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# Multi-channel Usage in Day 2 and beyond EU V2X Systems

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## Abstract

Initial deployment of basic safety related Cooperative-ITS applications in Europe is assumed to be realized via simple and cost effective V2X systems, generally consisting of single radio / single channel implementations. Subsequent deployment phases, are envisioned making use of multiple radios and multiple channels within the allocated frequency range.

The present paper discusses options for channel usage beyond initial deployment, taking into account new applications, their requirements, cross channel interference, and impacts from decentralized congestion control (DCC). Systems deployed after initial deployment are assumed to be able to operate on multiple channels in parallel, e.g. receive and optionally transmit on at least two channels in parallel. Systems operating on two channels in parallel are usually referred to as dual radio systems (dual RX/TX), operation on multiple channels in general as multi-channel operation (MCO).

As a result of the discussion the paper proposes components for a framework for MCO beyond initial deployment of V2X systems in Europe. The framework is flexible enough to accommodate future V2X applications in a communication resource efficient way.

## Keywords:

Vehicle-to-X (V2X) communication, Channel Usage, Multi-channel Operation (MCO)

## I. Introduction

Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communication (commonly referred to as V2X) will enable a number of safety, traffic efficiency, and infotainment applications. The communication architecture and protocols for these communication networks have been standardized in Europe by ETSI TC ITS [1] and in the United States (US) by IEEE Groups 802.11 and 1609 [2]. V2X communication is based on ad-hoc networking, there is no handshaking between transmitter and receiver, consequently it won't be known whether packages have been correctly received. By that a transmitter or an initiating ITS station can only inform receivers about it's own and other situations. The transmitter will never know, whether the receiver has received all information.

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[1] ETSI Technical Committee Intelligent Transport Systems (ETSI TC ITS), available online http://www.etsi.org/technologies-clusters/technologies/intelligent-transport

[2] IEEE 802.11p, available online http://standards.ieee.org/findstds/standard/802.11p-2010.html and IEEE 1609, Dedicated Short Range Communication Working Group, available online http://standards.ieee.org/develop/wg/1609_WG.html

Initial deployment of ITS G5 V2X systems in Europe is planned for the coming years. In order to simplify market introduction, stakeholders developed a simplistic single-channel / single transceiver solution as baseline for initial deployment. This configuration is commonly referred to as basic system configuration for Day 1 deployment initiated by the CAR 2 CAR Communication Consortium (C2C-CC) [3] in cooperation with the Amsterdam Group [4].

But already today, it is obvious that this simplification is only an option to enable initial deployment. In current European projects, multiple stakeholders are working on urban and automation related applications such as vulnerable road user (VRU) protection, fuel efficient speed advice (GLOSA), traffic prioritization, shock wave damping, cooperative-ACC (C-ACC), and platooning. Evaluations of these and other applications demonstrate the need for simultaneous usage of two or more channels. A dual transceiver concept is envisioned as minimum setup for Day 2 systems, allowing for future evolution towards multi-channel operation (MCO) covering ITS G5A, G5B, G5C, and G5D.

MCO provides advantages in terms of improved throughput and can lead to improved spectral efficiency. However, the improved performance increases system complexity due to additional logic being necessary for channel switching and the need for dual-radio (or in general multi-radio) transceivers. Furthermore, enabling MCO in V2X communication is challenging due to the characteristics of the network. First, vehicular networks enable a number of applications with distinct requirements, which MCO must provided support for. Second, the decentralized and dynamic nature of vehicular networks creates additional challenges in MCO protocol design, since nodes have only local information available for decision-making.

This paper discusses options for channel usage beyond Day 1, starting from the dual transceiver approach. The discussion takes into account applications, their requirements, cross channel interference, and impacts from decentralized congestion control (DCC) [1].

The remainder of this paper is organized as follows. Section II introduces European frequency regulation and the envisioned channel usage concept for Day 1. Section III summarizes requirements, followed by the presentation of Day 2 channel usage concepts in Section IV. Design recommendations for Day 2 MCO are discussed in Section V, followed by a summary of related work in Section VI. Section VII concludes the paper.

## II. Background and Channel Usage Concept for Day 1

The basis for Day 1 deployment of V2X communication in Europe is formed by ETSI EN 302 663 [2], specifying the European Frequency Profile for ITS G5 (Figure 1a)). It addresses channel allocation and channel usage based on EC Decision of August 5th, 2008 on the harmonized use of radio spectrum in the $5875 - 5905$ MHz frequency band for safety related applications of Intelligent Transport Systems (ITS).

For implementation, a Relaxed Frequency Profile (Figure 1b)) is currently under discussion and expected to be accepted before deployment of any ITS G5 system. At this time there is no indication this will not be accepted and even a further relaxation to $-30dBm/MHz$ is proposed as this is the normal value used.

The current European Frequency Profile Standard divides G5A, the $30MHz$ designated for traffic safety applications, into three frequency bands of $10MHz$ each, where the upper channel is called Service Channel 0 (SCH0) (also called Control Channel (CCH)), the lower channel Service Channel 1 (SCH1) and the center channel Service Channel 2 (SCH2) (see Figure 2). The G5D band is currently considered for traffic safety as well, so that in total $5x10MHz$ bands could be come available. The G5B band is not exclusively reserved for ITS communication. Other services may use it since this band is under SRD (Short Range Device) regulation.

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[3] CAR 2 CAR Communication Consortium (C2C-CC), available online https://www.car-2-car.org/

[4] Amsterdam Group, available online http://www.amsterdamgroup.eu

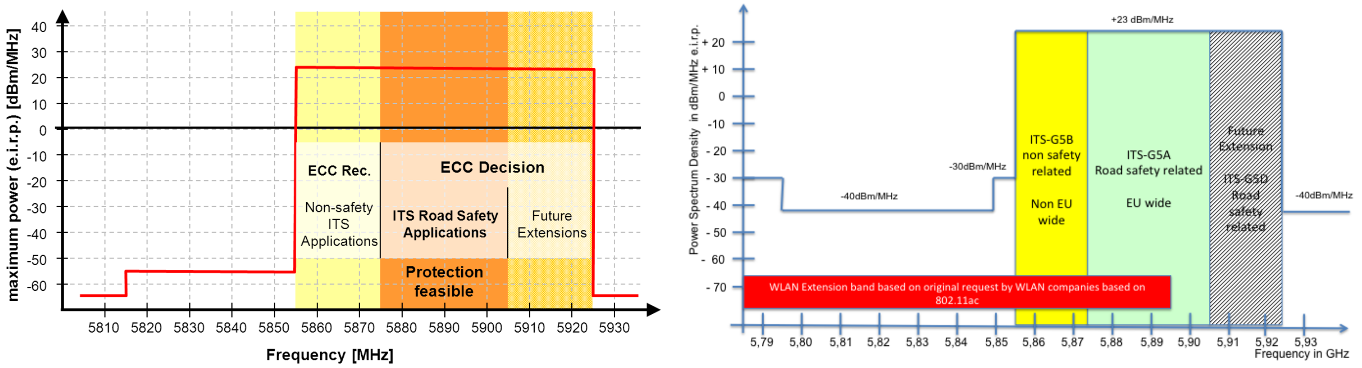

**Figure 1 – a) Frequency Allocation in Europe and b) Proposed Relaxed Frequency Profile in Europe**

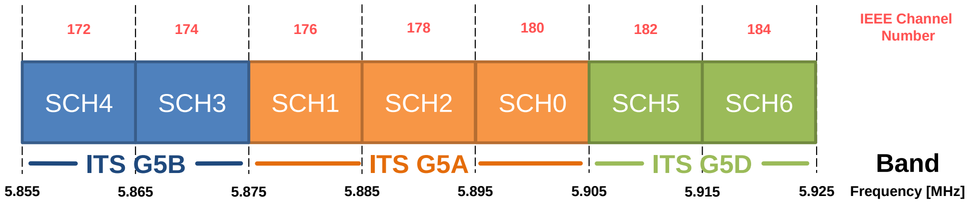

**Figure 2 – EU Channel Naming**

The ETSI standards as of today do not define mapping of applications to channels. For interoperability, stakeholders in C2C-CC agreed on a mapping to assure that a sender is not transmitting information on channel $A$, while the intended receiver is listening on channel $B$. Day 1 systems are assumed to assign all supported messages to a single channel, namely SCH0.

These messages are:

- Cooperative Awareness Message (CAM) (EN 302 637-2) [3]
- Decentralized Environmental Notification Message (DENM) (EN 302 637-3) [4]
- Signal Phase and Timing Message (SPaT) (TS 103 301, ISO 19091, SAE J2735) [5, 6]
- MAP (TS 103 301, ISO 19091, SAE J2735) [5, 6]
- In-vehicle Information (IVI) (TS 103 301, ISO 19321, ISO TS 14823) [5]

In high network load situations, only first hop distribution of multihop messages (such as DENM) is allowed on SCH0. Further hop distribution is either omitted (in accordance with DCC), or moved to SCH1 (in case a station supports more than single radio single channel operation).

This approach is valid, as CAMs sent periodically by each vehicle with a rate of $1Hz$ to $10Hz$ and DENMs are generated event-based. Even with first and multi-hop DENMs on SCH0, the vast majority of communication data exchange on the SCH0 can be attributed to CAMs, which makes DENM load on SCH0 negligible. Likewise, SPaT, MAP and IVI messages, will not have a significant impact to the channel load even though SPaT and MAP payloads are expected to be much larger than CAMs.

## III. Requirements for Day 2 and Beyond Channel Usage

The requirements for Day 2 channel usage originate from the kind of applications that are envisioned for Day 2, the corresponding application requirements, and the available resources on communication media, governed by DCC (Decentralized Congestion Control [1]).

### *A. Application Originating Requirements*

Envisioned applications for Day 2 and beyond include (but are not limited to)

| | Context | Range | Rate | Size | Latency | Alternative media |
|---|---|---|---|---|---|---|
| PVD | - | - | not periodic | large | - | cellular |
| IVS | - | 500m | low | large | - | cellular |
| RWW | - | 500m | low | large | - | cellular |
| EV charging | reservation | 1-100km | not periodic | < 100 Byte | 1-10 sec | cellular |
| | charging | 2-50m | 0.5-10Hz | 20-200 Byte | 50-500ms | WiFi |
| TPG | - | - | low | small | - | WiFi / BT |
| C-ACC | - | small | 10Hz | small | low | - |
| C-AD | - | small-large | 2-20Hz | small | low | - |
| VRU Protection | pedestrian | 150m | 1-2Hz | small | low | WiFi / BT |
| | powered two-wheeler | 300m | 10Hz | small | low | - |
| AID | - | - | low | medium | - | - |
| RLVW | - | 50m | low | large | - | - |

**Table I – Summary of application communication characteristics**

- Probe Vehicle Data (PVD)
- In-vehicle Signage (IVS) (enhanced version of IVI with additional capabilities)
- Road Works Warning (RWW) (extended version with additional information on the construction area)
- Electric Vehicle (EV) Charging
- Tire Pressure Gauge (TPG)
- Cooperative Adaptive Cruise Control (C-ACC)
- Cooperative Automated Driving / Maneuvers (C-AD)
- Vulnerable Road User (VRU) Protection
- Automatic Incident Detection (AID): Traffic Jam, Slow Vehicle, Weather, and Road Hazard Warnings
- Red Light Violation Warning (RLVW)

Each of these applications will use various existing or new dedicated message formats. Correspondingly, the communication characteristics such as transmission range, transmission rate, message size, and maximum latency are quite diverse. Additionally, for some applications these characteristics depend on the application context. Last but not least, further growth of applications is envisioned.

For example, IVS is expected to use large messages with low repetition rate and large communication range, whereas C-ACC will use small messages with high transmission rate and small communication range. While in cruise mode, C-ACC messages will have priority over vehicle signage to meet the latency requirements. EV charging will mainly require communication resources while in stationary/charging context.

Other examples are the envisioned communication support for existing safety applications that need to be offloaded to additional channel in cases when the load on primary channel (SCH0) is high. Or, stringent requirements from applications such as vehicle platooning, which will generate a large amount of high priority data that cannot be supported in parallel with existing services on SCH0.

Table I summarizes the requirements and characteristics of the listed Day 2 applications.

For this paper, we selected the EV charging characteristics to be looked at in more detail, as corresponding standards are already quite mature. They specify communication to support and control the charging of an EV. Remotely, EV users can discover, check, and reserve charging spots, using messages specified in ETSI TS 101 556-1 [7] and TS 101 556-3 [8]. At arrival at the charging spot, the charge control protocols (e.g. ISO/IEC 15118 [9]) will proceed with preparing, executing, monitoring, and accounting the charging session. It is an ongoing international standardization effort, on which medium these messages should be transmitted on to achieve a worldwide harmonized solution. As the different stages of EV charging have different communication requirements, they can be divided into three periods: Reservation, approaching, and charging. As shown in Table I, reservation and charging are candidates to use ITS G5.

Beyond the already mentioned applications, MCO will be key for enabling future, beyond-Day 2 applications, as the proliferation of deployed devices and new applications will increase the need for efficient use of the available channel resources. Since future applications will have different requirements and priorities, the first task will be their classification. As a starting point for classification, the existing application classes from ETSI TS 102 637-1 [10] can be used:

- Active road safety
- Co-operative (road) traffic efficiency
- Co-operative local services
- Global internet services

The purpose of application classes is to efficiently distinguish and categorize any future applications. For example, any application in class ”Active road safety” will have a higher priority than any application in all other classes. Two modes of operation can exist for applications in the same class:

- Every application has a unique priority, i.e. within an application class, each application can be ordered in terms of priority;
- Multiple applications have the same priority; in this case, additional arbitration is needed to determine which application is given priority. Some examples of arbitration are: a) random selection; b) first-come first-served; etc.

### *B. Communication Resources Originating Requirements*

The requirements with respect to communication resources mainly originate from cross-channel interference. A channel usage concept has to take into account that safety critical communication on SCH0 needs to be given priority over communication on any other channel. Consequently, DCC needs to be extended to support multi-channel operation. Recent efforts on DCC at ETSI [11] aim at providing efficient way to extend single-channel operation to MCO. Furthermore, the channel usage concept must either assure non-interference with communication on SCH0 (e.g. by using one channel as guard channel) or it has to be flexible enough to switch channels or adapt communication parameters such as rate and transmission power on demand.

## IV. Day 2 and Beyond Channel Usage Concepts

This section introduces multiple concepts for channel usage and MCO. The concepts are independent of each other, but bear the possibility to build on each other. After introducing the concepts, they are compared to each other, amongst others considering the requirements introduced in the previous section.

### *A. Concept Introduction*

One commonly known concept for Day 2 channel usage in Europe is a dual transceiver solution with fixed assignment of one transceiver on SCH0 and the second transceiver on SCH1. SCH2 is used as guard channel. Day 1 applications and messages remain on SCH0, multihop repetitions in high load scenarios are distributed on SCH1. New messages from Day 2 applications are exchanged on SCH1. This concept is a straight forward extension of the Day 1 approach not specifically addressing application requirements or application classes beyond Day 2.

This dual transceiver concept can be extended with so called service announcement messages (SAMs) on SCH1. They are used for advertising what kind of service is available on which channel. If a station is interested in one of the advertised services, it can tune the second transceiver on the corresponding channel. The first transceiver always remains tuned to SCH0.

Another extension is to dynamically offer the same service for different stations on different channels. With this extension one service can be provided to more stations than a single channel would allow for.

| | **Dual TX/RX with fixed channel assignment** | **Dual TX/RX with service announcement** | **Dual TX/RX with service announcement and simultaneous service offering on multiple channels** | **Application classes, class specific channel assignment and forwarding under DCC control.** |
|---|---|---|---|---|
| **Complexity** | Simple and safe, no potential interoperability issues as attribution of messages to channels is explicitly defined. Messages on both channels should usually be received as both receivers are permanently tuned to the two channels. | Requires intelligent switching of secondary transceiver between SCHs. | Requires intelligent switching of secondary transceiver between SCHs.<br>Additionally, service might be shifted dynamically from one channel to another one due to load situation on 1st channel. Nodes might have the same service with different partners on different channel simultaneously. | Simple, applications know the principle channel to find data. Likewise in congested situations where DCC requires offloading. Simple scheme for none safety and efficiency services with service announcement. |
| **Flexibility** | Limited, no adaptation e.g. in case of increased communication traffic | Flexible solution. Allows for scheduling applications where they can be reliably offered, in light of data traffic on all channels. | The most flexible solution. Allows for scheduling applications where they can be reliably offered (even simultaneously on multiple channels), in light of data traffic on all channels. | Flexible solution. Allows further development of applications but also extensions of priorities and the extensions of message sets. |
| **Extensibility** | Limited, new messages have to be assigned to one of the two channels if they are supposed to be received by vehicles integrating the proposed approach; might be extended with on of the service announcement concepts (limiting the benefit of nodes not supporting the extension). | Easily extensible to support new applications and functionalities; applications are assigned an unused application ID and assigned to a priority class. Extension to multiple radios possible. | | Easily extensible to support new applications and functionalities; applications are assigned an unused application ID and assigned to classes. Supports single, dual, and multi radio, as well as extension of applications, messages and priorities without system change. |
| **Overhead** | No overhead as no service announcement or coordination is required. | Overhead in the form of: 1) service announcement messages periodically sent on a predefined channel; and 2) channel switching overhead. | | |
| **Resource efficiency** | Limited, two channels are used independent of current communication load, other channels are not used. | High efficiency: applications can be scheduled dynamically so that each channel can be highly utilized. | | Highest efficiency: every channel is used up to the limits defined by DCC. |
| **Cross-channel interference (CCI)** | Separated by a 10MHz guard channel (if using SCH0 and SCH2). Setup and situation known by all ITS stations. | Certain channels can be prioritized (e.g., SCH1 having higher priority than SCH2), so that the interference is minimized. | | |
| **DCC aspects** | Per-channel DCC (i.e., no coordination between channels). | Allows for a more efficient cross-channel DCC solution - interaction between DCC and MCO possible (e.g., offloading triggered by DCC in case of high load on SCH0). | | Per-channel DCC. DCC state known to applications and possible DCC quality requirement (i.e., no coordination between channels) |
| **GNW aspects** | GNW on SCH0 should be extended to indicate dual TX/RX availability to support SCH0 offloading. | GNW can be extended to support cross-channel forwarding / offloading (forwarded messages can be transmitted on different channels by forwarders). | | |
| **Cost aspects** | Cost efficient, realizable with single antenna/single receiver. | Depending on the number of transceivers. | | |

**Table II – Comparison of MCO concepts**

Furthermore, there is the concept to group traffic safety and efficiency applications into classes (as described in Section III). Each of the classes is assigned with channels to support forwarding of messages to other channels in an predictable way, under control of Decentralized Congestion Control (DCC) . Additionally, as applications may have different states of urgency, messages may need different priorities at different times. Therefore, a message priority needs to be defined based on criteria such as safety level and timing to allow applications to send information to others based on the urgency recognized. This way, application can know on which channel information can be expected, also under communication congested situations. This holistic concept is designed to support future proof channel assignment to accommodate for applications expected to emerge in future. This concept makes efficient use the spectrum and thereby follows European spectrum allocation trunking efficiency needs. For none safety applications the use of SAMs with referencing to the none safety and traffic specific ITS G5 channels in bands B and C is suggested.

### *B. Concept Evaluation and Comparison*

This section compares the MCO concepts according to the following criteria. Complexity, flexibility, extensibility, overhead, efficiency, cross-channel interference (CCI), DCC aspects, GNW aspects, and cost aspects. The comparison is summarized in Table II. The result is that all candidates support or can be extended to support Day 2 and beyond requirements, consequently the remainder of this work will not focus on a single concept.

## V. Design recommendations for Day 2 and Beyond MCO

Based on our analysis in this work and the framework developed within simTD project [12], we present a set of design recommendations for MCO. These recommendations include a channel switching scheme that is driven by the requirements of applications.

According to the introduced concepts, we assume that Day 2 and beyond devices will be equipped with dual (or more) transceivers, from which one transceiver is continuously tuned to SCH0. The (or a) second transceiver might be fixed to SCH1, or can dynamically switch between other SCHs. Messages are assigned in pre-defined, i.e. standardized, application sets that are known to all SPs. Service users (SUs) decide which service to consume, provided that none of the services are safety critical.

Finally, we assume that each SAM at minimum contains an application ID to uniquely identify the service and the ITS-G5 channel on which the service is provided. Optionally, SAM may contain additional information, discussed in Section V-C).

In defining the recommendations for MCO behavior, we make use of the service provider (SP) and service user (SU) concept described in the simTD project [12]. In general, an entity can assume the SP and SU roles both concurrently and interchangeably (i.e a vehicle providing a service would assume an SP role, and likewise it could assume an SU role once it wants to consume a service).

### *A. Passive Channel Load Estimation based on Service Announcement Messages*

For a channel switching algorithm to schedule services efficiently, the SP needs to know the availability of channel resources and application needs on each of the SCHs. However, channel load estimation for multiple channels is not trivial unless a station has the same number of transceivers as there are channels. Since a certain amount of time is lost when a transceiver switches from one channel to another, and since the transceiver needs to stay on the channel for a certain period of time, in case when the number of channels is large, comparatively more time is spend switching across channels and measuring load. Furthermore, the measured load is an estimate of the channel load across a longer period of time, since the assumption is that the transceiver cannot be tuned to a channel all the time. For these reasons, we propose a new channel load estimation algorithm that uses SAMs to implicitly estimate the load on channels to which neither of the transceivers is tuned.

The algorithm for passive channel load estimation assumes that every communicating node (both vehicles and RSUs) continuously log the transmitted SAMs (which are sent to a default service channel). For each SCH, the node calculates an estimate of the channel load, which takes into account the information provided in SAMs on the load generated by the service. In cases where SAMs contain incomplete information (e.g., lacking message size), the algorithm should produce a probable range of channel load for each of the channels in the form of an upper and lower bound. In addition, each communicating node measures the channel load using channel busy ratio metric [11] or similar, for the channels it is currently on (i.e. SCH0 and one of the other SCHs). This is done in a passive way, whereby the node does not move to a particular channel just to measure the channel load; rather, it takes the opportunity to measure the load of those channels it is already on. This approach aims at reducing the number of times a transceiver needs to switch channels and minimizes the risk of missing service data.

### *B. Extending simTD Service Provider (SU) and Service User (SU) Behavior*

The channel selection and switching decision on the SP side is based on channel load estimation (Sect V-A). In an initial probing step, the SP, before sending a SAM on the SCH0, tunes to the ”best candidate” SCH identified by channel load estimation and measures load to make sure that it is in fact a non-congested channel. Once it selects a channel, the SP will provide all of its services on this channel (i.e. it does not provide services on multiple channels concurrently) until the load on the current channel reaches a predefined threshold. When the load is high, SP can stop providing its lowest priority services. For all of its services, the SP periodically rebroadcasts SAMs, so that new nodes entering the range can have up-to-date information on available services and periodically estimate the SAM-based load in their vicinity.

In the SU role – contrary to the SP role, where the services are categorized into priority groups – a node can load the user preferences, which list the application IDs in which the user is interested. Upon reception of a SAM, the SU moves to the channel that carries the higher priority service according to the user preference. This behavior allows the service users to select the services of their interest. In case of multiple concurrent highest priority services, if the SU was consuming one of the services, it stays with that service; alternatively, it randomly selects a service.

### *C. Service Announcement Message Modifications*

To enable the discussed service announcement design, we propose to add new information / fields in SAMs. Specifically, the more of the following information each SAM contains, the more precise the channel switching can be made:

- Service/application ID of the service generating the message (already included in existing SAM proposals)
- Service channel that the node plans to use for the service (already included in existing SAM proposals)
- Estimated channel load for the channel it plans to use for its service
- Estimate of channel load on SCH0 and secondary SCH
- The frequency of messages sent by the service (by SP, SU, or both)
- Message size
- Expected duration of the service

## VI. Related Work

MCO proposal as specified by the standard IEEE 1609.4 [13] also provisions for single-transceiver MCO operation via time-based channel switching. All systems are tuned to the control channel (CCH) for a specified time interval. As shown in Figure 3, IEEE 1609.4 considers four switching modes for single-transceiver MCO:

- a) Continuous mode, where there is no switching and the radio is always tuned on the CCH
- b) Alternating mode, where the transceiver periodically (e.g. every 50 ms) switches between CCH and SCHs
- c) Immediate mode, where the transceiver switches between CCH and SCHs without waiting until the end of the current channel interval
- d) Extended mode, where the transceiver switches to the SCHs without periodically returning to the CCH.

Available services on the other channels are announced using Wave Service Announcement (WSA) as specified in [14].

## VII. Conclusion

We have presented the single-channel / single transceiver solution that is designed as baseline for initial deployment of V2X systems in Europe, the so-called as C2C-CC Day 1 solution. While the single-channel / single transceiver solution uses only a subset of available spectrum, i.e. one channel, the developed standards provision for a more elaborate multi-channel / multi-transceiver operation. We have summarized the latest trends for Day 2 and beyond applications, including examples of their

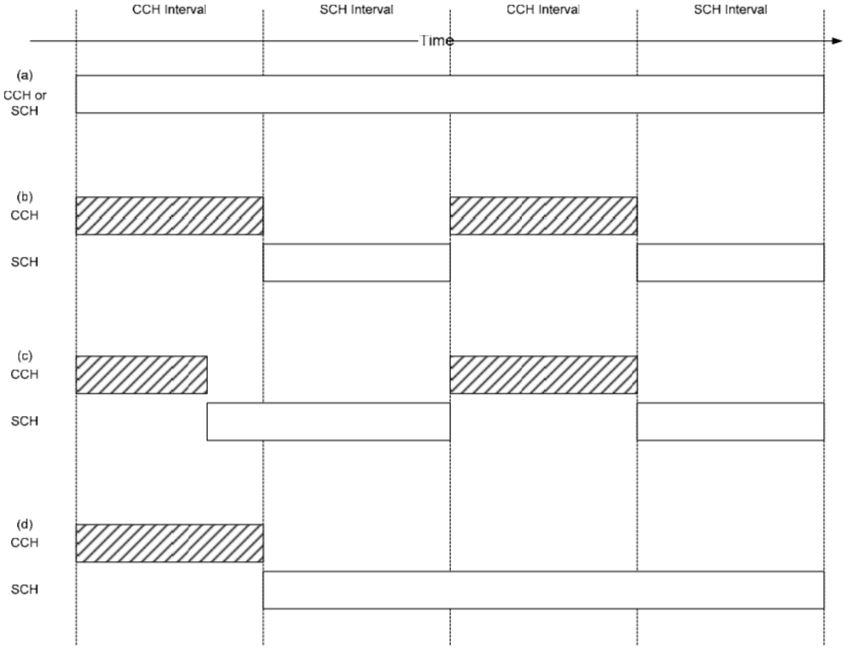

**Figure 3 – IEEE 1609.4 switching modes.**

communication requirements. These diverse applications will require careful coordination and efficient operation across multiple channels, which can be enabled by Multi-Channel Operation (MCO).

Subsequently, we have sketched four candidate solutions for and different aspects of MCO. Our analysis compares the candidates against each other and against the identified requirements. All candidates support or can be extended to support Day 2 and beyond requirements. Therefore we did not concentrate on a single candidate, but proposed components as design recommendations for a MCO framework for Europe. The components contain similar elements as the framework under development at IEEE 1609, also using SAMs for channel load estimation. Another component we identified is the more holistic approach grouping traffic safety and efficiency applications into classes. This approach needs further consideration and evaluation in future work.

All components developed and introduced in the context of this work will serve as input for future discussions for definition of an EU MCO approach in the stakeholder groups.

## Acknowledgements

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