range communications (dsrc) standards in the united states. *Proceedings of the IEEE*, 99(7):1162–1182, July 2011.

[8] M. Sander Frigau. Cross-layer transmit power and beacon rate adaptation for vanets. In *Proceedings of the Third ACM International Symposium on Design and Analysis of Intelligent Vehicular Networks and Applications*, DIVANet '13, pages 129–136, New York, NY, USA, 2013. ACM.

[9] T. Sukuvaara, P. Nurmi, M. Hippi, R. Autio, D. Stepanova, P. Eloranta, L. Riihentupa, and K. Kauvo. Wireless traffic safety network for incident and weather information. In *Proceedings of the First ACM International Symposium on Design and Analysis of Intelligent Vehicular Networks and Applications*, DIVANet '11, pages 9–14, New York, NY, USA, 2011. ACM.

[10] L. Zhang, Y. Liu, Z. Wang, J. Guo, Y. Huo, Y. Yao, C. Hu, and Y. Sun. Evaluating and improving the performance of ieee 802.11p/1609.4 networks with single channel devices. In *Communication Technology (ICCT), 2011 IEEE 13th International Conference on*, pages 877–881, Sept 2011.