SMART INTRODUCTION OF 5G BROADCAST IN CO-EXISTENCE WITH LEGACY BROADCAST SYSTEMS

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ABSTRACT

5G Broadcast offers broadcast network operators the possibility of reaching mobile devices directly, without requiring additional hardware in smartphones [1]. 5G Broadcast enables delivery of services such as linear TV, live content offload, or emergency messages to the general population while minimizing the hardware impact and the cost to the end customers.

When introducing a new broadcast standard, factors such as spectrum scarcity, the need to support legacy receivers, and regulatory constraints are of significant interest in non-greenfield markets. Due to these issues, in some cases it may not be desirable or feasible to vacate one entire broadcast UHF channel to deploy 5G Broadcast. Instead, a transition approach to refarming may be preferred, where the available bandwidth is flexibly allocated to 5G Broadcast or a legacy standard with a granularity finer than a broadcast UHF channel.

In this paper, we analyze how 5G Broadcast can be introduced and deployed while coexisting in the same UHF channel with several other legacy broadcast radio technologies, including ATSC 3.0, DVB-T2 and ISDB-T. Transmissions belonging to both technologies, i.e. the legacy system and 5G Broadcast, are multiplexed (in time and/or frequency, depending on the legacy system) in a manner that is backwards-compatible with legacy demodulators. By proper joint signal generation, decoding the legacy signal can be achieved by legacy receivers, unaware of the presence of the 5G Broadcast waveform, while the 5G Broadcast waveform can be decoded by the corresponding receivers, unaware of the legacy system as well. We present the techniques used by both 5G Broadcast and legacy standards to create “gaps” in their transmissions and investigate how these techniques can be paired across standards to successfully achieve coexistence.

INTRODUCTION

In recent years, 5G Broadcast [1] has attracted the attention of broadcasters worldwide due to the possibility of reaching mobile receivers directly, while reusing the baseband processing present in current handsets. Although the baseline deployment model for 5G broadcast would be to dedicate one or several UHF channels in their entirety to this technology, in some cases it may be beneficial or desirable to partially allocate one channel to 5G Broadcast while using the remaining capacity for a legacy broadcast system.

In the US, the regulation requires a NextGen TV broadcaster to transmit a free-to-air ATSC 3.0 TV program, while the remaining capacity in the channel can be used for *ancillary services* (which may include a 5G Broadcast transmission). In this case, the ATSC 3.0 signal would need to share the 6MHz channel with the 5G Broadcast transmission, and the joint signal should be constructed in such manner that existing ATSC 3.0 receivers can demodulate their corresponding program.

In other geographies, although not necessarily bound by regulation, there may be deployment constraints under which it is beneficial to share a broadcast channel between 5G Broadcast and legacy technologies. For instance, a broadcaster may choose to move one TV program from DVB-T2 to 5G Broadcast while keeping the rest of the programs in the same channel under DVB-T2. This would allow legacy receivers to keep demodulating the DVB-T2 programs while enabling new device types through 5G Broadcast. Other use cases for 5G Broadcast, such as emergency notifications, software updates, datacasting, etc. may not need to use a whole channel.

An additional issue arising from different broadcasting technologies co-existing in the same channel is how to tackle the different link budgets (i.e. the transmit power) required to obtain the desired coverage. In practice, it may be desirable that co-existing standards use the same transmit power (e.g., if the same tower(s) is/are used for transmission), with the understanding that a certain amount of gap fillers may be needed to obtain full coverage. In co-existence based on frequency division multiplexing (FDM), such as 5G Broadcast with ISDB-T (as described in this paper), interference mitigation across technologies may necessitate careful choices of transmit power(s). However, for time division multiplexing (TDM) based co-existence, such as for 5G Broadcast with ATSC 3.0 or DVB-T2 (as described in this paper), interference due to different transmit power(s) is less of an issue.

For 5G Broadcast, the challenges related to uplink/downlink interference are addressed by 3GPP specifications, such that cellular transmissions from smartphones do not significantly impair broadcast reception.

In the standardization groups, there is currently a work item in progress in ATSC to address the corresponding co-existence aspects we describe in the next sections, while there is currently a proposed work item for Release 19 in 3GPP to tackle CAS enhancements in 5G Broadcast. In the case of DVB-T2, it was not deemed necessary to address any issues.

In this paper, we present techniques that can be used to multiplex 5G Broadcast with other broadcast technologies (ATSC 3.0, DVB-T2 and ISDB-T) in the same broadcast channel. For each of the technologies, we present the basic frame structure and features that can be used for coexistence.

5G BROADCAST: FRAME STRUCTURE OVERVIEW AND LIMITATIONS

In 5G Broadcast there is an “always-on signal” (termed the “Cell Acquisition Subframe” (CAS)) that is present as a 1 ms long signal (which uses a 15 kHz subcarrier spacing as legacy LTE) and has a periodicity of 40 ms; the MBMS traffic (including control information) is transmitted using the Physical Multicast Channel (PMCH) within the 39 ms intervals between successive CASs. This is depicted in Figure 1 below.

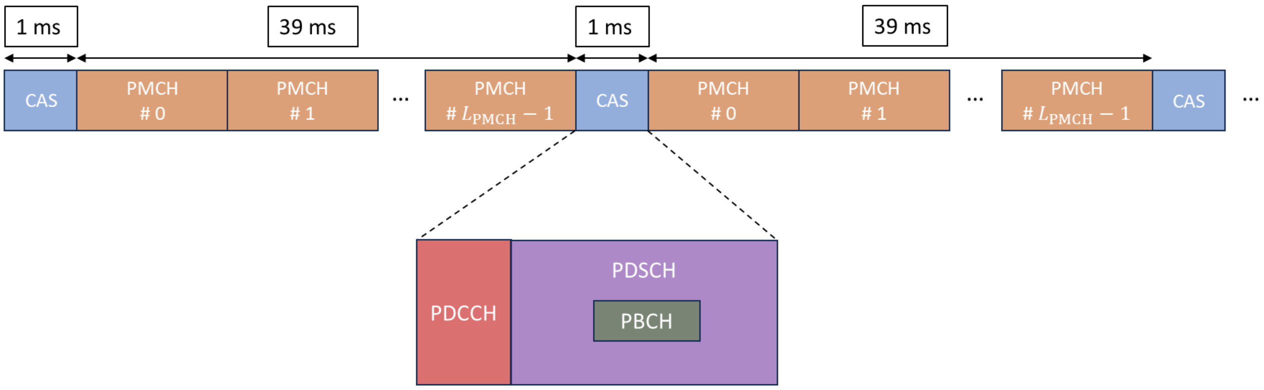

Figure 1: Current frame structure of 5G Broadcast. CAS is transmitted every 40ms. MBMS traffic is transmitted by the PMCHs in the 39 ms between CASs.

As an immediate consequence of this frame structure, one can observe that if 5G Broadcast is to co-exist in the same spectrum with other broadcasting technologies (e.g., via Time-Division-Multiplexing (TDM)), any scheduling unit of the co-existing standard would have to be contained inside a 39 ms unit of time. Moreover, there are going to be regular "interruptions" to such transmissions, due to the always-on nature of the CAS.

As an example of the difficulties this may give rise to in terms of co-existence, we can observe that the recommended practices for ATSC 3.0 [2] almost universally use an ATSC 3.0 frame duration of ≈ 250 ms which is not feasible to accommodate without interruptions within the 5G Broadcast frame structure depicted above.

Need for enhancing 5G Broadcast frame structure to facilitate in-band co-existence.

As outlined in a recent submission to the 3GPP RAN plenary [3], most modern broadcasting standards support features that allow the possibility of "blanking" part of the transmission for the introduction of future enhancements to the standard (or a new standard) without disrupting the operation of legacy receivers. For instance, ATSC 3.0 introduces the concept of a "bootstrap signal" (as defined in [4]) that allows to introduce "gaps" in the transmission to be used by future extensions of the standard. DVB-T2 introduces the concept of future extension frames (FEF) with a similar purpose [5]. It is also expected that 3GPP may introduce future enhancements to the currently defined broadcast systems to enable possibility of performing a "soft migration". A similar aspect of "forward compatibility" was widely discussed, e.g., in the early days of 3GPP 5G New Radio (NR) standardization.

Furthermore, in the US, the FCC regulation states that an ATSC 3.0 signal must be transmitted free-to-air to the public. Therefore, for enabling 5G Broadcast in the US it is imperative to standardize a technique that allows sharing a broadcast channel between ATSC 3.0 (targeting fixed reception) and 5G Broadcast. A technical analysis of coexistence between 5G Broadcast and ATSC 3.0 has been documented in [6, Sec 5.2] by the ATSC standard organization, and communicated to 3GPP TSG RAN in [7].

Furthermore, in DVB-T2 markets, the possibility to share a channel between 5G Broadcast and DVB-T2 could facilitate deployment of 5G Broadcast transmissions. In those markets where it is not possible now to free up an entire UHF channel from DVB-T2 for the introduction of 5G Broadcast it is still likely that some capacity on a given carrier may be made available, for example by reduction of data rates of TV programs or even dropping some of them completely.

In line with the technical analysis in [6], in the next section, we describe proposals to standardize the possibility of interrupting the 5G Broadcast transmission for periods longer than 39 ms by muting the CAS transmissions.

ENHANCEMENTS TO 5G BROADCAST TO FACILITATE CO-EXISTENCE

CAS Muting

In this approach, we move away from a “fixed” periodicity for the “always on CAS” by “muting” (not transmitting) some of the CASs. The muting patterns may be indicated in a preceding CAS (e.g. in the “system information” part of the CAS) in the MBMS-dedicated cell.

These muting patterns may be specified as “bitmaps” in the SIB or may be selected from a set of pre-specified muting patterns. We provide an illustration of CAS muting in Figure 2 below.

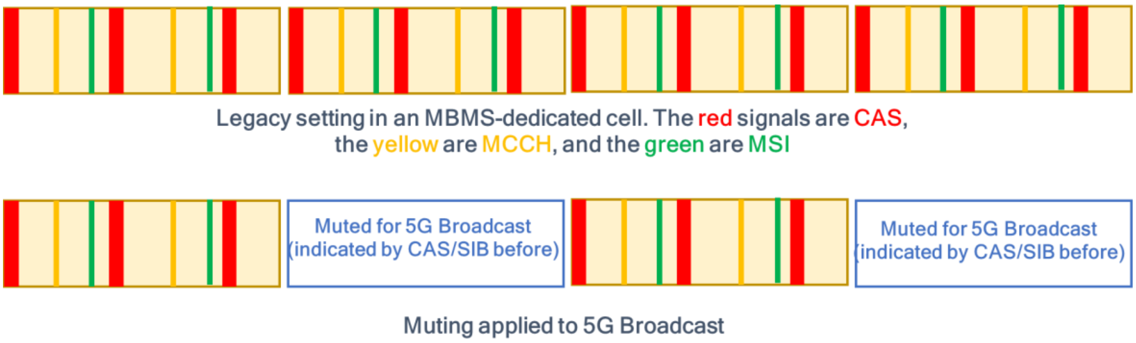

Figure 2: Example of selective CAS muting, to free up time intervals to schedule other broadcast technologies.

CO-EXISTENCE WITH ATSC 3.0

Flexibility afforded by the ATSC 3.0 Frame Structure

The ATSC 3.0 frame structure is premised on two important signals for the purposes of synchronization and transmission of key physical layer (L1) control information. Upon reading the bootstrap (B) and Preamble (P) signals, a receiver receiving the ATSC 3.0 transmission has the following important pieces of information:

- The ATSC frame length
- The value of the field “**min_time_to_next**”, transmitted in the bootstrap signal of ATSC 3.0, that can take values from 50 ms to 5300 ms [4, Table 6.3], and indicates the minimum time until an ATSC 3.0 receiver may expect another Bootstrap signal.

This field “**min_time_to_next**” is what provides the flexibility to mute ATSC 3.0 frame transmissions over a variable region in time, wherein the length of this region can be several (e.g., up to ≈ 5) seconds long. This is depicted in Figure 3 below.

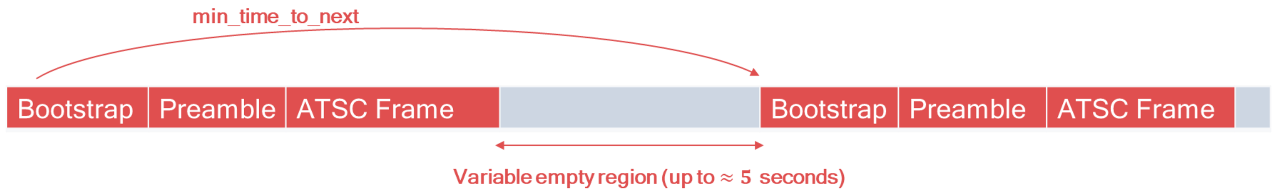

Figure 3: Illustration of the ATSC 3.0 Frame Structure, facilitating gaps between successive bootstrap signals.

Time-Division-Multiplexed operation between 5G Broadcast and ATSC 3.0

Leveraging the scheduling flexibility afforded by ATSC 3.0 together with the "CAS-muting" for 5G Broadcast we can achieve TDM-ed operation between the two technologies in the same broadcast spectrum, as show in Figure 4 below. Given the wide range of values (50ms to 5.3 seconds) afforded by ATSC 3.0 to modulate the duty-cycle of transmission, broadcasters are expected to have a wide range of options in terms of scheduling, according to their needs and requirements.

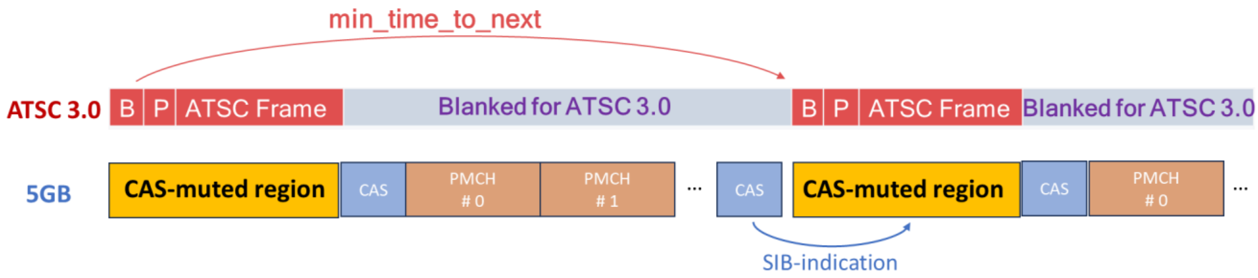

Figure 4: Example illustration of TDM-ed co-existence between ATSC 3.0 (per existing standards) and 5G Broadcast (with the CAS-muting enhancements described before).

Challenges related to co-existence with ATSC 1.0

Significantly less modern than its successor ATSC 3.0, ATSC 1.0 employs Vestigial Side Band (VSB) single-carrier modulation, which makes it extremely challenging to enable co-existence with 5G Broadcast (or other broadcast technologies) using a TDM approach as described in the previous sections. ATSC 1.0 has several synchronization signals that need to be transmitted periodically in an always-ON, namely the data segment sync and field sync signals [8, Section 6.5]. The data segment sync appears in every segment (~77us) and cannot be muted. Therefore ATSC 1.0 is an unappealing choice in terms of co-existence with 5G Broadcast.

CO-EXISTENCE WITH DVB-T2

The DVB-T2 standard [5] builds upon its DVB-T predecessor to provide greater flexibility and better performance in multiplex allocation, coding, modulation and RF parameters [9]. In the next two sections, we provide an overview of the features enabled in the DVB-T2 standard, as well as a detailed analysis on how to effectively enable co-existence between DVB-T2 and 5G Broadcast.

Overview of DVB-T2

Data transmission in DVB-T2 is organized in T2 super-frames, which contain T2 frames carrying DVB-T2 control and data information, and may also contain FEF frames, which may be used for transmission of data unknown to a DVB-T2 receiver addressing the current version of the standard [5]. An FEF frame always begins with a P1 symbol, and its maximum length is up to 250 ms for the T2-Base profile and 1s for the T2-Lite profile [5]. The framing structure in DVB-T2 is shown in Figure 5. A DVB-T2 receiver detects FEF frames within the DVB-T2 super frame using both the L1 signaling contained in the P2 symbols and the P1 symbol located at the beginning of the FEF frame, as shown in Figure 6.

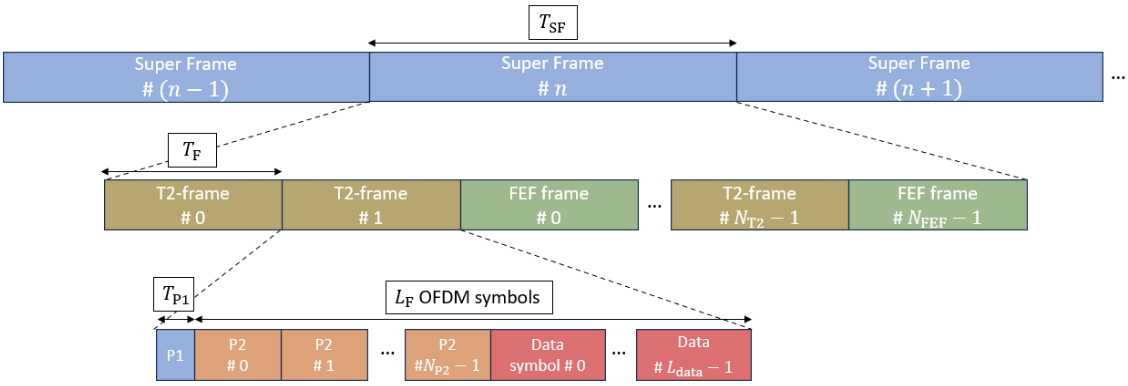

Figure 5: Frame structure in DVB-T2, in which super frames are composed of several T2 frames and may also contain FEF frames between consecutive T2 frames.

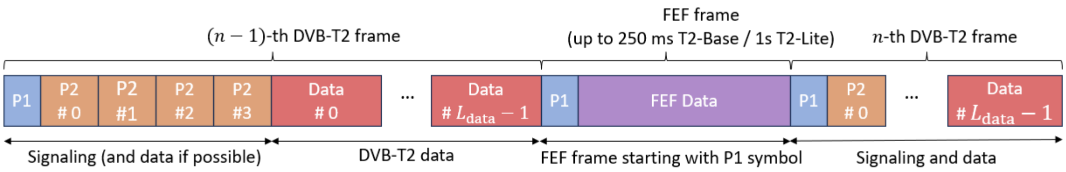

Figure 6: T2 frame followed by an FEF frame starting with a P1 symbol.

Enabling co-existence between 5G Broadcast and DVB-T2

From a co-existence perspective, the most important feature of DVB-T2 is the introduction of FEF frames, which naturally allow 5G Broadcast to be TDM-ed within DVB-T2 super frames, as illustrated in Figure 7. This TDM mechanism requires DVB-T2 to signal: 1) whether FEF frames are present in the T2 super frame using L1 signaling, and 2) where they are located therein so that legacy receivers can ignore the FEF frames while still receiving the T2 signal as desired. It is important to mention that FEF frames may only be inserted between consecutive T2-frames, and a T2 super frame must begin with a T2-frame. Furthermore, in order not to affect reception of T2-frames, the receiver's AGC is expected to be held constant for the duration of the FEF part so that reception of T2-frames is not affected by power variations during the FEF part [5].

To enable the scheme illustrated in Figure 7, coordination between DVB-T2 and 5G Broadcast transmitters is needed to ensure that the 5G Broadcast waveform fits within the FEF data portion without interfering with the initial P1 symbol. As in ATSC 3.0, the DVB-T2 standard uses L1 control signaling carried by the P1 and different P2 symbols in a T2 frame.

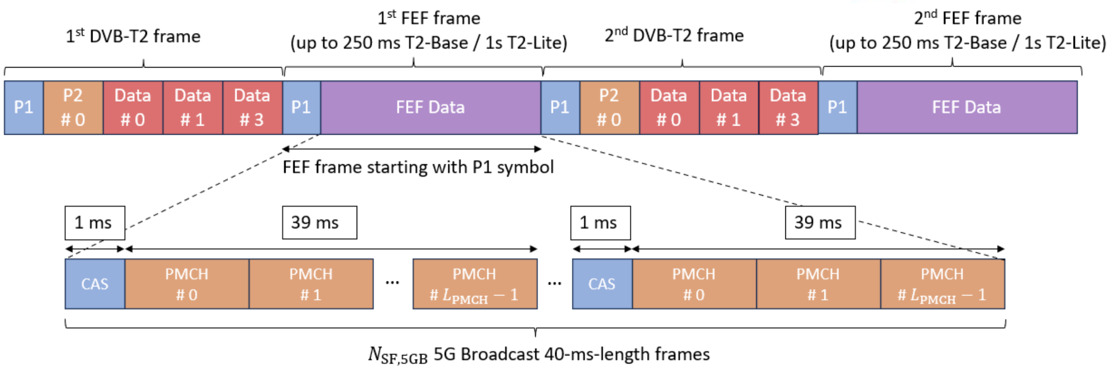

Figure 7: Example of co-existence scheme between DVB-T2 and 5G Broadcast in which 5G Broadcast data is transmitted during FEF frames. This example assumes 32K FFT size for T2-frames and a minimum number of OFDM symbols per T2-frame of 4.

The structure of the T2-frames and FEF frames within a DVB-T2 super-frame is shown in Figure 8. The main parameters (transmitted in P1 and P2 symbols as L1 signalling) that define the structure of the DVB-T2 super frame in terms of the presence of FEF frames, their duration and periodicity are:

- Parameter NUM_T2_FRAMES (8 bits): indicates the number of T2-frames per super frame [5, Section 7.2.2]. The minimum number of T2-frames is 2.
- Parameter NUM_DATA_SYMBOLS (12 bits): these bits indicate the number $L_{\mathrm{data}} = L_{\mathrm{F}} - N_{\mathrm{P2}}$ of data OFDM symbols (see Figure 6) per T2-frame, excluding P1 and P2 [5, Section 7.2.2]. The minimum value of L_{F} is $N_{\mathrm{P2}} + 3$ when using 32K FFT size, and $N_{\mathrm{P2}} + 7$ otherwise. The number of OFDM symbols L_{F} must be even for 32K FFT size [5, Section 8.3.1].
- Parameter FEF_LENGTH (22 bits): as illustrated in Figure 8, this parameter indicates the length of the FEF part as the number of elementary periods from the start of the P1 symbol of the FEF part to the start of the P1 symbol of the next T2-frame [5, Section 7.2.3.1]. For the T2-Lite profile, the FEF_LENGTH_MSB field includes 2 additional bits to extend the range of the FEF part duration.
- Parameter FEF_INTERVAL (8 bits): also illustrated in Figure 8, these bits indicate the number of T2-frames between two FEF parts. A super-frame containing both T2-frames and FEF frames must always start with a T2-frame [5, Section 7.2.3.1].

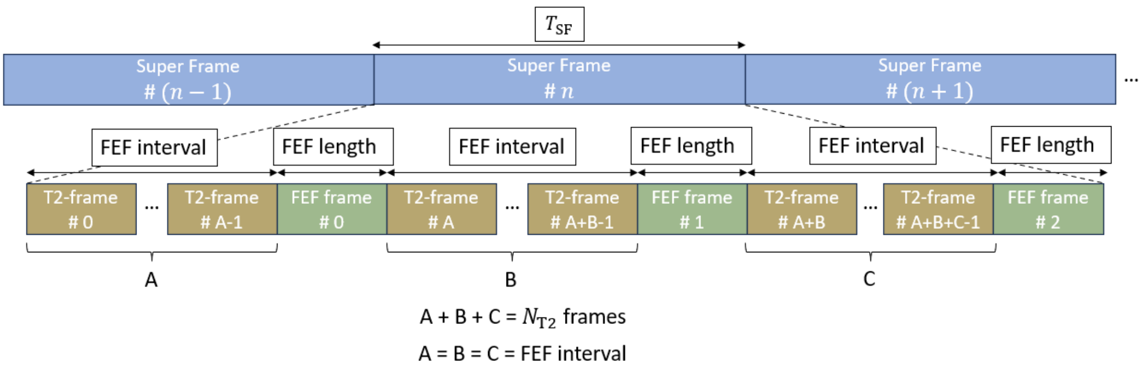

Figure 8: Example of the structure of a DVB-T2 super frame containing 2 FEF frames, in which periodic insertion of T2 frames and FEF frames allows a legacy DVB-T2 receiver to know the location and number of T2 frames and ignore the content of FEF frames.

To enable the scenario in Figure 8, after enabling FEF frames using the P1/L1-pre signaling parameters mentioned above, the FEF length T_{FEF}, FEF interval I_{FEF}, and the T2-frame duration T_{F} govern the effective utilization of DVB-T2 and 5G Broadcast as

$$R_{\mathrm{DVB-T2}} = \frac{I_{\mathrm{FEF}} T_{\mathrm{F}}}{T_{\mathrm{FEF}} + I_{\mathrm{FEF}} T_{\mathrm{F}}} \qquad R_{\mathrm{5GB}} = \frac{T_{\mathrm{FEF}}}{T_{\mathrm{FEF}} + I_{\mathrm{FEF}} T_{\mathrm{F}}}.$$

Last, we analyze the flexibility of the DVB-T2 standard to accommodate 5G Broadcast transmissions in the FEF frames in terms of the actual time utilization of the latter within the DVB-T2 super frame duration. We provide upper bounds on the utilization for 5G Broadcast when co-existing with DVB-T2, as well as other combinations of parameters leading to either more similar (e.g. 50/50) or more skewed utilization towards either DVB-T2 or 5G Broadcast (e.g. 75/25, 25/75). Due to the dependence of these bounds on the FFT size, guard interval size, and bandwidth, we provide numerical examples for 8 MHz channel bandwidth in Table 1 for an FFT size of 32K. The total duration of a T2-frame is given by $T_{\mathrm{F}} = (N_{\mathrm{P2}} + L_{\mathrm{data}})\, T_{\mathrm{OFDM}} + T_{\mathrm{P1}}$ [5, Sec. 9.5], with $T_{\mathrm{P1}} = 2048T$ being the duration of the P1 symbol, T_{OFDM} being the total OFDM symbol duration, and $T = 7/64\ \mu$s the elementary period. For the computation in Table 1, we consider the minimum guard interval allowed for an FFT size of 32K [5, Table 60] and the number of P2 symbols given in [5, Table 44].

FFT Size	GI ratio	$N_{\mathrm{P2}} + L_{\mathrm{data}}$	T_{F} [ms]	$R_{\mathrm{DVB-T2}}$	R_{5GB} (T_{5GB})
32K	1/128	1 + 10	39.732	48.61%	51.38% (42 ms)
32K	1/128	1 + 34	126.42	75.06%	24.94% (42 ms)
32K	1/128	1 + 11	43.34	26.54%	73.46% (120 ms)
32K	1/128	1 + 3	14.448	5.46%	94.54% (250 ms)

Table 1: Analysis of parameters for co-existence of DVB-T2 and 5G Broadcast with minimal duration of DVB-T2 frames for 8 MHz channel bandwidth, 50/50, 25/75 and 75/25 time utilization percentage for both standards.

This analysis shows the flexibility of DVB-T2 to co-exist with 5G Broadcast, enabling a wide range of possibilities to configure the amount of time that can be used for transmission of these broadcasting standards.

CO-EXISTENCE WITH ISDB-T AND ISDB-TB

The last family of standards for which we consider enabling co-existence with 5G Broadcast are the Integrated System Digital Broadcasting Terrestrial (ISDB-T) standards. The ISDB-T physical and control layer signaling are described in [10], and a modified version of this system was created and adopted in Brazil renamed as ISDB-TB [11, 12]. From a wireless transmission standpoint, the only difference between ISDB-T and ISDB-TB is the assignment of the transmission frequencies [12, 13]. Consequently, our co-existence analysis applies to both ISDB-T and ISDB-TB.

Overview of ISDB-T

The physical layer transmission system of ISDB-T is based on OFDM, in which the transmission band is segmented hierarchically in up to three layers mapped to 13 segments, namely layer A, B, and C, in which the channel coding rate, modulation and time interleaving length can be independently selected for each layer [10], as shown in Figure 9. The receiver acquires the information needed to decode each layer using the TMCC synchronization signal. The bandwidth of every segment is approximately 429 kHz [10].

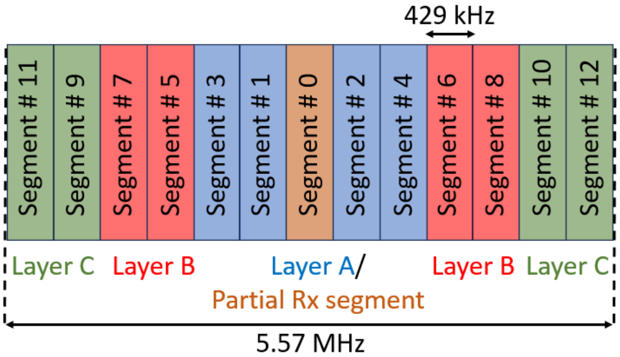

Figure 9: Illustration of segmented-OFDM transmission in ISDB-T. If layer A is configured with a single central segment (highlighted in orange), such segment can be configured for partial reception by a sound broadcasting receiver [10, Chapter 3].

Enabling co-existence between 5G Broadcast and ISDB-T standards

In previous sections, co-existence between 5G Broadcast and other broadcasting standards could be enabled by TDM-ing the different standards in a coordinated manner. In the case of ISDB-T, by sharp contrast, a frequency multiplexing approach (i.e. FDM) needs to be enabled due to the lack of flexibility to introduce other waveforms within the ISDB-T frame structure. From this perspective, we can exploit the segmented-OFDM transmission structure of ISDB-T to mute a few segments within the ISDB-T spectrum and transmit 5G Broadcast therein. This idea is illustrated in Figure 10, in which two potential configurations are depicted. The first configuration is based on cancelling 4 central ISDB-T segments to free 1.72 MHz and introduce a 1.4 MHz 5G Broadcast carrier therein, while the second configuration is based on cancelling 8 segments and free 3.432 MHz, such that a 3 MHz 5G Broadcast carrier can be transmitted within that gap. For these configurations to be enabled, the TMCC synchronization signal needs to indicate that no segments are allocated for layer A transmission, so that ISDB-T payload is mapped to the strongest modulation scheme.

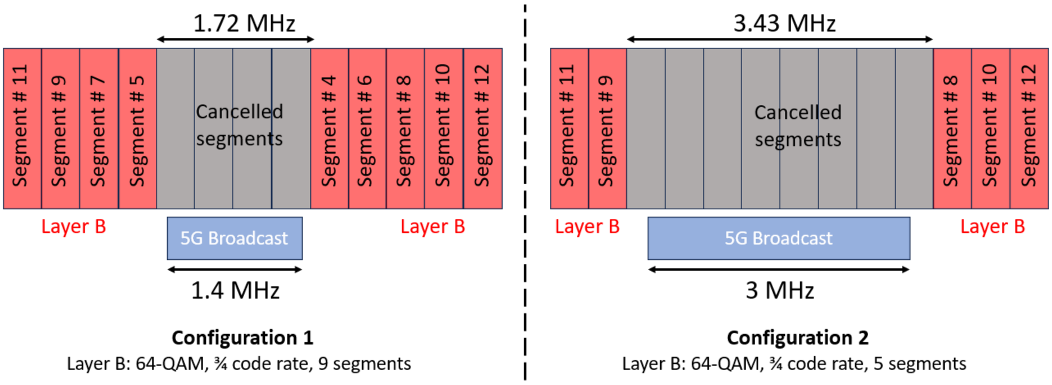

Figure 10: Example configurations for co-existence of 5G Broadcast and ISDB-T.

CONCLUSIONS

In this paper, we provided technical solutions to address the baseband aspects of enabling co-existence between currently deployed broadcasting standards (ATSC 3.0, DVB-T2 and ISDB-T) and 3GPP-based 5G Broadcast. We showed that the frame structures of ATSC 3.0 and DVB-T2 naturally allow co-existence with 5G Broadcast using time multiplexing with different time utilization granularities, while a frequency multiplexing approach is preferred for ISDB-T. The technical solutions presented herein emphasize the potential and feasibility of deploying 5G Broadcast without requiring changes to the specifications of the broadcasting standards under study, thereby ensuring backwards compatibility with legacy receivers.

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