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Next steps for Multi-channel Operation in EU V2X Systems

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Abstract

Cooperative Intelligent Transport Systems (C-ITS) operating in the 5 GHz band in Europe is expected to use only a single communication channel during initial deployment phase. The initial deployment is focused on a limited set of applications assuming a rather small equipment rate of vehicles and road side stations. Current efforts spent on future C-ITS application research indicate considerable growth of C-ITS penetration in following years. The increasing C-ITS penetration rate and the introduction of novel applications will result in growing demand of communication bandwidth that can be addressed by utilizing multiple radio communication channels in parallel.

This paper discusses requirements for multi-channel operation (MCO) in European C-ITS, analyzes boundary conditions in the designated frequency bands, presents a concept for offloading and backloading information from congested communication channels, and describes extensions to the GeoNetworking protocol to support MCO.

Keywords:

Vehicle-to-X (V2X) communication, ETSI ITS G5, Channel Usage, Multi-channel Operation (MCO)

I. Introduction

Initial deployment of 5.9 GHz V2X[1] communication systems in Europe is expected to use a single radio device operating on single channel for Cooperative Intelligent Transport Systems (C-ITS) use cases as specified in the Basic Set of Applications at ETSI [1]. The 10 MHz bandwidth of a single channel is commonly regarded to be sufficient for basic safety and traffic efficiency applications, including the information exchange with roadside infrastructure such as traffic lights. Appropriate mechanisms to handle data congestion and to avoid overload on the wireless channel in dense road traffic have been developed and specified [2].

With an increasing equipment rate of vehicles and the introduction of novel applications and services currently under development, the demand for bandwidth grows and exceeds the capacity of a single 10 MHz channel. In particular, use cases such as Cooperative ACC (C-ACC), platooning, Vulnerable Road User (VRU) protection, and Urban ITS have high bandwidth demands. These demands can be met by utilizing multiple radio communication channels in parallel. Corresponding requirements and technical concepts for multi-channel operation (MCO) have been discussed in previous work in [3].

[1]Short for vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and infrastructure to vehicle (I2V).

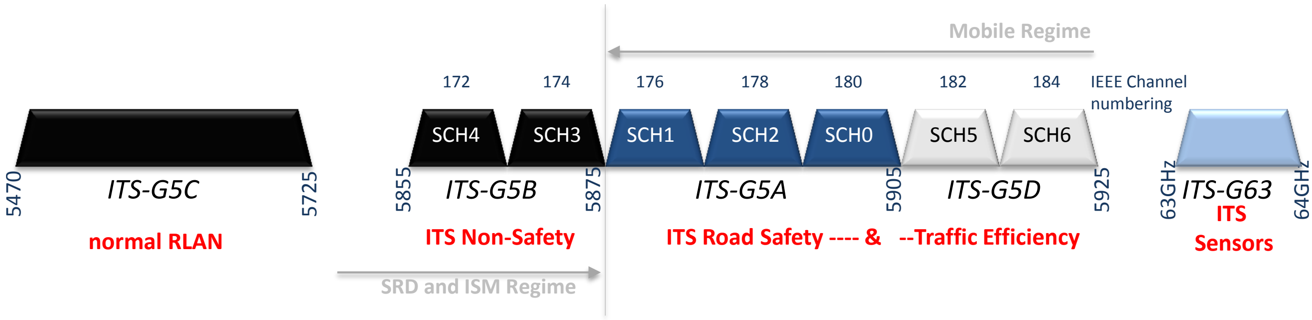

Figure 1 – European ITS Spectrum with Channel Naming

The work presented in this paper is based on our previous work in [3]. It specifically focuses on the new use cases C-ACC, platooning, VRU protection and Urban ITS, and their requirements that go beyond those of the Day 1 use cases for basic safety and traffic efficiency applications. The paper further presents a concept for offloading and backloading of data among channels with different load, and extensions of the GeoNetworking protocol for MCO support. It also discusses potential technical issues that arise from the use of MCO in a mixed deployment with MCO-capable and MCO-incapable devices. The GeoNetorking extensions and the offloading/backloading concept are applied to a basic configuration with two channels and two transceivers. This configuration can be seen as starting point for a generalized MCO scheme in configurations with more than two channels and transceivers as also discussed in [3].

The remainder of this paper is organized as follows. The next section discusses technical background of 5.9 GHz V2X communication with focus on multi-channel operation (MCO). This is followed by a summary of use cases, resulting communication resource requirements, and available C-ITS frequency bands. The next two sections cover GeoNetworking extensions for MCO, offloading and backloading, and the effects of MCO in mixed scenarios. Finally, the last section summarizes and concludes the paper.

II. Technical Background

In the European C-ITS [4], V2X communication operating in the 5 GHz frequency band is based on ITS G5 [5], the European variant of the IEEE 802.11-2012 OCB mode[2] [6]. It uses up to seven channels in the 5 GHz frequency band, as shown in Figure 1. The designated channel for single radio, single channel operation is SCH0. Further extension of C-ITS is foreseen in the 63–64 GHz band, allowing for line-of-sight (LOS) communication.

On top of the ITS G5 radio technologies, networking & transport protocols and facilities build the protocol stack, complemented by vertical entities for security and management. Figure 2 sketches the complete European C-ITS communications architecture, details are specified in [7]. The protocols at the networking & transport and facilities layers are highly tailored to V2X communication, i.e. are primarily designed for broadcast communication and for dissemination of information in ad hoc networks. To be able to operate on multiple wireless channels, there is a need to manage the channels using a combination of functions at the networking & transport and facilities layers.

GeoNetworking is the networking protocol in the C-ITS protocol stack that realizes packet distribution in ad hoc networks, specifically addressing the needs of automotive scenarios. The protocol covers single hop broadcast message dissemination, as well as multi-hop packet distribution in geographic areas. GeoNetworking is specified in [8], media-dependent extensions for the ITS G5 frequency band in [9]. With respect to MCO, the media-dependent extensions already contain functionality to indicate whether a certain packet is allowed to be offloaded to a different channel, and the default channel the packet is supposed to be disseminated. Furthermore, it reserves fields in the Single Hop Broadcast (SHB) extended

[2]Outside the context of a BSS.

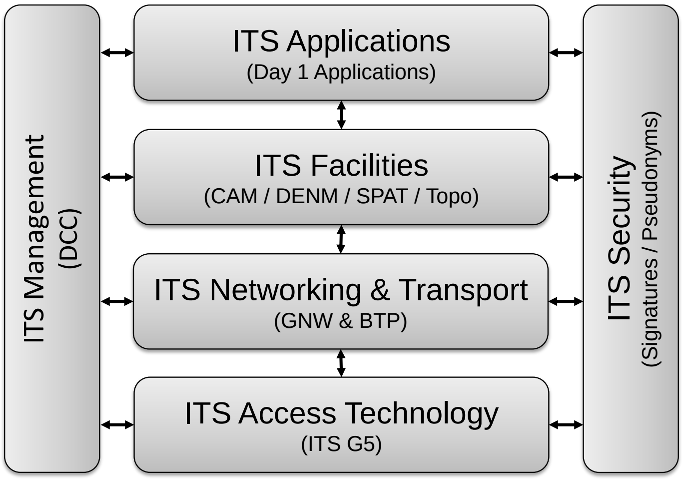

Figure 2 – European C-ITS Communication Architecture

header to be used for MCO. However, the recent specification of GeoNetworking is limited to a single network interface that is permanently tuned to a single wireless channel.

The framework for mechanisms avoiding communication channel overload (decentralized congestion control, DCC) is specified in [2]. The mechanisms of DCC include dropping multi-hop packets, reducing message repetition rate, and reducing message generation rate. One of the intentions of MCO is to avoid these restrictions by offloading data to other channels instead. In case of multi-hop message dissemination, the message transmission might be switched back to the original channel, once the vehicles reach an area where the load on the original communication channel is low again. We refer to this as backloading.

III. Use Cases and Communication Resources

This section is split in two parts. The first part provides an overview on the functional and performance requirements of the novel use cases C-ACC, platooning, VRU protection and Urban ITSs. It also explains how these novel use cases are enabled using combinations of new messages beyond CAM [10] and DENM [11], and compares their requirements with the Day 1 use cases.

The second part of the section provides an analysis of the technical capabilities and limitations of the available C-ITS frequency bands to enable these novel use cases. This analysis considers in particular the dependencies among the channels.

A. Use Case Requirements

Novel use cases such as C-ACC, platooning, VRU protection and Urban ITS require additional information beyond what is required for Day 1 use cases. For example, results from R&D projects such as SARTRE [3] or AutoNet2030[4] [12] indicate that platooning requires message repetition rates of up to 30 Hz, but comparatively short communication ranges. Platooning relies on similar data as already disseminated in Cooperative Awareness Messages (CAMs) [10]. However, in the current specifications, the CAM dissemination rate on SCH0 is limited to a maximum of 10 Hz. The message repetition rates for C-ACC are assumed to be similar to platooning. Note that platooning requires additional communication to support the exchange of data to improve Geolocation referencing and to manage the platoon.

[3]SARTRE project, http://www.sartre-project.eu/, last visited 2016/05/25.
[4]AutoNet2030 project, http://www.autonet2030.eu/, last visited 2016/05/25.

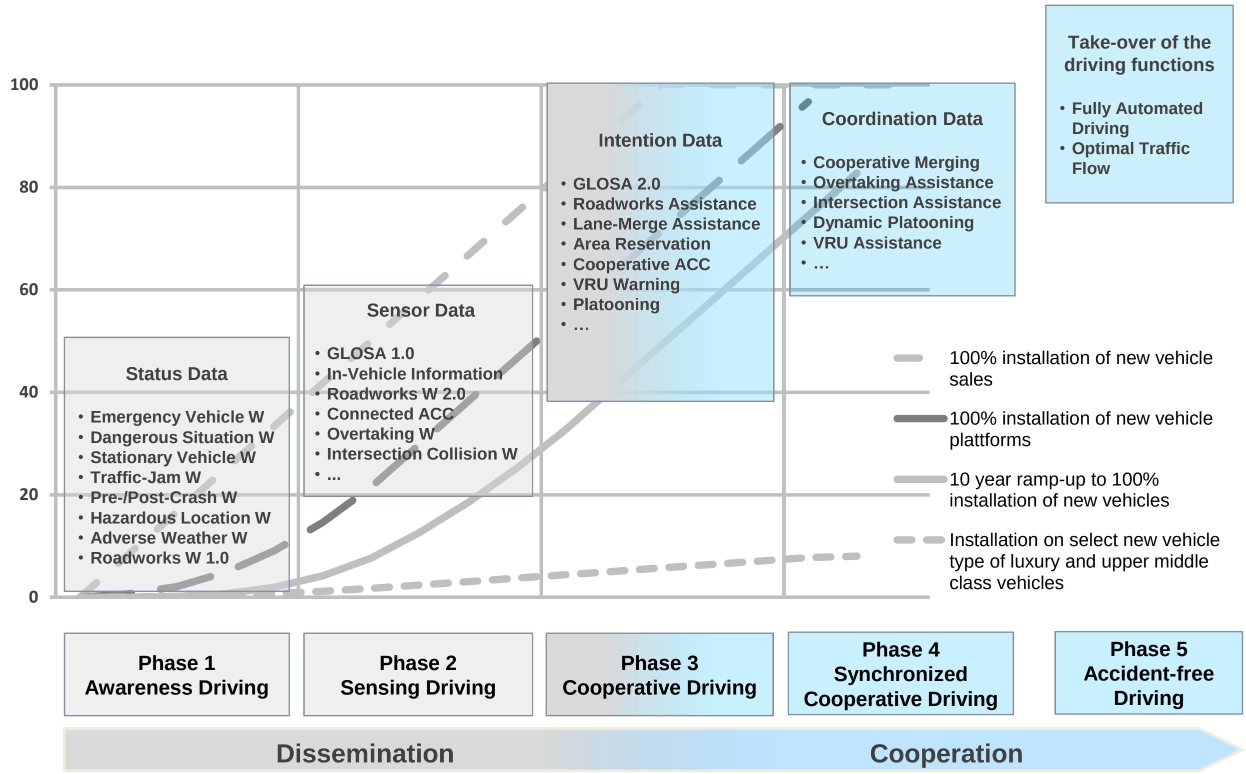

Figure 3 – 5G Automotive Vision: C2C-CC Applications Roadmap [13]

VRU protection use cases are further examples for novel services requiring bandwidth. Results of the EU H2020 project VRUITS[5] show that VRU protection requires additional communication in dense populated areas, but not at high message rate and is mostly event driven (warning oriented).

So far, no R&D project has evaluated the total number of Urban ITS data exchange requirements for safety critical vehicle/motorized oriented services. However, when combining general experiences of R&D projects, which have investigated different services[6], the need for additional bandwidth of about 10–20 MHz to support the related awareness services can be recognized, event driven data exchange not included.

Note that in urban areas the use of C-ACC or platooning is not expected to be used intensively in coming years. As a consequence, one might consider the possibility of re-using the C-ACC / platooning bandwidth for Urban ITS in cities, and vice versa. However, as highways run cross cities, bandwidth between C-ACC, platooning and Urban-ITS can not be shared.

In addition to the use case requirements for these concrete upcoming services — where requirements like status, and first levels of sensor and intention data are identified in ongoing R&D projects — the 5G Automotive Vision [13] identifies new requirements that can be expected from automated driving in terms of additional Sensor, Intention and Coordinated data. This evolution of use case requirements is reflected in the C2C-CC [7] applications roadmap shown in Figure 3.

In conclusions, we can recognize novel C-ITS use cases currently being developed in R&D projects that will easily require a 30–50 MHz bandwidth for data exchange. When considering additional information exchange for future use cases for advanced intention and coordinated data it is obvious that 10 MHz bandwidth is not enough; R&D projects' estimations indicate a need of 50 MHz for safety-related use

[5] VRUITS project, http://www.vruits.eu, last visited 2016/01/25.

[6] services such as Green Light Optimum Speed Advisory (GLOSA), Red Light Violation Warning (RLVW), Intersection Collision Warning (ICW), Traffic Jam and Pre/Post Crash Warning, In-vehicle Information (IVI), Road works warning (RWW), and Object Awareness

[7] C2C-CC - Car-2-Car Communication Consortium, https://www.car-2-car.org/, last visited 2016/07/10.

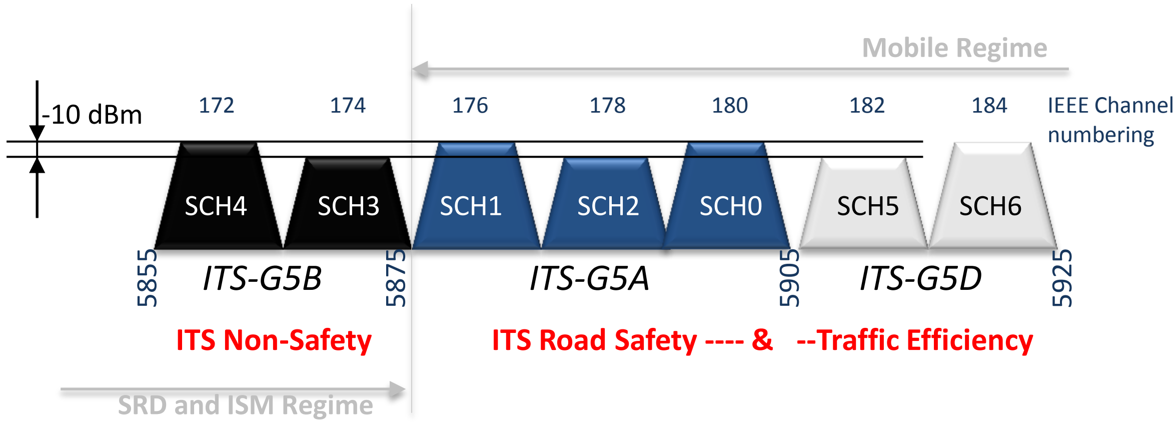

Figure 4 – European 5 GHz C-ITS Spectrum Usage Restrictions

cases alone. This implies that the estimations of bandwidth needs for safety and non-safety information exchange with 70 MHz in total made more than 10 years ago were not incorrect. Furthermore, it shows that the development of a MCO approach is an obvious next step of development to ensure that currently researched use cases can be brought to market in the upcoming years. The Day 1 use cases are just the first ITS applications — future use cases will reuse information from the existing Day 1 message set (i.e. CAM and DENM) and in addition will require new message types to be disseminated with different repetition rate, communication range and payload sizes.

B. ITS Frequency Bands

As shown in Figure 1, Europe has allocated specific C-ITS spectrum in similar frequency bands as the US. There is the EU recommendation ECC/REC/(08)01 and decision ECC/DEC/(08)01 covering the regulation of the ITS-G5A and ITS-G5D spectrum covering 5 x 10 MHz band from which ITS-G5A is designated and ITS-G5D allocated for traffic safety and traffic efficiency. As this spectrum falls under the general EU mobile regulation, it is protected against other use, although other use is allowed under interference restrictions. ECC/REC/(08)01 and ECC/DEC/(08)01 also cover the ITS-GB and ITS-G5C spectrum. The ITS-G5B band is allocated for ITS none-safety. This spectrum falls under general spectrum SRD regulation and therefor no priority can be granted in these bands. The ITS-G5C can be used for ITS services but this spectrum is also used for normal RLAN operation.

Besides this spectrum in the 5 GHz band there is also a 1 MHz band allocated in the 63–64 GHz band. The 63–64 GHz frequency band is primarily based on the ITU Radio Regulations (RR) and regulated by EU decision ECC/DEC/(09)01) with the allocation to traffic safety and traffic efficiency related use for Europe. It has different characteristics compared to the 5 GHz band and it cannot be used for the same purpose as the 5 GHz band. Short range communication in the 5 GHz band will generally reach all other stations within 300 meters (360°) in non-urban areas. Propagation possibilities in the 63–64 GHz band are very directional and therefore this band basically can only be used for direct line of sight (LOS) communication, with expected lower transmission levels reaching distances of up to 100 meters. The 63–64 GHz frequency band is able to support direct high volume data communication (raw data, e.g. video data) from one vehicle to one other.

Initial deployment of C-ITS functionality will mainly use SCH0. Further deployments will use the other channels starting with focus on SCH1 and SCH2 for the first use cases beyond Day 1. The channels cannot be evaluated equally as the characteristics of these channels are not the same. Side-band interference needs to be taken into account requiring reduction of transmit power on the intermediary channels. Current thinking is shown in Figure 4. A 10 dBM power reduction for SCH2, SCH3 and SCH5 is envisioned, resulting in limitation in use for those channels. For other channels also a different modulation scheme, such as 6 Mbit (QPSK with 1/2 symbol rate) and higher modulation level (e.g. 16-QAM) can be chosen. These channel differences have influence on the possible use of these channels.

IV. Technical Concepts Enabling MCO

This section discusses technical concepts that enable efficient MCO. First, a Service Announcement Service (SAS) is introduced that complements our previous work in [3].

Second, enhancements of the GeoNetworking protocol to support MCO are being proposed. These enhancements extend the GeoNetworking header, allowing using multiple network interfaces in a GeoNetworking router, and enable dynamic per-packet channel routing.

Third, the section describes a concept that allows for offloading data transmission from one channel to another in congested spatial areas, and backloading the transmission in non-congested areas. The concept covers single-hop and multi-hop communication.

A. Service Announcement Service

The Service Announcement Service (SAS) is a facility service enabling advertising a specific service in a specific area, not necessarily only relevant for this area but seen relevant for those in the dissemination area addressed. The SAS may be used for safety as well as non-safety announcements. It provides information about the location where services can be found/provided. It does not include any content information. The reference may refer to a specific service on a specific ITS-G5 radio channel, another communication channel such as WiFi channels, or even a radio channel such as DAB+ and the related service in this channel. The SAS specifies the communication protocol such as ITS-G5 or IP so that any network can be addressed. It therefore is not bound to a specific technology or system.

In our previous work [3] service announcement was used to specifically use the available ITS-G5 traffic safety and traffic efficiency channels so that related applications could be directed to a specific ITS-G5 band. The concept introduced in this work expects that safety time critical information exchange is handled by a specific separate channel usage scheme not described here and that SAS is used for more legislation related (e.g. eco-zones), operational (e.g. security safety), and none safety referencing (e.g. parking).

One option for dissemination of the SAS messages is to use SCH0. Especially in this case, SAS priority classes are required to manage channel use depending on network load on SCH0. One possibility could be the following classes

- Safety critical
- Legislation
- Security
- Non-safety

The use of SAS is intended to reference to any kind of radio or internet destination but explicitly not to the ITS-G5 safety bands G5A and G5D as they are used for more safety critical information exchange. The following references are envisioned

- ITS-G5B and ITS-G5C bands with different protocols
- ITS-G63 with different protocols
- WiFi at any band with different protocols
- DAB+ with reference to a specific part of the information and related protocol
- Cellular 3G-5G and related protocol
- Internet link

For each of the classes as described, but also for the Internet link, additional functional classification will be required to enable the receiving ITS system to determine what to do with the provided announcement. Examples are different types of raw data when referencing to the ITS-G63 band, or for legislation classes to a Internet link where active eco-areas can be found.

B. GeoNetworking Extensions for MCO

The current specification of GeoNetworking [8] with its media-specific extensions of ITS-G5 rely on a configuration with a single transceiver operating on a single wireless channel. In order to support MCO in GeoNetworking, the protocol needs to be extended. The extensions for MCO enable advanced concepts for information dissemination with offloading and backloading of data on SCHs. Protocol principles of the GeoNetworking protocol remain unchanged, but the required extensions affect several key building blocks, including the upper-layer interface, location table management, addressing, packet handling procedures and packet forwarding algorithms, which are described next.

[Upper-layer interface.] A basic assumption for MCO support in GeoNetworking is that the upper layer entities, i.e. Facilities layer or (if appropriate) the application are in control of MCO and can determine whether the forwarding decision is restricted to a single SCH or MCO can be applied. In general, the traffic class (TC) parameter being passed via the interface expresses the transmission requirements and is extended by a flag that determines whether offloading/backloading is allowed.

[Location table management.] The GeoNetworking location table maintains soft-state information from other nodes in the ad hoc network. An entry in the location table indicates the presence of a node and the reachability of the node, either directly or via multi-hop communication. A location table entry includes link-layer address, position vector (position, speed, heading) and other information. Parts of the data structure depend on the transceiver/channel used by the node and need to be duplicated for a second/additional transceiver(s). A particular challenge is that the characteristics of the used SCHs can be different, e.g. due to different transmit power values or interference levels on the channels. This may result in scenarios, where a node is reachable via a direct link on one SCH, but only by multi-hop on the the other. Consequently, the maintenance of the entries, i.e. their lifetime and timeout-based removal, is different.

[Addressing.] We assume that every transceiver is identified by a (temporarily stable) unique link-layer address (i.e. MAC address), that is necessary for unicast communication between a source-destination pair. When an area-based forwarding scheme is used to disseminate a packet to nodes in a geographical area, a transceiver-specific link layer address can be used to prioritize a particular forwarder for multi-hop communication. In addition, the source node's link-layer addresses are also used to route a packet internally from the GeoNetworking packet forwarding engine to the intended transceiver.

[Packet handling procedures.] In GeoNetworking, a forwarder buffers packets when no suitable neighbor is available as next forwarder, which is referred to as store-carry & forward (SCF). When the packet buffer is flushed, i.e. a neighbor becomes available, the packets can be forwarded on another SCH exploiting the MCO capabilities.

[Packet forwarding algorithms.] The existing forwarding algorithms for GeoNetworking — non-area and area-based — take the forwarding decision based on the availability of neighbor nodes on the same SCH on which the packet has been received and take additional information, such as distance from the previous forwarder and distance to the destination, respectively, into account. The presence of a second SCH for forwarding the data packets adds an additional dimension in the forwarding algorithms. In particular, with contention-based forwarding (CBF), packets are broadcasted to all neighbors, who buffer the packet and overhear other nodes' re-transmissions to decide whether its own transmission is required. With CBF, the overhearing function needs to be extended since other nodes may re-transmit packets on another SCH.

C. Offloading and Backloading

Offloading and backloading are concepts that address situations where network traffic has to be reduced in order to avoid network congestion / overload (that is in congested spatial areas). In such situations, single channel systems have to drop or omit dissemination of packets with least important information. Offloading denotes the process of shifting such packets from SCH0 to different channel(s) in MCO enabled systems. Backloading denotes the process of shifting packets back to SCH0 that were previously offloaded to another channel, in case network load on SCH0 allows for that. Rationale behind backloading is to provide single channel systems with the information they would not receive otherwise.

Offloading and backloading rely on the capabilities of the aforementioned GeoNetworking extensions to coordinate multi-channel usage, i.e. the extension of the location table to determine on which channels neighboring stations are currently operating on. Packets that have to be dropped/omitted in single channel system can be grouped into own station originating packets and received packets for forwarding (remote station originating packets). In the following, offloading and backloading of packets are discussed separately for both cases.

[Own station originating packets.] According to the cross-layer DCC approach, the creation process(es) of own station originating packets should be reduced to the number of packets that is still allowed to be transmitted by every host. DCC is responsible for steering this/these packet creation process(es). For an offloading MCO enabled system, DCC has to be extended to signal and steer packet creation processes for multiple channels. This includes ensuring that as many packets as possible/allowed by DCC are disseminated on SCH0, resulting in the same behavior as a single channel system. In addition, packet creation processes have to create additional packets according to application / facility packet generation rules and schedule these packets for transmission over other channel(s). By nature, for own host created packets, applications or facilities can decide to enable or disable offloading for the 1st hop. For packets that are supposed to be disseminated of multiple hops, the GeoNetworking layer has to be informed to set the offloading flag accordingly via inter-layer interfaces. Note that the offloading flag should be used to communicate approval/disapproval for offloading/backloading in combination.

[Remote station originating packets.] Multi-hop packets received for forwarding are analyzed by the GeoNetworking layer and forwarding decision are taken depending on network load at the GeoNetworking protocol. In single channel systems, the forwarding process refrains from forwarding a packet if a certain network load is reached on SCH0. For packets received on SCH0, MCO enabled systems check the offloading flag in the GeoNetworking header. If not set, the packet is not forwarded. If set, the forwarding process continues using a non-congested channel (unless there is none). For packets received on another channel than SCH0, the GeoNetworking layer determines the (originally) intended dissemination channel by looking at the TC ID in the GeoNetworking header. If this header indicates that the intended dissemination channel is SCH0 and the network load on SCH0 allows for forwarding on SCH0, the packet is forwarded on SCH0. This is what we refer to as backloading. If the network load on SCH0 does not allow for backloading the packet, the forwarding process continues on the channel the packet was received on. Note that this requires MCO enable systems to run forwarding algorithms such as contention based forwarding across multiple channels.

V. MCO in Mixed Scenarios

This section briefly analyzes the effects of MCO in a mixed deployment consisting of single channel systems (MCO incapable) and MCO enabled systems.

Single channel systems have disadvantages compared to MCO enabled systems if the latter start offloading packets from SCH0. Offloading reduces performance of single channel systems as for instance the update rate of Single Hop Broadcast (SHB) packets reduces, or multi-hop packets such as GeoBroacasts are not received in areas beyond the first hop.

Our proposal to mitigate these disadvantages is to only offload packets that would otherwise be dropped by DCC, as described above. In this way, single channel systems receive exactly the same packets, independent of the presence of MCO enabled systems.

Offloading in combination with backloading is even improving the situation for single channel systems. Packets that would have to be dropped in congested spatial areas can be forwarded on alternative channels. As soon as they reach non-congested spacial areas, backloading switches the packets back to SCH0, enabling reception by single channel systems.

VI. Conclusions

In this paper we present a comprehensive discussion of multiple aspects of multi-channel operation (MCO) in EU V2X systems.

Starting from an overview on novel use cases we derive communication requirements and provide an overview on available frequency bands including their properties and limitations in use. Based on this knowledge we present and discuss three MCO enabling concepts.

We introduce a Service Announcement Service (SAS) that complements our previous work in [3], specifically targeting announcement of non-safety information services. For GeoNetworking, we describe required extensions of key building blocks, including the upper-layer interface, location table management, addressing, packet handling procedures and packet forwarding algorithms. Furthermore, we propose and discuss the concept of offloading with backloading to address congested spatial areas. We discuss the effects of MCO in mixed scenarios, specifically when using offloading and backloading. Especially backloading increases the possibility for single channel system (non MCO capable systems) to obtain information that would otherwise be dropped due to high network load.

In future work, we plan to include the concepts of this work in an overall MCO framework capable of evolving from a simple dual channel dual transceiver configuration to a n-channel m-transceiver system (with $n > 2$ and $m \geq 2$).

Acknowledgements

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