Short Paper: Design and Evaluation of a Multi-Channel Mechanism for Vehicular Service Management at 5.9GHz

Laura De Martini and Jérôme Härri
Mobile Communications
EURECOM, Sophia Antipolis, France
Email: {jerome.haerri,laura.demartini}@eurecom.fr

***Abstract*—Dedicated short range communication (DSRC) has been allocated (3 EU, 7 US) dedicated channels at 5.9GHz for vehicular communications. Although resource allocations on the Control Channel (CCH) reserved for safety-related applications have been well investigated, efficient usage of the other Service Channels (SCH) has attracted less attention. In this paper, we propose the design of an asynchronous multichannel mechanism for service management at 5.9GHz. Whereas the service phase defined in the IEEE WAVE standard requires vehicles to remain tuned on a given service channel, the proposed mechanism relies on cognitive principles to let service providers and users dynamically switch between channels and converge to a rendezvous channel where they can negotiate service support and conditions. The mechanism has been implemented on the ETSI compliant ITS simulation platform iTETRIS. We investigate the delay required to converge to such rendezvous channel and illustrate that an optimal cognitive parameter set manages to keep it within an acceptable range, and yet provides more flexibility to the channel usage.**

I. Introduction

Proximity networking has been largely led so far by the IEEE 802.15 Bluetooth technology. Yet the WiFi Alliance and the 3GPP also recently started competing for this technological niche following the exponentially increasing need to interconnect and spontaneously share media and experiences. The general trend followed by leading industry backing Bluetooth, WiFi-Direct and the upcoming LTE-Direct is to face a large penetration of services spontaneously and directly available between individuals or machines.

Although having been developed purposely for proximity services on the road, DSRC is yet the missing competitor in this domain. DSRC has been allocated a 70Mhz spectrum in the US (30Mhz in EU). And besides the innovations related to traffic safety applications and the efficient usage of a scarce 10Mhz Control Channel (CCH) spectrum, the remaining 6 channels (2 in EU) are widely unexploited. Looking beyond traditional traffic efficiency applications, a wider application range could be expected from proximity networking (between vehicles, pedestrians, bicycles etc..). DSRC having the double advantage of being a very flexible technology and second having dedicated spectrum, such potential should be better exploited for proximity services.

The current DSRC specification for service management [1] suggests a two step mechanism, where services are announced on a known channel, and services are provided on multiple alternate channels. Each transceiver interested in offering or consuming proximity services must therefore switch between CCH and SCH channels [2]–[5]. Synchronous channel switching is required by all stations to be simultaneously on the CCH for safety-related messages. But such scheme, which halves the channel resources between CCH and SCH phases, leads to a complex and inefficient usage of the overall channel capacity. In particular, asynchronous channel switching mechanisms [6], [7] cannot rely on CCH to reserve resources on alternate SCH, as the CCH capacity must be reserved for safety-related communication. A proposal by the ETSI [8] is to let CCH and SCH must be independently operated by two transceivers, for which synchronous channel switching is no longer required.

In this paper, we describe the solution space of asynchronous multi-channel operation for proximity services. We propose a flexible mechanism based on cognitive principles to let Service Providers/Users (SP/SU) rendezvous on a given service channel without relying on the CCH. SP/SU dynamically alternate between a Service Announcement Channel (SACH) phase to receive service announcements and a service phase on other SCH to receive or offer services. The flexible design of the channel switching configuration maximizes the dynamic SCH usage during and between proximity services. We illustrate that a key aspect in this schema is fairness between monitoring services and offering or consuming services, as an increased SACH phase guarantees a fast rendezvous, yet at the cost of a reduced service capacity.

The rest of this paper is organized as follows: In Section II, we introduce the proposed multi-channel switching and management mechanisms, while in Section III, we briefly describe the additional required modules on the iTETRIS ns3 platform. In Section IV, we provide initial performance assessment of the proposed multi-channel switching and management. We finally discuss early results in Section V.

This work has been partially supported by the European Commission and the ETSI ITS for the ETSI STF447. EURECOM would like to acknowledge the support of its industrial members: BMW Group, iABG, Monaco Telecom, Orange, SAP, SFR, ST, Swisscom, Symantec.

II. Multi-Channel Service Management

In this section, we describe a multi-channel service management aiming at optimizing the rendezvous channels between a Service Provider (SP) and a Service User (SU). We describe the mechanisms in two phases: Multi-channel switching and Multi-Channel Management.

A. Asynchronous Channel Switching

When considering safety-related communications, it is important that all stations are on the same channel (CCH or any SCH). Accordingly, the time a transceiver remains on any of these channels must be fixed and common to all stations. Unlike safety-related communications, non-safety-related services do not have a fixed service duration on a given channel and efficient usage of all SCH would require that stations move on a different channel once a service is complete. Accordingly, enforcing synchronous channel switching could lead to unnecessary service synchronization and to inefficient channel usage.

As DSRC does not contain a scanning phase, Service Announcement Messages (SAM) must be sent on a known reference Service Announcement Channel (SACH). The scare resources on the CCH (in particular considering synchronous channel switching defined by [2]) suggest that the SACH be a SCH instead of CCH. The ETSI [8] proposes SCH1 to be such SACH. As the SCH1 cannot sustain all possible services and that multi-channel service management requires SP/SU to be able to constantly receive updated SAMs, SU and SP must periodically return to the SACH while on different SCH.

We therefore defined a fully asynchronous multi-channel switching mechanism inspired from [2] but adapted to service management. We define a Duty Cycle, *T_Duty*, during which any station must return to the SACH. We then define *T_SCH1* as the time interval any station stays on the SACH. *T_SCH1* is independently configurable but must be at least bigger than the time to monitor the load on a given channel, *T_SCH1* $\geq$ *T_mon*[1]. The placement of such *T_SCH1* within a *T_Duty* is also configurable, but considering that each stations' *T_Duty* are not synchronized, having *T_SCH1* right at the beginning of each *T_Duty* would make the probability of not finding any station simultaneously on SCH1 very likely. We therefore define *T_offset* as a random offset time from the beginning of a *T_Duty* to spread *T_SCH1* more uniformly within *T_Duty* and reduce such probability.

Our proposed mechanism is therefore fully defined by the following triplet: { *T_Duty, T_SCH1, T_offet* }. Fig. 1 illustrates this concept, where two stations STA1 and STA2 are following non synchronous *T_Duty*, and where *T_SCH1* may vary within the *T_Duty* given *T_offset*.

B. Asynchronous Service Management

For efficient spectrum usage, proximity services must be offered on multiple channels. Multi-channel service management defined in [1] and at the ETSI require SAM to indicate

[1]*T_mon* is currently assumed to be $200ms$

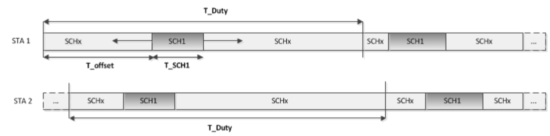


Fig. 1. Illustration of the asynchroneous channel switching mechanism, where T_Duty not be synchronous between multiple STA, and where T_offset makes the time location of the T_SCH1 phase vary.

the target channel(s) of such services. Accordingly, a service management process operates in two steps. First a SAM must be exchanged to announce a given service, which includes the service configuration (QoS,..) as well as the service channel(s). Second, stations switch to the channel indicated in the SAM.

The challenge behind this two-step service management when using the previously described multi-channel switching mechanism is for SU and SP to rendezvous on the SACH to receive a SAM. It is very likely that SPs would provide multiple types of proximity services, which would force SP to recurrently switch between the various service channels and return to the SACH to announce these various services. Also, a station may be both SP and SU, and thus even SU must periodically return to the SACH. Finally, SP may propose modifications of a given service through SAMs to change the SCH (due to congestion), proposes an alternate channels for higher service quality, etc..Accordingly, SU must be able to receive SAM sent by at least the SP to which they consume the current service.

Figure 2 describes such a Service Management, where a SP sends a SAM indicating a service on *SCH5* during the *T_SCH1* and then switches to *SCH5* to provide the service. The figure depicts the unsynchronized return to the SACH by all SUs, and where only SU3 may receive the SAM during the first *T_SCH1*. Accordingly, it receives the time and channel (SCH5) where to get the service. It takes another *T_Duty* for SU2 to receive the SAM and switch. We may note that if a SU receives a SAM indicating a recurrent service (multiple occurrence over a *T_Duty*), such switch will remain at a given time indicated in the SAM so that a SU does not need to receive subsequent SAMs to keep receiving the service. Finally, SU1 on Fig. 2 does not receive the SAM after two *T_SCH1*, but might receive it later. The challenge it to know a upper bound for such SU to receive at least one SAM, which is subject to our current investigations.

III. Implementation

We implemented the mechanisms described in the previous section on the iTETRIS platform [9], but only employed the ns-3 side of the platform. We fed it with a static highway mobility pattern consisting of 6 straight lanes (3 each direction) with inter-vehicular time of $2s$ at an average speed of $120km/h$.

Figure 3 illustrates in grey the vehicular extensions to ns-3 implemented for iTETRIS, and in red the additional extensions for the multi-channel operations described in this work. A Service Provider/User (SP/SU) function has been added in the application layer, a new Service Announcement Message

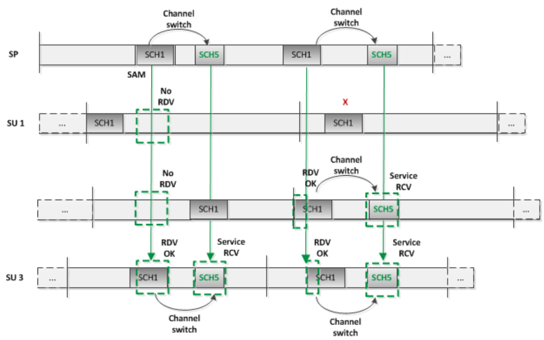


Fig. 2. Illustration of the asynchroneous channel management, where a SU and SP need to be tuned simultaneously to SCH1 when a SAM is sent. When a RDV is found, both SP and SU may switch to the SCH5 to consume the service.

(SAM) has been completed at the facilities layer, and the access layer has been enhanced with channel switching and channel load measurement functions.

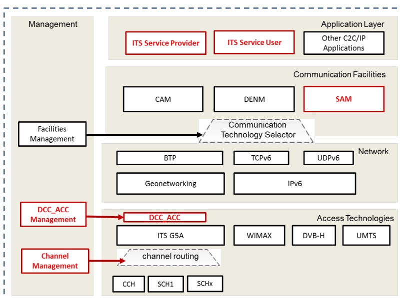


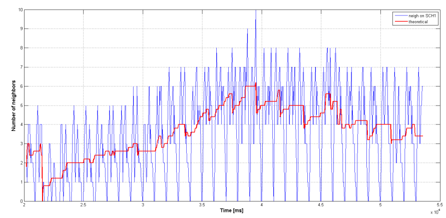
Fig. 3. Extensions to the iTETRIS ns-3 (in red) to support the multi-channel operations described in this paper.

IV. Initial Performance Evaluation

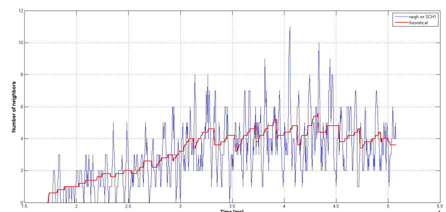
We provide here an initial evaluation of the described schemes. The objective of the multi-channel switching is to efficiently move between channels, yet still maximize the chances for all stations to rendezvous on the SACH (SCH1). The performance of the schema is therefore related to the average number of neighbors on the SACH at any time instant. The multi-channel switching schema allows an easy simplified analytical formulation. Considering that each station must return on the SACH *T_SCH1* every *T_Duty*, the probability to find a neighbor at any time is given by $T\_SCH1/\ T\_Duty$. Accordingly, considering a total number of neighbors in any channel N_{tot}^{nb}, the number of neighbors that may be found at any time instant on the SACH SCH1 may be formulated as:

$$N_{SCH1}^{nb} = N_{tot}^{nb} \frac{\dot{T}_{SCH1}}{T_{Duty}} \quad (1)$$

This formulation is not meant to be tight, and has only purpose to provide a rough estimate of the number of neighbors on SCH1 for performance evaluation reasons. But as it may be illustrated on Fig. 4, such simplified formulation closely follows the simulated average number of neighbors. Fig. 4 also illustrates the impact of the offset factor *T_offset*. When each station returns to the SACH SCH1 right at the beginning of a *T_duty* phase, the instantaneously number of neighbors on SCH1 shows strong oscillations. Although such results could partially come from sampling artifacts, a high number of samples show zero neighbors. When each station set a random offset before returning to the SACH SCH1, we can observe that the oscillation is attenuated and the chances of finding neighbors on SCH1 is significantly increased. We conclude from this that the natural desychronization of the *T_Duty* between stations require to more uniformly distribute the *T_SCH1* in time.



(a) Zero Offset



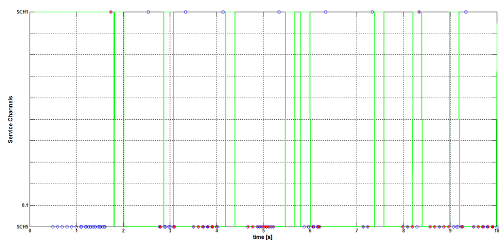
(b) Random Offset

Fig. 4. Illustration of the impact of the offset parameter in increasing the chances of a Rendezvous point.

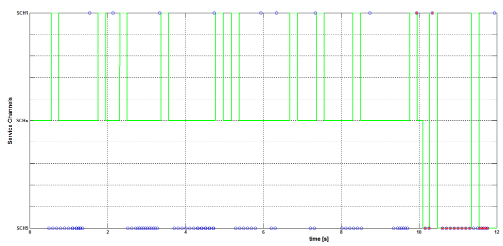
We illustrate next the performance of the multi-channel service management with two key performance indicators: *T_rdv* and *T_service*, respectively the time for a SP and a SU to rendezvous on a SACH SCH1 and receive a SAM, and the time to start consuming the respective service. As such performance heavily depends on the length of *T_SCH1*, we test two cases: *T_SCH1 = 20% T_Duty* and *T_SCH1 = 50% T_Duty*. Also, similarly to any multi-channel mechanism, the delay to converge to a rendezvous point depends on the two stations' starting channel. We evaluate two typical cases: either the SU is already on SCH1 (e.g. SU just need to wait for the first SAM), or the SU is away from the SCH1. The Y-axis on Fig.5 and Fig. 6 indicates three channels: SCH5 (Service) bottom, SCHx (any SCH) middle, and SCH1 (SACH) top. The X-axis correspond to the time and the green lines correspond to SP or SU switching between various channels. To receive a SAM, a SU must be simultaneously on the same channel as the SP.

Figure 5 confirms how the starting channel significantly influences the required time to catch the first SAM (indicated in red darker circles on the figure). Whereas only one *T_Duty* is required when the SU is already on SCH1, 10 cycles are required when the SU is away on an alternate channel. This case is yet very pessimistic, as it assumes a fully saturated

SU (which could also be a SP) on all other SCH. In practice, the number of cycles to catch a SAM should be in lower, in particular if we consider services also offered on SCH1.



(a) SP and SU camp on same reference SCH1



(b) SP and SU are on different SCHx

Fig. 5. 20% SCH1 on sync interval - Service management - Rendezvous point for SAM on SCH1 for Service on SCH5

Figure 6 has the same objectives as Fig. 5, but on more favorable conditions, where *T_Duty* composes 50% of the duty cycle. We can immediately see that an increased *T_SCH1* has positive effects on the delay to catch a CAM and consume services, where 1 single cycle is required when the SU is already on SCH1, and only 2 cycles when it is on other channels. Even though it looks as pure benefit, we still need to investigate the impact of an increased *T_SCH1* on the QoS offered or consumed by the SU on other channels, as a 50% *T_SCH1* reduces the available time on other SCH to offer/consume other services.

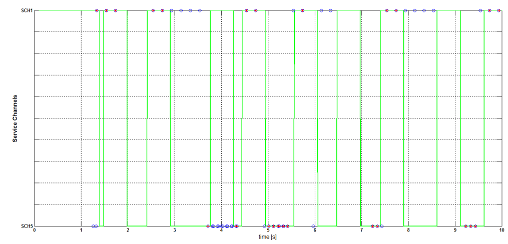
We summarize on Table I the two delay metrics, *T_rdv* and *T_service*, considering a SU camping or being away from SCH1 and for two different *T_SCH1*.

T_SCH1	Camp on SCH1	Away from SCH1
20%	884 [μs] / 0.82[s]	2.5[s] / 3.5[s]
50%	883 [μs] / 1.44[s]	0.42[s] / 1.5[s]

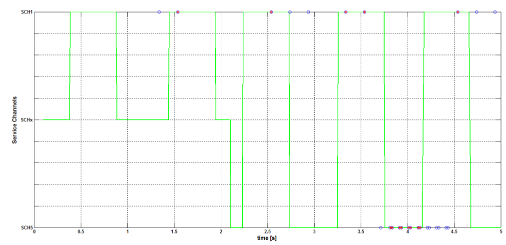
TABLE I
AVERAGE *T_rdv* / *T_service* FOR VARIOUS *T_SCH1* AND INITIAL SCH FOR SU.

V. Discussion and Next Steps

We presented a flexible multi-channel switching and service management scheme targeted at DSRC-based future non-safety-related proximity services on the road. The schema dynamically alternates channels between a Service Announcement Channel (SACH) and multiple Service Channels (SCH) in a fully asynchronous way to optimize channel usage at 5.9GHz.



(a) SP and SU camp on same reference SCH1



(b) SP and SU are on different SCHx

Fig. 6. 50% SCH1 on sync interval - rendezvous point for SAM on SCH1 for Service on SCH5

This work is an initial proposal to the problematic of efficient spectrum usage for proximity services on the road. It is currently under investigation at the ETSI ITS for multi-channel operations. We will extend the study to also evaluate the impact of some key parameters on fairness, e.g. the maximization of one service against others taking place on alternate channels. We will also further evaluate the multi-channel switching mechanism to provide upper bounds for stations to rendezvous on the SACH.

References

[1] IEEE, "Standard for wireless access in vehic- ular environments (wave) - networking services," 2012.

[2] IEEE, "Standard for wireless access in vehic- ular environments (wave) - multi-channel operation," 2012.

[3] C. Campolo and A. Molinaro, "Multichannel communications in vehicular ad hoc networks: a survey," *Communications Magazine, IEEE*, vol. 51, no. 5, pp. 158–169, 2013.

[4] R. Lasowski, F. Gschwandtner, C. Scheuermann, and M. Duchon, "A multi channel synchronization approach in dual radio vehicular ad-hoc networks," in *Vehicular Technology Conference (VTC Spring), 2011 IEEE 73rd*, 2011, pp. 1–5.

[5] J.-H. Chu, K.-T. Feng, C.-N. Chuah, and C.-F. Liu, "Cognitive radio enabled multi-channel access for vehicular communications," in *Vehicular Technology Conference Fall (VTC 2010-Fall), 2010 IEEE 72nd*, 2010, pp. 1–5.

[6] J. Shi, T. Salonidis, and E. W. Knightly, "Starvation mitigation through multi-channel coordination in csma multi-hop wireless networks," in *Proceedings of the 7th ACM international symposium on Mobile ad hoc networking and computing*, ser. MobiHoc '06, 2006.

[7] C. Han, M. Dianati, R. Tafazolli, and R. Kernchen, "Asynchronous multi-channel mac for vehicular ad hoc networks," in *Vehicular Networking Conference (VNC), 2011 IEEE*, 2011, pp. 109–115.

[8] ETSI, "Intelligent transport systems (its); harmonized channel specifications for intelligent transport systems operating in the 5 ghz frequency band," 2012.

[9] The itetris platform. [Online]. Available: http://www.ict-itetris.eu/10-10-10-community/