How Much of DSRC is Available for Non-Safety Use?

Zhe Wang and Mahbub Hassan
School of Computer Science and Engineering
The University of New South Wales
Sydney 2052, Australia
Email: {zhewang, mahbub}@cse.unsw.edu.au

Technical Report
UNSW-CSE-TR-0814
May 2008

THE UNIVERSITY OF NEW SOUTH WALES

School of Computer Science and Engineering
The University of New South Wales
Sydney 2052, Australia

Abstract

The Dedicated Short Range Communication (DSRC) technology is currently being standardized by the IEEE to enable a range of communication-based automotive safety applications. However, for DSRC to be cost-effective, it is important to accommodate commercial non-safety use of the spectrum as well. The co-existence of safety and non-safety is achieved through a periodic channel switching scheme whereby access to DSRC alternates between these two classes of applications. In this paper, we propose a framework that links the non-safety share of DSRC as effected by the channel switching to the performance requirements of safety applications. Using simulation experiments, we analyze the non-safety opportunity in the DSRC under varied road traffic conditions. We find that non-safety use of DSRC may have to be severely restricted during peak hours of traffic to insure that automotive safety is not compromised. Our study also sheds interesting insights into how simple strategies, e.g., optimizing the message generation rate of the safety applications, can significantly increase the commercial opportunities of DSRC. Finally, we find that adaptive schemes that can dynamically adjust the switching parameters in response to observed traffic conditions may help in maximizing the commercial use of DSRC.

1 Introduction

To combat road fatalities, the U.S. Federal Communication Commission (FCC) has allocated a 75MHz spectrum at 5.9GHz for vehicle-to-vehicle and vehicle-to-infrastructure communications. The proposed vehicular communication technology, known as the Dedicated Short Range Communication (DSRC), is currently being standardized by the IEEE [1,3]. Many major car manufacturers have responded positively and are actively working together in bringing this promising technology into fruition [5,6].

Although the primary purpose of DSRC is to enable communication-based automotive safety applications, e.g., cooperative collision warning (CCW), the standard also provisions for a range of non-safety applications, from electronic toll collection to multimedia downloading [5]. The motivation for allowing non-safety over DSRC is to create commercial opportunities thereby making the DSRC technology more cost-effective. Commercial operators wishing to conduct business over DSRC will be expected to acquire the appropriate spectrum licenses.

For non-safety to coexist with safety applications over the same DSRC spectrum, it is absolutely necessary to have proper mechanisms in place to protect safety communications from the harmful interference of non-safety data transmissions. To this end, the DSRC standard divides the entire 75MHz spectrum into seven 10MHz channels and reserves one of the channels, called *control channel* (CCH), exclusively[1] for safety communications. The remaining six channels, referred to as *service channels* (SCHs), are to be used for non-safety applications.

At first, it may appear that a large share of the DSRC (6 out of 7 channels) is available for non-safety communications. However, continuous non-safety communication on a SCH would be possible only if *all* DSRC devices were capable of simultaneously monitoring the CCH while exchanging non-safety data on SCH. To accommodate single radio DSRC devices that must switch between CCH and SCH to support both safety and non-safety, it is mandatory for all devices, single or dual-radio, to synchronize their safety (and consequently non-safety as well) transmissions. The synchronization requirement leads to the cyclic transmission phenomenon in vehicular networks where safety activities on CCH are followed by non-safety on SCH in a repetitive fashion. In such cyclic transmissions, the share of DSRC available for non-safety is strictly given by the length of the two intervals. For non-safety to avail a large share of DSRC, the safety interval has to be very small compared to the non-safety interval.

Clearly, to answer the question posed in the title of this paper, one has to work out the channel intervals that would satisfy the requirements of safety applications. In this paper, we propose a framework to derive these intervals as a function of the required updating frequency and communication reliability for safety messaging, the latter being dependent on the vehicular traffic density on the roads. The framework is numerically analyzed using detailed simulations of the DSRC channel coordination scheme. We discover several interesting results. We find that a large share of DSRC is available for non-safety usage only in low to moderate traffic conditions. Contrary to the first impression, non-safety activities may have to be severely restricted, or even shut down altogether, in high density traffic. We also show how simple strategies, e.g., optimizing the message generation rate of the safety applications, can significantly increase the commercial opportunities of DSRC. Finally, we observe that, given traffic density on our roads varies over time and space, it may be necessary for the DSRC channel synchronization to adaptively adjust the safety and non-safety intervals based on the traffic situation (or time of day).

[1]Except for some occasional service advertisements at low priority.

The rest of the paper is organised as follows. Section 2 reviews the DSRC channel synchronization and coordination scheme proposed in the IEEE standard. In Section 3, we present our approach to derive the channel intervals, and consequently the share of non-safety usage, from the performance requirements of safety applications. The simulation setup is described in Section 4 followed by the discussion of the results in Section 5. We briefly review the related work in Section 6 before drawing our conclusions in Section 7.

2 DSRC Channel Synchronization Scheme

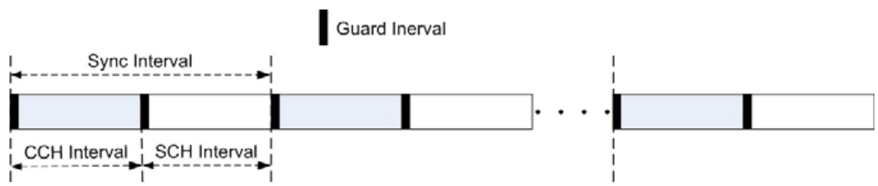

Figure 1: DSRC Channel Synchronization and Coordination Scheme

Figure 1 shows the channel synchronization and coordination scheme proposed by the IEEE 1609.4 standard [4]. It is assumed that the devices participating in the communication are synchronized to a common time base through external sources such as GPS. The periodically repeated Sync Interval (SI) contains a CCH Interval (CCHI) followed by a SCH Interval (SCHI), along with two Guard Intervals (GIs). A GI is used at the beginning of each channel interval to enable the radio devices to complete channel switching and account for any synchronization inaccuracy. The radio devices must stay in CCH to transmit and receive the safety application packets. The communications of non-safety applications are performed during the SCHI.

At this stage, the standard has not recommended any specific values for the CCHI, SCHI, and GI. However, in the following section, we use these variables to reason about the share of DSRC that is available for conducting non-safety activities in the vehicular environment.

3 Problem Formulation

With the channel coordination scheme explained in the previous section, the share of DSRC available for non-safety use is directly given by the the fraction of time a vehicle stays in SCH. Let us denote this fraction as $\rho = \frac{\mathrm{SCHI}}{\mathrm{SI}}$. Clearly, to support potentially unlimited non-safety applications, we would like the ρ to be as high as possible. However, because safety has the priority, ρ would be limited by the performance requirements of safety applications.

Typical safety applications, e.g., the CCW, rely on vehicles acquiring the positional and kinematic status information from all nearby vehicles at a certain frequency f, typically about 10Hz [10]. To fulfil this requirement, both the SI and the CCHI parameters have to be adjusted properly. In the context of channel switching, status information can be exchanged only during the CCHI. Therefore, the fHz requirement could be met by setting SI equal to $1/f$ seconds, which would give the vehicles f opportunities per second to tune to the CCH.

In addition to setting the SI to 1/f, we also need to make sure that vehicles are indeed able to successfully exchange their status information at every CCHI. The status information are embedded in broadcast packet and transmitted in the channel which is accessed abiding the contention based 802.11 MAC protocol. It is widely perceived that the broadcast channel will be congested when the traffic density is high [6, 7]. When the channel is congested, the packet loss rate is high so the status information updating becomes unreliable. We define the reliability of safety applications under the multi-channel operation as the probability of receiving at least one packet from a given vehicle within a CCHI. Intuitively, confining the broadcast transmission within a shorter period of time (i.e. shorter CCHI) will aggravate the channel congestion and the shorter this period is, the more packet loss will happen. Therefore, the reliability R is a function of CCHI and the function monotonically increases with CCHI. To guarantee a reliability requirement r, there exists a minimum CCHI so that:

$$\text{for any CCHI} \geq \mathrm{CCHI_{min}},\ \mathrm{R(CCHI)} \geq \mathrm{r} \tag{1}$$

Based on the above analysis, we can derive the maximum value of ρ as:

$$\rho = \begin{cases} \frac{\mathrm{SI}-\mathrm{CCHI_{min}}}{\mathrm{SI}} = \frac{1/f-\mathrm{CCHI_{min}}}{1/f}, & \mathrm{CCHI_{min}} < 1/\mathrm{f} \\ 0, & \text{otherwise} \end{cases} \tag{2}$$

With Equation 2, ρ is linked with the updating frequency requirement f. Another variable in this equation, $\mathrm{CCHI_{min}}$ is decided by the reliability requirement r. In the following two sections, $\mathrm{CCHI_{min}}$ is derived by simulation experiments.

4 Simulation Setup

In this section, we describe our simulation testbed that simulates safety communications in the framework of DSRC channel synchronization and coordination scheme reviewed in Section 2.

4.1 DSRC Implementation

The PHY and MAC layer standards of DSRC (a.k.a IEEE 802.11p) is developed based on IEEE 802.11a. The QualNet [2] software is widely used to simulate IEEE 802.11 networks for its detailed implementation of the PHY and MAC layers of the 802.11 standards. The simulation experiments of this are performed based on the QualNet 3.9.5 simulator with several modifications to represent the characteristics of DSRC.

First, we modified the PHY layer parameters of 802.11a to conform the DSRC radio specifications. According to the draft DSRC standard [3], the carrier frequency is set to 5.9GHz and the channel bandwidth is reduced from 20MHz to 10MHz. Accordingly, the OFDM symbol duration and short symbol length are doubled. All broadcast communications use 6Mbps data rate (QPSK modulation with 1/2 coding rate). The two-ray model is chosen to calculate the radio signal path loss with constant shadowing effect. The transmission power and the receiving sensitivity of all the nodes are tuned achieve the transmission rage of 200 meters.

Second, an add-on module is developed for 802.11 MAC to implement the DSRC multi-channel operation specified in IEEE 1609.4 [4]. The synchronization is assumed to be achieved through external sources without incurring in-band communication overhead, so all the nodes enter and leave CCH at exactly the same time. The IEEE 1609.4 patched 802.11 MAC only delivers (collects) broadcast packets to (from) the physical layer within CCHI. The CCHI, SCHI and GI values are configurable but all the nodes use the same values in a single simulation run. Because only the performance of safety packets broadcasting is considered in this study, the SCHI and GI have no effect on the results so they remain unchanged (SCHI=10ms, GI=0ms)

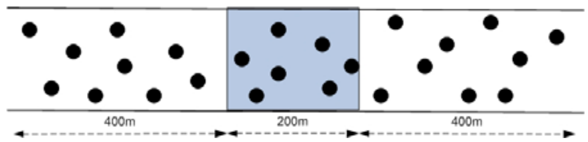

Figure 2: A typical section of a 4-lane road

in all the simulations. Due to the carrier sensing and random backoff of 802.11 MAC, there might be some packets remaining in the MAC buffer waiting to be transmitted when the radio leaves CCH and starts switching to SCH. We believe that the information contained in these packets are obsolete and they should not compete the channel resource with newly generated packets. In our implementation, these packets are discarded at the beginning of each CCHI.

Third, a broadcast packet generator/collector is developed to simulate the vehicular safety applications. The generator randomly generates k 100-byte packets within each CCHI. k is configurable but all the nodes use the same value in a single simulation run. The generation time of each packet are uniformly distributed in [0,CCHI]. The collector keeps a record for all the nodes within the transmission range and update the record only when the first packet is received within a CCHI.

4.2 Vehicular Environment Setup

To simulate a typical section of a 4-lane road, we set the simulation area to be a 20m×1000m rectangle. Compared with the transmission range (200m), the length of the area (1km) is long enough to observe the effect of hidden node effect. All the nodes are uniformly distributed in this area. For the situation of high traffic density, in the same lane, the distance between two adjacent vehicle is around 10 meters, so the total number of nodes to 400. We define the traffic density n as the average number of other nodes within a node's transmission range. Given the transmission range and the length of the area, n equals 160 in the high density scenario. We also simulate the medium and low density scenario, in which n equals 80 and 40 respectively. The simulation time of each possible configuration is dynamically set so that the simulations are run sufficiently long to reach steady states (at least 2000 cycles were simulated in each experiment).

All the nodes take part in the communication, however, to avoid edge effects, the statistics are only collected from the nodes located in the central 200m area (the shaded area in Figure 2). We name the nodes inside this area reference nodes (RN). In vehicular networks, due to the hidden node and power capture effects, the probability of a packet being successfully received decreases with the distance between the sender and receiver [11], so the reliability is a function of the distance between two vehicles. Because the traffic density is changed and the positions of nodes are randomly chosen, we cannot get the any arbitrary distance between the sending and receiving node. For ease of comparing the results of different traffic density, when collecting statistics of a RN, we divide the sending nodes in this RN's record list into 10 groups (10±10m, 30±10m, ..., 190±10m) according to the distance between the sending node and the RN, and take average of the sending nodes in the same group.

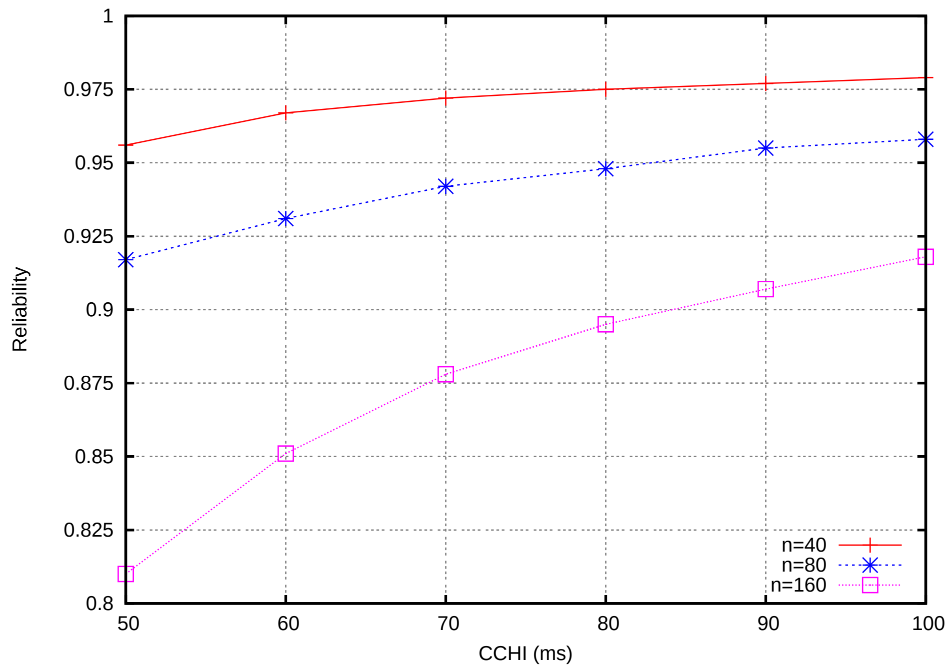

Figure 3: Reliability (90±10m) as a function of CCHI

Table 1: CCHI for reliability 0.90

Vehicle density	40	80	160
CCHI	30ms	50ms	90ms

Table 2: CCHI for reliability 0.95

Vehicle density	40	80	160
CCHI	50ms	90ms	170ms

5 Simulation Results

First, we run the simulations with k equals to 1, i.e., each node transmits one packet per CCHI. The reliability at the distance of 90±10m for different traffic densities are plotted in Figure 3. It is clearly shown that the reliability increases monotonically with the CCHI. With the curves in Figure 3, for a certain reliability requirement, we can find the $\mathrm{CCHI}_{\mathrm{min}}$ that guarantees the required reliability. With the derived $\mathrm{CCHI}_{\mathrm{min}}$, ρ can be calculated using Equation (2).

Figure 3 also shows that $\mathrm{CCHI}_{\mathrm{min}}$ is decided by the traffic density. For example, in the medium density situation, the CCHI must be more than 90ms to achieve a 0.95% reliability, while in the low density situation, CCHI larger than 50ms will guarantee the same reliability. Table 1 and 2 list the minimum CCHI for the 90% and 95% reliability respectively. It can be seen from these two tables that $\mathrm{CCHI}_{\mathrm{min}}$ is tripled with traffic density increased from low to high, which implies that ρ drops dramatically with the traffic density.

To quantitatively illustrate ρ, we assume that f equals to 10Hz[2]. According to the analysis in Section 3, SI equals 100ms in this case. Based on the results in Table 1 and 2, the derived ρ are shown in Figure 4. We can observe that when the traffic density is high, ρ is very small with the 90% reliability. Furthermore, it becomes zero if the reliability requirement is 95%, which means the non-safety applications cannot be operated because the radio devices have to stay in the CCH all the time for the safety communications.

[2] 10Hz is considered by many researchers [7, 10]

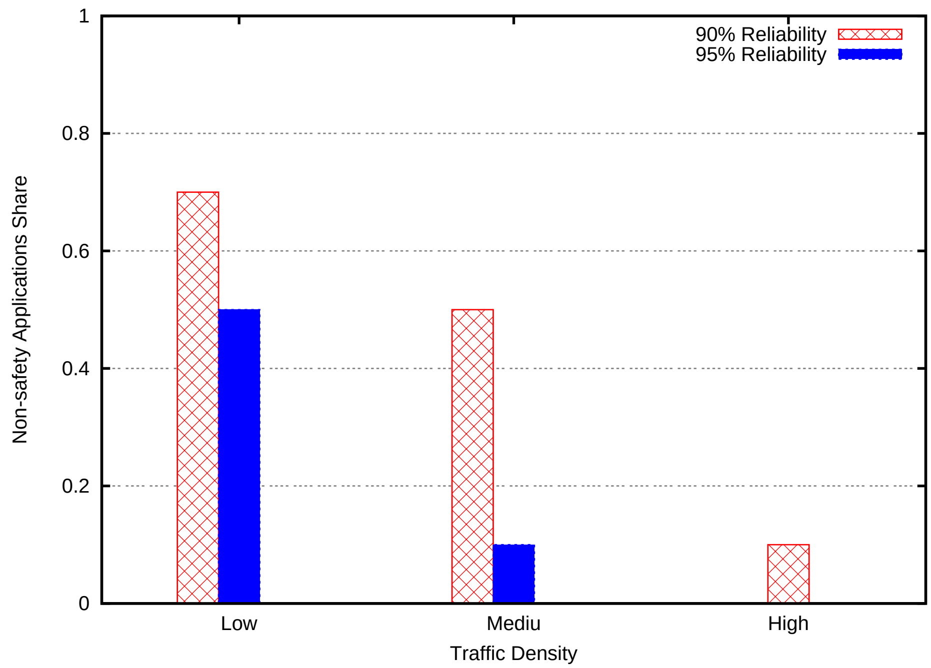

Figure 4: Share of non-safety applications for different traffic densities

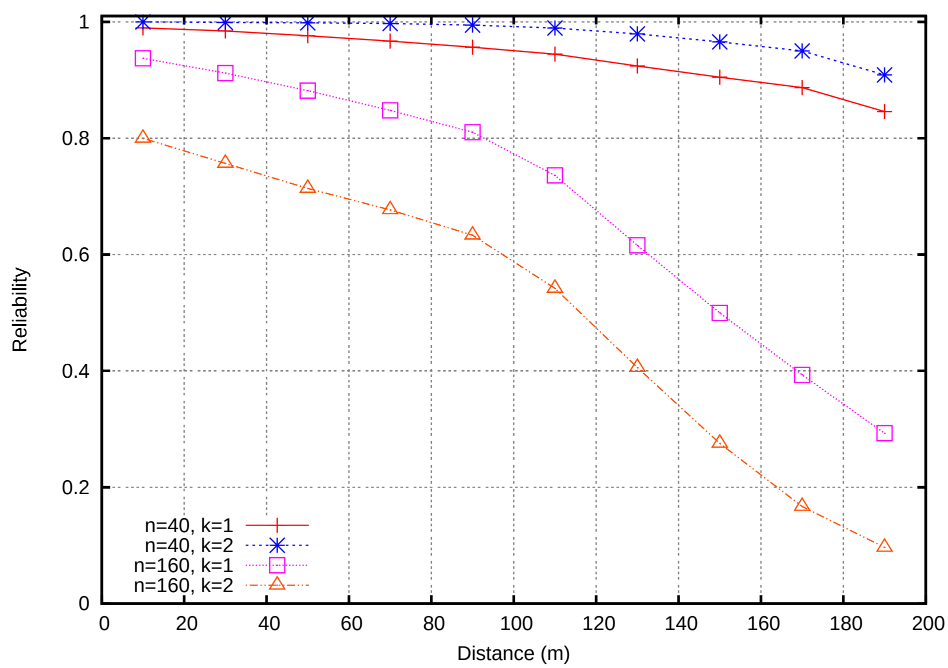

Figure 5: Reliability achieved when CCHI=50ms

The performance results shown in Figure 4 were derived with the most basic packet generation scheme with $k = 1$. It has been shown by other researchers that broadcast reliability could be improved by repeating the broadcast several times. To be more precise, it was discovered

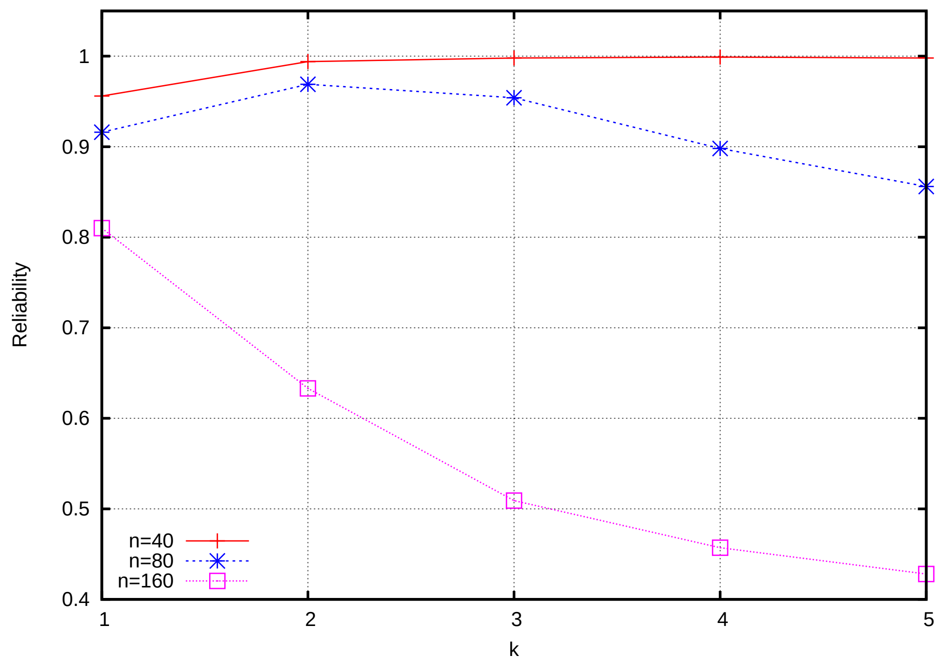

Figure 6: Reliability (90±10m) achieved for different k when CCHI=50ms

Table 3: Optimized k values

CCHI	40ms	50ms	60ms	70ms	80ms
High density	1	1	1	2	3
Medium density	2	2	3	4	4
Low density	3	4	5	6	7

in [11] and [7] that there exists a optimal packet generation rate to maximize the broadcast communication performance. To investigate the benefit of such advanced packet generation schemes, we conducted another set of simulation experiments by setting k greater than 1. Figure 5 shows the reliability achieved with different k. It is interesting to observe that increasing the number of packets generated per CCHI has different effects on the reliability. Under high density condition, increasing k from 1 to 2 reduces the reliability while the opposite effect is observed in the low density situation. The reason of this phenomena is that the channel is not congested when traffic density is low, so increasing the packet generation rate creates more chances of receiving at least one packet within CCHI. However, when the channel is highly congested, higher packet generation rate aggravates the congestion and reduces the reliability as a consequence of that. Figure 6 confirms that for a given combination of CCHI and traffic density, there exists an optimum k that maximises reliability. To find the optimal k, for each traffic density and CCHI (10ms, 20ms,..., 100ms) combination, we run the simulations for different k and select the one which gives the highest reliability. Some of the optimized k values are listed in Table 3.

Intuitively, it is expected that given a reliability requirement, the optimal k would yield a shorter CCHI_{min}, which in turn would increase the share of non-safety (i.e., ρ). The ρ achieved under optimal k is shown in Figure 7. Compared with Figure 4, we can observe that the share

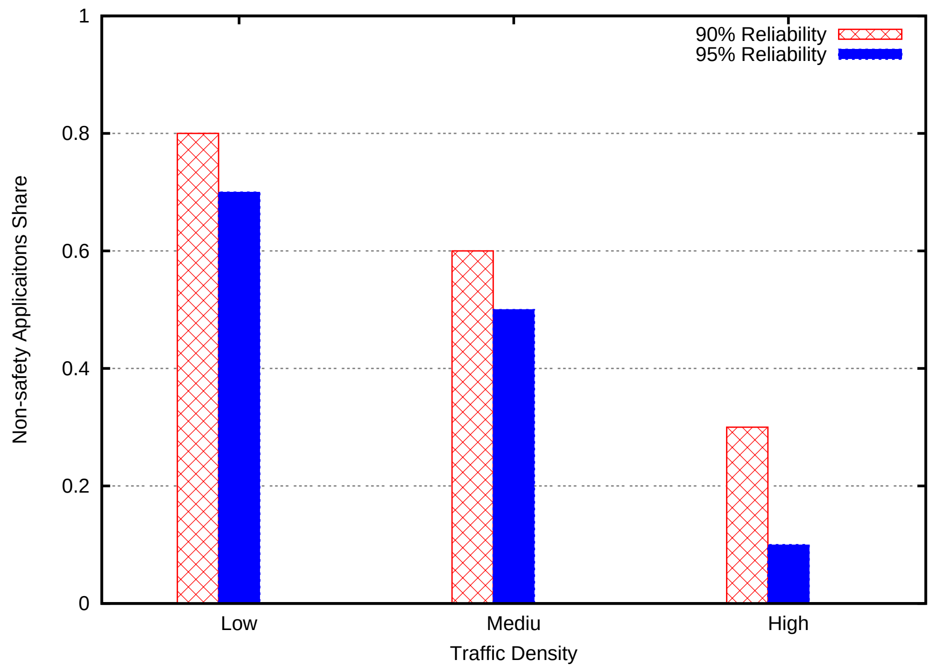

Figure 7: Share of non-safety applications for different traffic densities (with optimal k)

of non-safety applications in DSRC is significantly increased with the optimization of the packet generation rate. This finding suggests that any other schemes that improve broadcast reliability of safety applications is also likely to increase the commercial opportunities of the DSRC.

Another insight we gain from Figure 4 and 7 is that it may be a good idea to adaptively adjust the CCH and SCH intervals in response to the observed vehicle density. If the CCHI is fixed, the channel resource will be either wasted by spending unnecessary time in CCH (when the vehicle is in low density area) or not allocated properly so that the performance of safety applications are compromised (when the vehicle is in high density area). Dynamically adjusting CCHI and SCHI settings could help maximizing the non-safety share of DSRC and minimize the risks to vehicular safety at the same time (it seems to be an interesting research issue worthy of future study).

6 Related Work

The reliability of one-hop broadcast communications in vehicular environment has been studied through both analytical models [8, 12] and simulation experiments [7, 11]. However, in these studies the reliability was analyzed assuming continuous access to the channel. The DSRC channel synchronization and coordination was not considered. To the best of our knowledge, evaluation of the reliability of DSRC safety applications under the IEEE 1609.4 multi-channel operation has not yet been reported in the open literature.

Some researchers have explored multi-channel coordination schemes that are different than the one specified in IEEE 1609.4 standard. In [9], the authors proposed a protocol relying on a road side hot-spot to synchronize the channel coordination. In [6], a protocol named *Peercast* was proposed so that the channel switching is performed *asynchronously*. It may be possible that non-safety applications would get a better share of DSRC under such *asynchronous* channel coordination schemes, but the analysis of asynchronous or any other 'non-standard' schemes were outside the scope of the current study.

7 Conclusion

We have proposed a methodology to derive the channel intervals in the IEEE 1609.4 multi-channel operation scheme. Through simulation experiments, we have evaluated the reliability performance of safety applications with different control channel intervals and traffic densities. Based on the simulation results, we have analyzed the share of non-safety applications as the function of safety performance requirements and traffic density. We have found that the non-safety use may have to be severely restricted, or even shut down completely, in densely populated road segments. Using the packet generation rate optimization as an example, we have shown that the non-safety applications benefit from any improvement to the reliability of safety applications. This calls for more research into techniques that can improve broadcast reliability in 802.11-based transmissions, especially when large number of nodes compete for the channel. Finally, we believe that dynamic adjustment of control channel interval, as opposed to a static configuration, needs to be explored to support effective co-existence of safety and non-safety in DSRC.

References

[1] Family of standards for wireless access in vehicular environments (WAVE). *IEEE 1609*.

[2] Qualnet 3.9.5. Scalable Network Techologies. *http://www.scalable-networks.com*

[3] Standard specification for telecommunications and information exchange between roadside and vehicle systems - 5.9 GHz Band Dedicated Short Range Communications (DSRC) Medium Access Control (MAC) and Physical Layer (PHY) Specifications. *ASTM*, (E2213-03), 2003.

[4] IEEE Trial-Use Standard for Wireless Access in Vehicular Environments (WAVE) - Multi-channel Operation. *IEEE 1609.4*, 2006.

[5] F. Bai, T. ElBatt, G. Holland, H. Krishnan, and V. Sadekar. Towards characterizing and classifying communication-based automotive applications from a wireless networking perspective. In *First IEEE Workshop on Automotive Networking and Applications (AutoNet 2006)*, in conjunction with Globecom 2006.

[6] D. Jiang, V. Taliwal, A. Meier, W. Holfelder, and R. Herrtwich. Design of 5.9 ghz dsrc-based vehicular safety communication. *IEEE Wireless Communications*, 13(5):36–43, 2006.

[7] T. ElBatt, K. G. Siddhartha, H. Gavin, K. Hariharan, and P. Jayendra. Cooperative collision warning using dedicated short range wireless communications. In *Proceedings of the 3rd international workshop on Vehicular ad hoc networks, VANET06*. ACM Press, 2006.

[8] X. Ma and X. Chen. Delay and broadcast reception rates of highway safety applications in vehicular ad hoc networks. In *IEEE INFOCOM Workshop on Mobile Networking for Vehicular Environments (MOVE)*, pages 85–90, 2007.

[9] T. K. Mak, K. P. Laberteaux, and R. Sengupta. A multi-channel vanet providing concurrent safety and commercial services. In *Proceedings of the 2nd ACM international workshop on Vehicular ad hoc networks, VANET05*. ACM Press, 2005.

[10] C. L. Robinson, L. Caminiti, D. Caveney, and K. Laberteaux. Efficient coordination and transmission of data for cooperative vehicular safety applications. In *Proceedings of the 3rd international workshop on Vehicular ad hoc networks, VANET06*. ACM Press, 2006.

[11] M. Torrent-Moreno, S. Corry, F. Schmidt-Eisenlohr, and H. Hartenstein. IEEE 802.11-based one-hop broadcast communications: understanding transmission success and failure under different radio propagation environments. In *Proceedings of the 9th ACM international symposium on Modeling analysis and simulation of wireless and mobile systems*, pages 68–77, Terromolinos, Spain, 2006.

[12] Z. Wang and M. Hassan. Analytical evaluation of the 802.11 wireless broadcast under saturated conditions. Technical Report UNSW-CSE-TR-0801, School of CSE, University of New South Wales, 2008.