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Safety Communication Based Adaptive Multi-channel Assignment for VANETs

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Abstract Dedicated short-range communication technology has been proposed for wireless access in vehicular environment (WAVE) standard. With this technology, road users can benefit from utilizing inter-vehicle and infrastructure to vehicle communication services, which are crucial for enhancing road safety and facilitating efficient transportation. WAVE standard provides different channel assignment patterns. In addition to the baseline standard IEEE 802.11p, which provides continuous access channel operation, WAVE offers the MAC extension to support multi-channel operation with the standard IEEE 1609.4. By using standard channel assignments, WAVE system suffers from decreasing service performance especially for safety applications in the scenario with high vehicle density. Moreover, fixed channel assignment may not offer best solution for different traffic situations. This paper proposes a mechanism called safety communication based adaptive multi-channel assignment, which allows flexible multi-channel usage based on real-time communication traffic condition. Several test scenarios have been implemented and the system performance has been observed via simulations. The results show that our proposed method can optimize and maintain good system performance in all test cases, while other channel assignment mechanisms can only offer good performance for certain traffic conditions.

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1 Introduction

With growing number of vehicles on the road, increase in traffic congestion and collision inevitably followed. A large amount of effort from both academic and industrial sectors has been focusing on the development of technologies for intelligent transportation system (ITS). The main purpose is to increase transportation safety and efficiency. With this system, vehicles will be equipped with onboard computing and communication platforms. In order to provide intelligent system, vehicles need to aware of the current road situation via their enhanced sensing capabilities. Then, they can collaboratively inform other vehicles for suitable operation. To provide vehicular communication networking, Vehicular Ad-hoc Network (VANET) [1] has been proposed. VANET operates in decentralized and self-organized manner without the need of pre-established infrastructure. In terms of regulation and standardization effort, Dedicated Short-Range Communication (DSRC) technology [2] has been developed for Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication under the IEEE standard called Wireless Access in Vehicular Environment (WAVE) [3, 4]. The U.S. Federal Communication Commission (FCC) has allocated 75 MHz wide spectrum band for DSRC at 5.9 GHz in 1999. The DSRC band is a licensed spectrum restricted to the specific usages and technologies, however it is free of usage charge. The channel assignment defined for use by DSRC in the U.S. is illustrated in Fig. 1.

DSRC spectrum composes of seven channels with channel bandwidth of 10MHz. According to the standard, channel 178 is the control channel (CCH) specified for safety message communication. There are six service channels (SCHs) including channel 172, 174, 176, 180, 182, and 184. Channel 172 and 184 are reserved channels. Channel 174 and 176 can be combined to produce 20-MHz channel, called channel 175. Channel 180 and 182 can also be combined into channel 181. These service channels are available mainly for non-safety message.

With only one CCH being used for safety applications, the communication performance can be influenced by dense road traffic situation, when communication traffic on CCH is built up. Ref. [5] observes the decrease of CCH service performance due to this so called channel congestion problem. Several research works have been done to propose mechanisms to solve channel congestion problem and this will be elaborated in the next

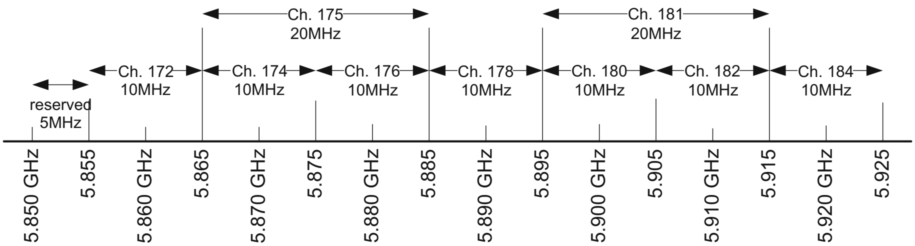


Fig. 1 The channel assignment of DSRC [4]

section. In this work, safety communication based adaptive multi-channel assignment for VANETs is proposed. The idea is to adaptively adjust channel switching interval based on a real-time level of congestion on CCH and SCH. In particular, longer CCH intervals can be allocated in response to built-up congestion on CCH to support safety applications. As a result, more flexible and efficient multi-channel usage can be achieved. Eventually, the system performance can be optimized.

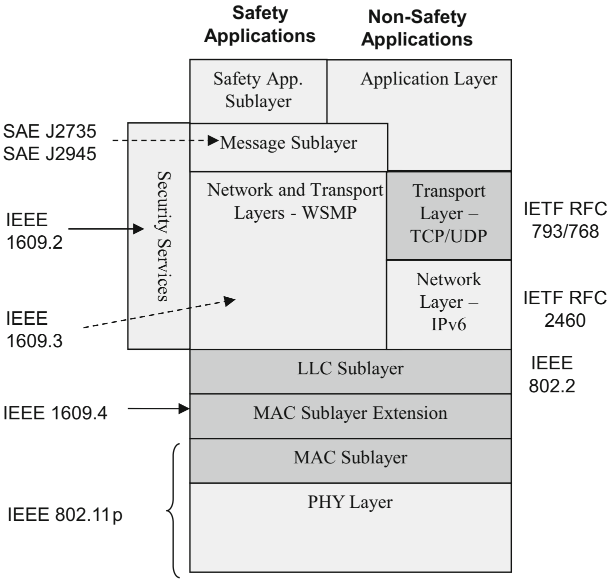
The rest of this paper is organized as follow. In Sect. 2, overview of the multi-channel operation provided by WAVE standard is provided. Section 3 discusses related works offering mechanisms to solve channel congestion problem. Sect. 4 illustrates our proposed safety communication based adaptive multi-channel assignment. In Sect. 5, the simulation model utilized in this work for the performance evaluation and test scenarios is given. Section 6 shows the simulation results and discussion. Finally, the paper is concluded in Sect. 7.

2 Multi-channel Operation in WAVE

The WAVE protocol architecture is shown in Fig. 2. The lower part of the protocol architecture is the IEEE 802.11p, which is the approved amendment to the IEEE 802.11. IEEE 802.11p specifies physical (PHY) layer and Medium Access Control (MAC) protocol supporting WAVE application. OFDM PHY with 10 MHz channel bandwidth is chosen based on the established technology of IEEE 802.11. Several key modifications lead to the creation of the 802.11p amendment in order to achieve a robust connection and a fast connection setup for moving vehicles.

On top of the PHY layer and MAC protocol provided by the IEEE 802.11p, DSRC employs the IEEE 1609 protocol stack, which consists of IEEE 1609.4, 1609.3, and 1609.2 standards. IEEE 1609.2 is for security services and IEEE 1609.3 is for network and

Fig. 2 WAVE protocol stack [6]



transport layer services including WAVE Short Message Protocol (WSMP). IEEE 1609.4 is defined as MAC extension to support multi-channel operation. With this extension, systems with one or more radios are able to switch among the available channels and can find each other. IEEE 1609.4 describes the channel intervals, which is divided by time to alternating CCH intervals and SCH intervals. Both CCH and SCH period are 46 ms long in addition with the 4 ms Guard Interval (GI). This results in 50 ms long for each CCH interval and SCH interval. CCH and SCH intervals pair as a Sync interval of 100 ms period. At the beginning of an interval, there is a Coordinated Universal Time (UTC) aligned, which provides the time synchronization from satellites by using Global Position System (GPS). This is the key concept of keeping accurate timing synchronization. If there are lacks of signal from satellite position systems or temporary signal loss, the vehicular devices can use distributed synchronize approach by receiving timing information signals from other devices over the air. Figure 3 displays continuous access channel operation provided by the IEEE 802.11p and alternating access multi-channel operation provided by the IEEE 1609.4.

DSRC is mainly designed for safety messages during CCH interval and for other types of services and applications during SCH interval. In continuous access mode, the device always tunes to the same channel, CCH or SCH. The concept of multi-channel operation in alternating access mode is to keep track of the start and the end of CCH and SCH intervals at all time. The vehicular devices would send safety messages throughout CCH interval for the safety benefit of other nearby vehicles. The messages that are sent during other specific channel interval will be kept in queues in correlation to the current active channel interval until the next channel interval cycle.

3 Mechanisms for Channel Congestion Control

As mentioned, decreasing service performance due to channel congestion problem is observed in [5]. Research works proposing mechanisms to solve congestion problem have therefore increased. Congestion control mechanisms can be categorized based on the priority consideration into two types including uni-priority mechanisms, which target the congestion caused by traffic of the same priority i.e. message from safety application

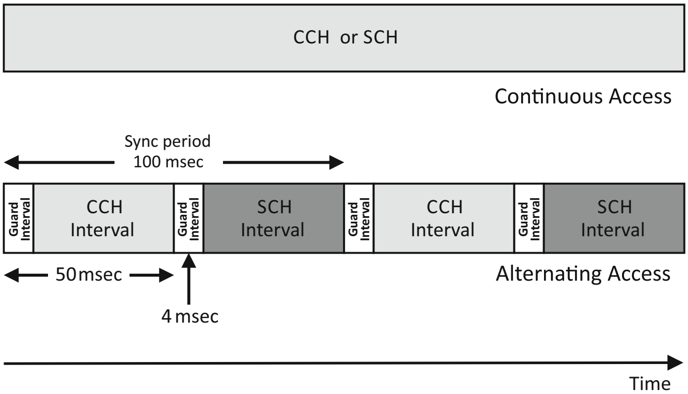


Fig. 3 The channel assignment based on IEEE 802.11p and IEEE 1609.4

typically, and multi-priority mechanisms, which try to provide safety message priority over other traffic. Multi-priority type considers that lower priority applications may exhaust the channel resource hence impact service quality. Under the umbrella of uni-priority mechanisms, [7] proposes Vehicular Collision Warning Communication (VCWC) protocol, which defines congestion control policies for emergency warning messages in order to provide low delivery delay as well as eliminating redundant emergency warning messages. For the multi-priority type, mechanisms proposed by [5] and [8] are examples. In [5], the authors proposed WAVE-enhanced Adaptive Broadcast (WAB) scheme, which dynamically adapts beacon transmit power to the channel condition by using a distributed load estimator metric and priority mechanisms. In [8], congestion control mechanism based on MAC transmission queue manipulation has been proposed. The idea is to provide safety message absolute priority over other traffic by dynamically reserve a fraction of bandwidth for such higher priority traffic with adaptive QoS parameters.

Different classification for congestion control mechanisms is presented in [9], in which information used for the mechanisms to derive their decision is considered. Accordingly, congestion control mechanisms can be divided into three classes consisting of reactive congestion control, proactive congestion control, and hybrid congestion control. In reactive congestion control approaches, first order information about the channel congestion status is used to decide the action. For the reactive algorithm, [10] proposes power or rate based congestion control, which adjusts transmit power or packet generation rate according to locally measured channel busy time. For the proactive type, information based models are used to try to estimate transmission parameters in order to avoid channel congestion. Vehicle-to-vehicle communication protocol approach for Cooperative Collision Warning (VCCW) [11], hop-by-hop proactive congestion control approach for VANETs [12], and Cross-layer Congestion Control (Cross-layer CC) [13] are examples of proactive mechanisms. Hybrid approaches attempt to combine the advantages of both proactive and reactive approaches. Examples of proposed algorithms under hybrid congestion control are combined transmit power and rate congestion control (Power & Rate combined CC) [14] and adaptive inter-vehicle communication control (AICC) [15].

In the next section, our proposed safety communication traffic-based adaptive multichannel assignment will be presented. Our approach concentrates on real-time channel congestion condition, hence it is more towards reactive type of congestion control. This is because the proposed mechanism tries to response to actual traffic condition dynamically and accordingly.

4 Proposed Safety Communication Traffic-Based Adaptive Multi-channel Assignment

Based on the standard IEEE 802.11p, continuous access channel operation is provided. In this mode, vehicular devices always tune to the CCH for safety message communication. In the case that there is no accident or low-density traffic condition (less warning messages being sent), vehicle drivers will not be able to use any other applications, which are available on SCHs. In such case, alternating access might be a better option. On the other hand, if there are a lot of safety messages being sent possibly due to large accident happening on the road or high-density traffic condition, devices operating with alternating access may loss certain amount of crucial information (i.e. safety messages). In this case, continuous access would provide a better service than that offered by using alternating access.

Since the situation on the road changes dynamically, suitable channel assignment should be offered on a real-time basis and in response to communication traffic demand. In this work, safety communication traffic-based adaptive multi-channel assignment for VANET is proposed. The aim is to provide channel utilization flexibility through dynamic channel assignment. The proposed mechanism takes into account communication traffic condition on both CCH and SCH (in case device currently operates with channel switching mode) and decides on multi-channel assignment accordingly. In other words, CCH intervals can be extended according to the degree of safety communication traffic. As a result, spectrum resource can be efficiently utilized while trying to make sure safety messages can always be distributed.

The process of our proposed scheme consists of two major steps including the congestion measurement process and the multi-channel assignment.

4.1 Congestion Measurement

In this step, channel condition is observed in order to detect the level of channel congestion. The methods for channel congestion detection have been proposed in several existing works. In [6], two kinds of congestion detection methods are introduced. The first one is the event-driven detection, which monitors the safety applications for the current activities. The second method is the measurement-based detection, in which each device periodically senses the channel usage level and detects congestion when the measured usage level exceeds the predefined threshold.

Refer to the measurement based congestion detection proposed in [6], adaptation has been done and our congestion measurement and estimation is proposed by using the following equations:

$$Channel\,Usage_{CCH} = \frac{D_{CCH\_busy} + D_{CCH\_backoff}}{D_{CCH}} \times 100\,\% \tag{1}$$

$$Channel\,Usage_{SCH} = \frac{D_{SCH\_busy} + D_{SCH\_backoff}}{D_{SCH}} \times 100\,\% \tag{2}$$

Equations. (1) and (2) denote the percentage that CCH and SCH are busy during each monitoring interval, respectively. D_{CCH_busy} and D_{SCH_busy} are the estimated channel busy duration of CCH and SCH. $D_{CCH\_backoff}$ and $D_{SCH\_backoff}$ are the estimated backoff duration of CCH and SCH. D_{CCH} and D_{SCH} are the durations of CCH interval and SCH interval, correspondingly. The main difference from the measurement-based congestion detection proposed by [6] is our congestion estimation considers condition of both CCH and SCH. As discussed earlier, when there is high load on SCH and CCH is not congested, it is possible to gain benefit from using such SCH offered services, however with suitable multi-channel assignment. Note that when the current channel assignment is set to operate on CCH continuously, only Eq. (1) is used for the channel congestion estimation.

4.2 Multi-channel Assignment

This step takes the outcome from channel congestion estimation, which considers the channel usage of both CCH and SCH, and uses simple rule-based method to decide on multi-channel assignment. In every decision making interval (100 ms in this case), channel usage on both CCH and SCH will be calculated via congestion measurement process.

These parameters will be used as input to the decision making engine developed here. As a result, decision for multi-channel assignment pattern of the next Sync interval (100 ms) is made. Figure 4 illustrates the flow diagram of our proposed rule-base decision making engine.

Since safety application is the first priority, the process starts by comparing CCH usage level $(Channel\,Usage_{CCH})$ with the set threshold $(CCH_{threshold})$. If the system detects that CCH is busy $(Channel\,Usage_{CCH} \geq CCH_{threshold})$, in the next Sync interval, device will maintain on CCH only in order to support high safety application traffic. On the other hand, if the system detects that CCH is not busy $(Channel\,Usage_{CCH} < CCH_{threshold})$, channel usage value of SCH will be considered by comparing SCH usage level $(Channel\,Usage_{SCH})$ with the set threshold $(SCH_{threshold})$. If SCH is busy $(Channel\,Usage_{SCH} \geq SCH_{threshold})$, in the next Sync interval device will follow alternating access with 50 ms CCH interval and then switch to SCH for 50 ms SCH interval. However, if there is no traffic one SCH $(Channel\,Usage_{SCH} = 0)$, CCH continuous access will be chosen for the next Sync interval. Note that in case SCH channel usage is not available, alternating access pattern will be used in the next Sync interval in order to observe SCH congestion level. By using this proposed

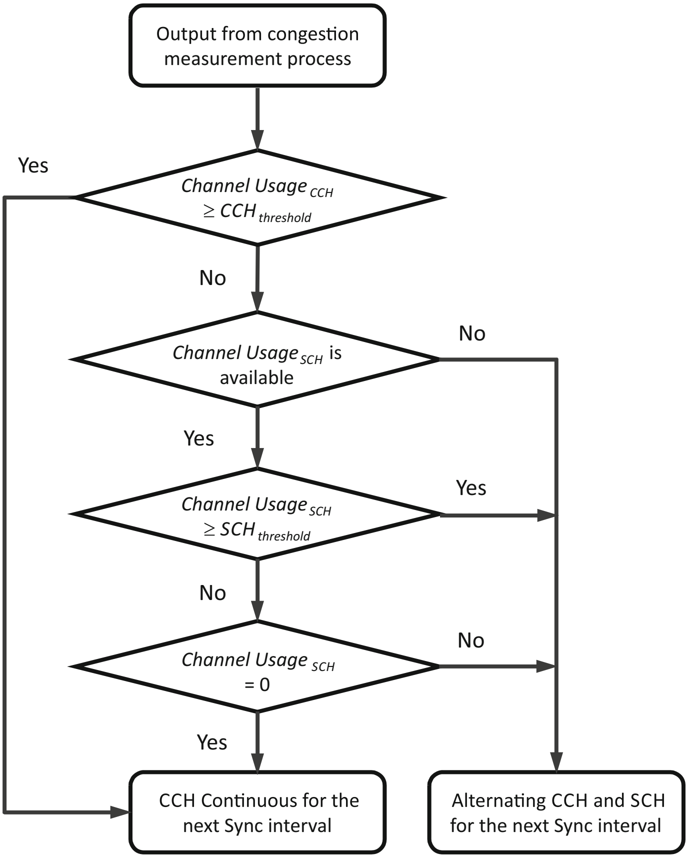


Fig. 4 Rule-base decision making engine

method, node can make use of the time synchronization priory utilized by traditional alternating access mode of IEEE 1609.4.

In Fig. 5, the proposed safety communication traffic-based adaptive multi-channel assignment is presented. As can be seen, the method provides dynamic extension of CCH period in response to increasing traffic congestion condition of safety applications. However, situation with low safety application traffic but high SCH traffic can be supported by alternating access as shown in the lowest channel assignment pattern in Fig. 5.

5 Simulation Model and Test Scenarios

Simulation model is setup in order to observe the performance of our proposed safety communication traffic-based adaptive multi-channel assignment. The simulation model used in this work is developed based on OMNET++ [16] as a network simulation framework. Veins [17] is utilized in order to extend the network simulation to cover vehicular communication. For the road traffic simulator, SUMO (Simulation of Urban Mobility) [18] is integrated to OMNET++ and Veins platform. SUMO is used to provide road traffic simulation for realistic node mobility.

Shown in Fig. 6 is the generated traffic scenario, which is used in our performance evaluation. The realistic highway map has been imported from Open Street Map (OSM) [19] covering 10 kilometers highway. Each direction of the highway consists of two lanes: a fast lane and a slow lane. With this created road traffic scenario, two major traffic conditions have been simulated including the scenario with high safety application traffic and scenario with high SCH traffic demand. The traffic condition generated for our performance testing will be further elaborated in the next section along with the simulation results.

Table 1 presents simulation parameters used in this test.

The carrier frequency and some other parameters used in this test as stated in Table 1 are referred to those recommended by the standard. For a realistic scenario, certain parameters are referred to that used in [20].

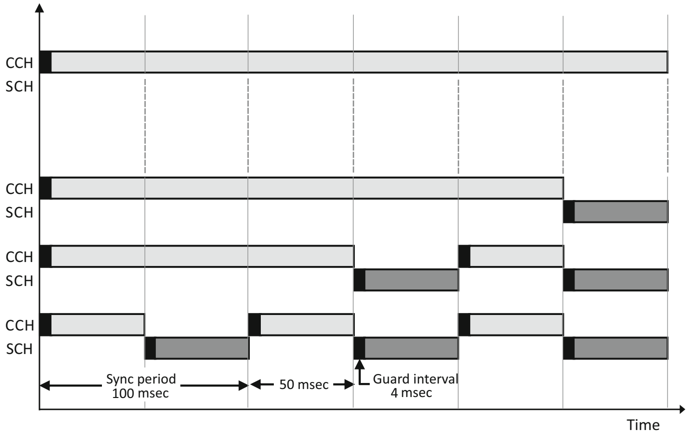


Fig. 5 Channel assignment based on the proposed mechanism

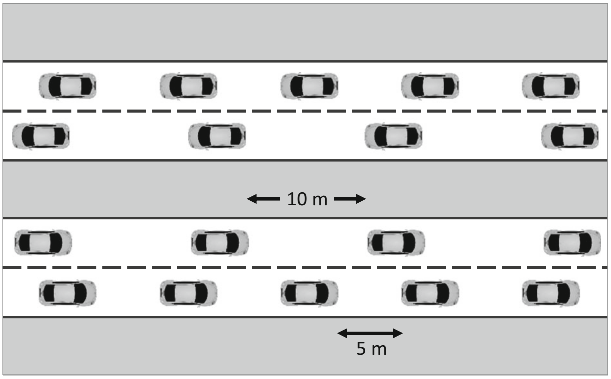


Fig. 6 Simulation test scenario

Table 1 Simulation parameters

Parameter	Value
Carrier frequency	5.9 MHz
Data rate	6 Mbps
Beacon interval (safety messages)	
High safety traffic case	100 ms
High SCH traffic with low safety traffic case	600 ms
Beacon size/packet size	400 B
Maximum transmission power	100 mW
Receiver sensitivity	−89 dBm
Vehicle length	5 m
Distance between cars (fast lane, slow lane)	10, 5 m
Vehicle speed (fast lane, slow lane)	14, 10 m/s

6 Simulation Results and Discussion

Using our simulation setup discussed in the previous section, system performance evaluation has been done. To prove our concept of the proposed method, there are two communication traffic cases being simulated here. The aim is to observe the flexibility of the proposed system in handling different road situations and provide suitable system adaptation accordingly. The first case being simulated is the situation with high safety application traffic and the second case is the situation with high SCH traffic demand while there is low safety application traffic being generated. In the next subsections, each traffic situation will be elaborated and the simulation results will be given.

6.1 High Safety Application Traffic Case

This case mimics the situation when there are large amount of safety messages being broadcasted possibly due to large accident or disruption on the road such as road work, vehicle breakdown, etc. In this test, only beacon messages are being generated and sent on CCH for safety application. The beacon interval is set to be broadcasted every 100 ms.

Number of cars is varied in order to increase traffic congestion. In our evaluation, system performance is observed in terms of system throughput and average packet delay. Figures 7 and 8 show the simulation results for system throughput and average packet delay while number of cars is being varied from 20 to 200.

In Fig. 7, the system throughput performance comparison is given for the system operating with continuous access of the standard IEEE 802.11p, alternating access of the standard IEEE 1609.4, and our proposed safety communication traffic-based adaptive multi-channel approach while number of cars is varied from 20 to 200. It can be seen that as number of cars increases, system throughput achieved from all channel assignment methods rises up according to increasing amount of safety beacon messages. System with continuous access provides the best system throughput especially with large number of cars. It is obvious since the system operates solely on CCH, however vehicle drivers have no access to other available services on SCH. One the other hand, alternating access offers the lowest system throughput. This is due to the fact that half of the time devices switch to operate on SCH. It can be seen that our proposed method provides considerably higher throughput than that offered by the system with alternating access, although slightly lower throughput compared with the continuous access. The benefit is that users can also utilize other SCH-based services with our proposed method. As mentioned, estimated channel usage is utilized to compare with CCH threshold and SCH threshold, which are initially set in this test. These values could be tuned or dynamically set according to the system or situation. This issue will be further investigated in our future work. The mechanism for adjusting congestion detection threshold and decision making process will be our next concern in order to tune the system to offer closer result to the baseline, in this test case the continuous access.

In Fig. 8, the average packet delay performance comparison is given for the system operating with continuous access, alternating access, and our proposed approach while number of cars is varied from 20 to 200. Average packet delays for all systems are in general higher at low number of cars than at high number of cars. It can be seen that at low number of cars, continuous access mode offers the lowest average packet day and our proposed scheme offers slightly higher delay. Alternating access provides the largest delay at low number of cars. When the road has large number of cars, all systems perform

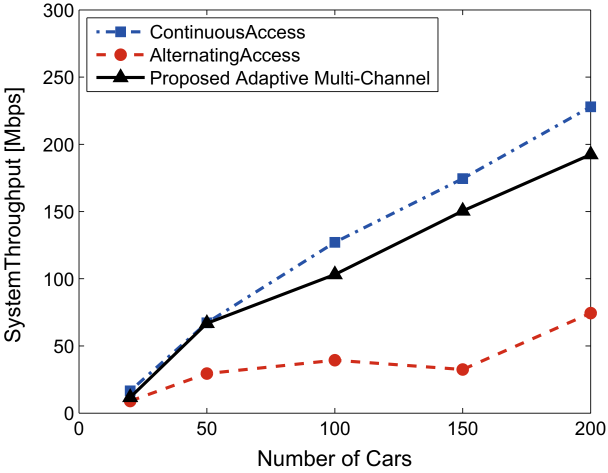
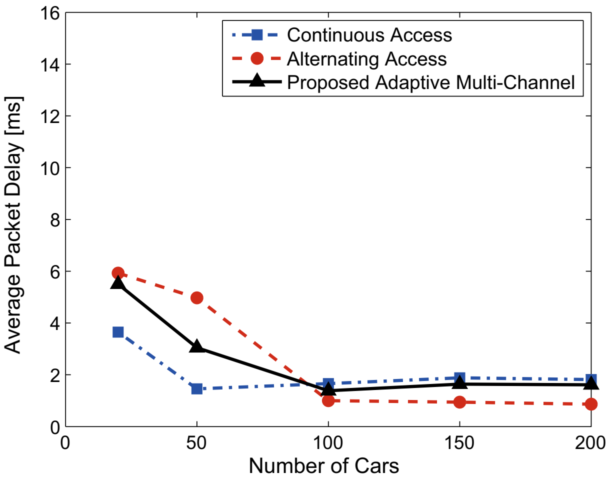


Fig. 7 System throughput performance comparison for high safety application traffic case

Fig. 8 Average packet delay performance comparison for high safety application traffic case

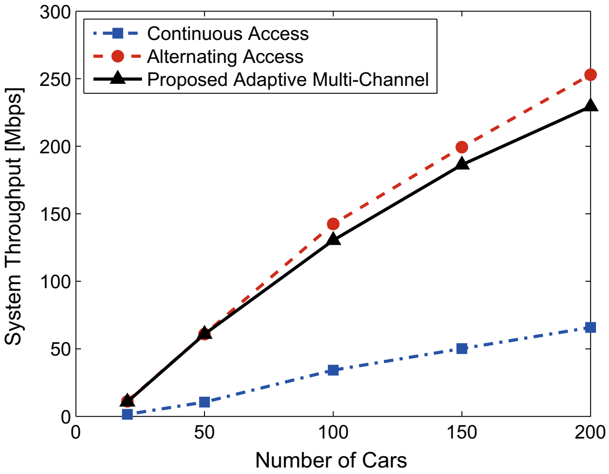


similarly although alternating access now offer lowest delay while continuous access offers highest delay. Our proposed system maintains delay level between the other two accessing modes of the standards.

6.2 High SCH Traffic with Low Safety Traffic Case

To observe system flexibility in handling different situations, this second test case is implemented. In this case, both safety beacon messages and SCH service messages are generated. High SCH traffic is generated mimicking high demands for application services on SCH, while there is low safety beacon messages. The beacon interval is set to 600 ms. Figures 9, 10, and 11 show the simulation results for throughput performance comparison while number of cars is being varied from 20 to 200. In Fig. 9, system throughput plots for all three approaches are displayed. The system with continuous access offers rather low

Fig. 9 System throughput performance comparison for high SCH traffic case



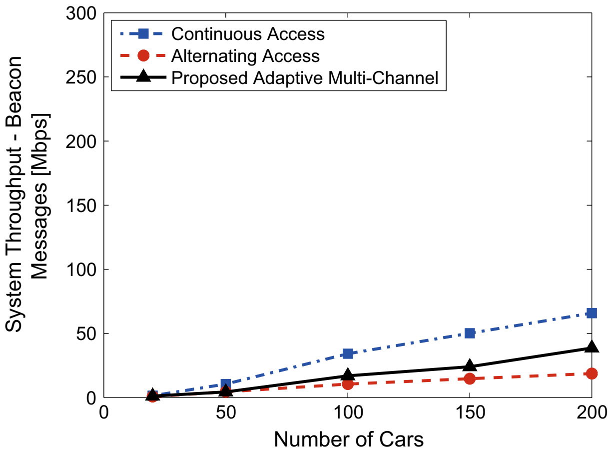
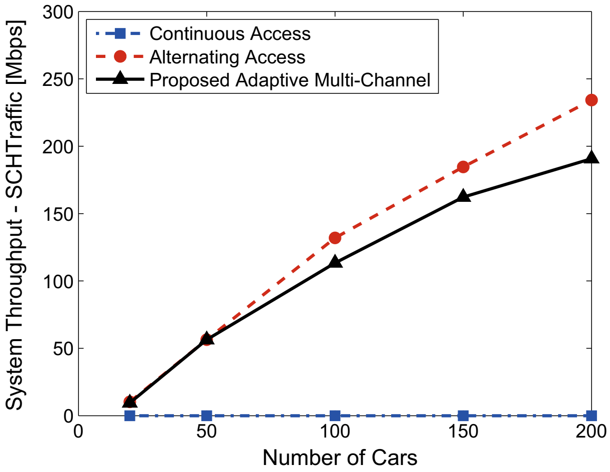


Fig. 10 Throughput performance comparison of beacon message for high SCH traffic case

Fig. 11 Throughput performance comparison of SCH traffic for high SCH traffic case



system throughput for all number of cars. It is obvious that the entire system throughput measured from this system is solely the safety beacon traffic since the system is not offering any SCH services. On the other hand, system with alternating access provides the highest throughput since it allows users to operate on SCH half of the time. Our proposed method offers rather close result although slightly lower throughput performance at high number of cars to that offered by alternating access. With our current decision making engine, the highest portion of SCH intervals would be half of the Sync interval, which is similar to the channel switching pattern of alternating access.

Figure 10 illustrates the throughput when considering only safety messages of all three systems and Fig. 11 presents the throughput achieved from SCH service messages only of all three systems. It can be seen that if only safety beacon is taken into account, system with continuous access provides higher throughput than the others two systems. However,

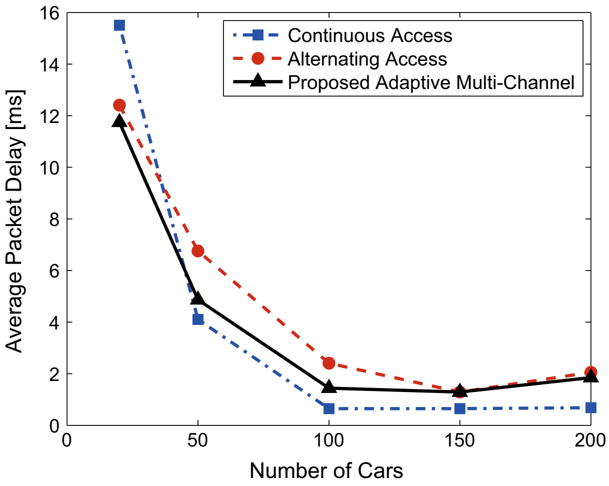


Fig. 12 Average packet delay performance comparison for high SCH traffic case

our proposed method offers better result than alternating access system. When only SCH is counted, best throughput is offered by system with alternating access while our proposed method offers slightly lower results. By operating only on CCH, the system with continuous access does not support any SCH traffic, hence the zero count of throughput in Fig. 11.

In Fig. 12, the average packet delay performance comparison is given for the system operating with continuous access, alternating access, and our proposed approach while number of cars is varied from 20 to 200. For average packet delay performance, the general trend is similar to result obtained in the first test case. Packet delay is higher at low number of cars and getting lower to somewhat stable state at higher number of cars. The delay of all three systems are in the same trend with similar range.

7 Conclusion

This paper presents safety communication based adaptive multi-channel assignment for DSRC. With this proposed method, system always aware of real-time traffic situation via our congestion measurement process. Then, suitable multi-channel assignment can be achieved from the decision making process. As a results, the channel assignment pattern changes dynamically to best respond to the changing traffic situations. Simulation has been used to evaluate system performance of our proposed mechanism in comparison with the continuous access of the IEEE 802.11p and the alternating access of the IEEE 1609.4. Two test scenarios have been implemented including the test case with high safety beacon message and the test case with high SCH traffic. The simulation results ensure that using continuous access benefits in the first test case, where there is large CCH traffic, however it poorly performs in the second case. On the other hand, alternating access offers best performance in second test case, since it can well support transmission of SCH service messages but performs poorly in the first test case. Our proposed technique provides system flexibility to cope with different traffic situations via dynamic adaption of multi-channel assignment. Shown by the simulation results, system with our method obtains rather high performance in both cases. For future work, mechanism to set the evaluation thresholds as well as decision making enhancement methods will be studied.

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References

1. Dahiya, A., & Chauhan, R. K. (2010). A comparative study of MANET and VANET environment. *Journal of Computing*, *2*(7), 87–92.
2. Chen, Q., Jiang, D., & Delgrossi, L. (2009). IEEE 1609.4 DSRC multi-channel operations and its implications on vehicle safety communications. In *2009 IEEE vehicular networking conference (VNC)* (pp. 1–8).
3. IEEE (2011). IEEE standard for wireless access in vehicular environments (WAVE)multi-channel operation. In *IEEE Std 1609.4-2010* (Revision of IEEE Std 1609.4-2006) (pp. 1–89).
4. IEEE. (2014). IEEE guide for wireless access in vehicular environments (WAVE)—Architecture. IEEE Std 1609.0-2013 (p. 178).
5. Torrent-Moreno, M., Santi, P., & Hartenstein, H. (2005). Fair sharing of bandwidth in VANETs. In *The 2nd ACM International workshop on vehicular ad hoc network (VANET)* (pp. 49–58).
6. Kenney, J. (2013). Dedicated short range communication (DSRC) applications tutorial. In *IEEE 802.11-13/0541r1*. https://mentor.ieee.org/802.11/dcn/13/11-13-0541-01-0wng-dsrc-applicationstutorial.pptx.
7. Yang, X., Liu, L., Vaidya, N. H. & Zhao, F. (2004). A vehicle-to-vehicle communication protocol for cooperative collision warning. In *The first annual international conference on mobile and ubiquitous systems: networking and services (MOBIQUITOUS 2004)* (pp. 114–123).
8. Zang, Y., Stibor, L., Cheng, X., Reumerman, H.-J., Paruzel A., & Barroso, A. (2007). Congestion control in wireless networks for behicular safey application. In *The 8th European wireless conference* (p. 7).
9. Sattari, M. R. J., Nooor, R. M., & Keshavarz, H. (2012). A taxonomy for congestion control algorithms in vehicular ad hoc networks. In *IEEE International conference on communication, networks and satellite (ComNetSat)* (pp. 44–49).
10. Khorakhun, C., Busche, H., & Rohling, H. (2008). Congestion control for VANETs based on power or rate adaptation. In *International workshop on intelligent transportation (WIT)*.
11. Yang, X., Liu, J., Vaidya, N. F., & Zhao, F. (2004). A vehicle-to-vehicle communication protocol for cooperative collision warning. In *The first annual international conference on mobile and ubiquitous system, network Services (MobiQuitous)* (pp. 114–123).
12. Wischhof, L., & Rohling, H. (2005). Congestion control in vehicular ad hoc networks. In *IEEE international conference on vehicular electronics and safety* (pp. 58–63).
13. Zang, Y., Stibor, L., Cheng, X., Reumerman, H.-J., Paruzel, A., & Barroso, A. (2007). Congestion control in wireless networks for vehicular safety applications. In *The 8th European wireless conference* (p. 7).
14. Baldessaro, R., Scanferla, D., Le, L., Zhang, W., & Festag, A. (2010). Joining forces for VANETs: A combined transmit power and rate control algorithm. In *International workshop on intelligent transport (WIT)*.
15. Huang, C.-L., Fallah, Y. P., Sengupta, R., & Krishnan, H. (2010). Adaptive intervehicle communication control for cooperative safety systems. *IEEE Network*, *24*(1), 6–13.
16. Omnetpp.org. (2014). OMNeT++ discrete event simulator Home. http://www.omnetpp.org. Accessed February 2015.
17. Veins.car2x.org. (2015). Veins. http://veins.car2x.org. Accessed February 2015.
18. Pattberg, B. (2015). DLR—Institute of transportation systems—SUMO Simulation of urban mobility. *Sumo-sim.org*. http://sumo-sim.org/. Accessed February 2015.
19. Openstreetmap.org. OpenStreetMap. http://www.openstreetmap.org/.
20. Alaa, M., Abdala, M. A., & Al-Sherbaz, A. (2014). Evaluation study of IEEE 1609.4 performance for safety and non-safety messages dissemination. *International Journal of Enhanced Research in Science Technology and Engineering*, *3*(11), 29–36.

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