Physical Layer simulative comparison of DVB-S2X/RCS2 and 3GPP 5G NR-NTN technologies over Geostationary Satellite Scenario

Baptiste Chamaillard
Business Line Telecommunication
Thales Alenia Space
Toulouse, France
baptiste.chamaillard@thalesaleniaspace.com

Albekaye Traoré
Business Line Telecommunication
Thales Alenia Space
Toulouse, France
albekaye.traore@thalesaleniaspace.com

Nathan Borios
Business Line Telecommunication
Thales Alenia Space
Toulouse, France
nathan.borios@thalesaleniaspace.com

Stefano Cioni
Telecommunication Systems and Techniques Section
European Space Agency
Noordwijk, Netherlands
stefano.cioni@esa.int

***Abstract*—This simulation study aims to compare the physical layer performance of the 5th Generation (5G) New Radio Non-Terrestrial Networks (NR NTN) air interface with Digital Video Broadcasting (DVB) technologies, specifically analyzing the Second Generation Satellite Extensions (S2X) standard on the Downlink (DL) and DVB- Return Channel via Satellite 2nd generation (RCS2) standard on the Uplink (UL). The study assumes a reference geosynchronous satellite telecommunication system operating in the Ka-band frequencies. The comparison analysis of the physical layers demodulation performance on the Forward (FWD) link reveals an average spectral efficiency decrease from 15 to 26% for NR PDSCH (Physical Downlink Shared Channel) in comparison to DVB-S2X. The analysis of the Return (RTN) link indicates comparable performance between NR PUSCH (Physical Uplink Shared Channel) and DVB-RCS2, with a marginal advantage for either technology based on specific study cases. The conclusions drawn from the performance comparison emphasize the potential for optimizing NR waveform configuration to improve spectral efficiency and reduce implementation losses through enhanced channel estimation and phase tracking algorithms. Moreover, this study outcome advocates for the completion of the physical layer comparison with System Level simulations of both technologies. This would make it possible to consider additional implications such as non-linear amplification effects, control plane overhead, and scheduling efficiency.**

Keywords—3GPP, 5G, NR, NTN, DVB, S2X, RCS2, GEO, Ka-band, physical layer, performance, comparison, satellite network simulation, satellite communication

I. Introduction

This article presents a physical layer simulative performance comparison between the 5th Generation (5G) New Radio Non-Terrestrial Networks (NR NTN) air interface and Digital Video Broadcasting (DVB) technologies, more specifically the Second Generation Satellite Extensions (S2X) standard on the downlink (DL) and the DVB- Return Channel via Satellite 2nd generation (RCS2) standard on the uplink (UL). The waveform configurations and channel model used for comparison are defined to be representative of a reference satellite telecommunication system. This reference system is based on a Geostationary Orbit (GEO) satellite operating within the 20-30 GHz frequencies, commonly known as the Ka-band, or Frequency Range 2 (FR2-NTN) in 3rd Generation Partnership Project (3GPP) terminology and offering broadband services. The satellite payload is assumed to be transparent and the User Terminal (UT) fixed on the ground. The choice of a reference system based on a GEO transparent payload has been motivated by the fact that it is often perceived by the satellite operators as the easiest and natural scenario to migrate to the 5G NTN eco-system and make the first evaluations of the technology.

The DVB-S2X [1] [2] and DVB-RCS2 [3] standards have been developed by the DVB project consortium for satellite telecommunication applications. Television broadcast was historically the initial targeted service but many other services have been considered and supported since then including broadband services. These standards are still actively maintained and sometimes extended to support new applications.

The NR standard has been initially developed by 3GPP to support the 5th generation of mobile terrestrial communications systems. In the last years, a continuous standardization effort has been driven by 3GPP to support NTN in Frequency Range 1 (FR1) as part of 3GPP Release 17 [4] and later in FR2 as part of 3GPP Release 18 [5]. The NTN NR physical layer relies essentially on the same features and technologies developed for Terrestrial Networks (TN) with few but essential additional mechanisms [6] to deal with larger propagation delays and significant Doppler effect.

The study results presented in this article have been also submitted to the European Telecommunications Standards Institute (ETSI) Satellite Earth Stations & Systems – Satellite Communications & Navigation (SES-SCN) working group as a contribution to the work item “Comparison of DVB-S2X/RCS2 and 3GPP 5G-NR NTN based systems for broadband satellite communication systems”. The work item analytical and simulative comparison and its conclusions are reported in [7].

II. Simulator Descriptions

This section describes the Link Level Simulators (LLS) used to produce the simulation results used for comparison of the physical layers performance of NR NTN and DVB-S2X/RCS2 technologies.

A. DVB-S2X/RCS2 Link Level Simulator

A C++-based simulation environment has been used whose primary function is to enable the processing of data flows through a series of interlinked processing blocks. In this study context, it was used to support the simulation of baseband digital communication chains conforming to DVB-S2(X) and DVB-RCS2 standards. The S2X and RCS2 LLS offer the capability to generate S2(X) Payload Frames (PLFRAMEs) or RCS2 waveform bursts according to various standardized parameters, such as Modulation and Coding (MODCOD) selection or roll-off values. The generated waveform goes through a simulated communication channel whose internal models can be parameterized to reflect noise levels and impairment effects. Subsequently, the received signal is demodulated, enabling the evaluation of successful decoding performance.

The receiver implementations can be configured to match the achievable performance in Additive White Gaussian Noise (AWGN) conditions assuming perfect synchronization provided in [1] [2] and [3] for S2X and RCS2 respectively. Alternatively, it can be configured to reflect the demodulation performance with channel impairments and a practical synchronization implementation [1] [2] mostly based on DVB implementation guidelines.

B. 5G NR NTN Link Level Simulator

The NR link level simulators are based on MathWorks MATLAB environment, and more specifically the 5G Toolbox framework [8] which provides standard-compliant functions for the modelling, simulations, and performance evaluation of 5G NR communications systems. The 5G NR Physical Downlink and Uplink Shared Channels PDSCH/PUSCH (PxSCH) Link Level Simulators enable to generate NR PxSCH waveform associated to a given Transport Block (TB) based on the standardized NR carrier and PxSCH configurations, make it go through a communication channel whose models can be parameterized to reflect noise levels and impairment effects and demodulate the received waveform to evaluate successful decoding performance. As for DVB, the NR receiver implementations can be configured either to match the achievable demodulation performance in AWGN conditions assuming a perfectly synchronized receiver or to reflect the demodulation performance with some channel impairments and some practical synchronization [3] and channel estimation implementations.

III. Simulation Assumptions

A. Channel types definition

Two reference channel types have been considered in this study as presented in Table I.

Table I. Channel Types description.

Channel Type	Phase Noise	Gain Flatness & Group Delay (GF/GD)	Propagation Channel
A	Yes	Yes	SISO, LOS, AWGN
AWGN	No	No	SISO, LOS, AWGN

The considered impairments characteristics of Channel Type A are detailed in [7], Section 5.2.5. The phase noise profiles considered are representative of the total aggregated contributions generated by the satellite transparent payload, the terminal, and the feeder gateway. Two different profiles have been considered, one for the forward (FWD) direction and one for the return (RTN) direction. The channel filtering effects introduced by the radio-frequency (RF) and digital equipment through which the signal of interest goes are modelled by a single equivalent filter designed to be representative of the aggregated GF/GD variations as seen by the receiver. The same filter response has been considered for both directions. Due to the fixed directive terminal type and the GEO orbit considered in the study, the propagation channel is considered as a Line of Sight (LOS), non-frequency selective and non-time variant channel for both channel types. The channel model is based on a Single Input Single Output (SISO) configuration as it is adopted in the vast majority of satellite telecommunication systems. The relative average power of the AWGN introduced in the propagation channel w.r.t. the average power of the transmitted signal of interest is configured by the Signal to Noise Ratio (SNR) usually expressed in dB. Finally, note that no Non-Linear amplifier modeling has been introduced in the physical layer simulations. Instead, it has been directly modeled in the System Level Simulators (SLS) [9] [10] by considering an additional intermodulation noise contribution in the link budget calculations. The level of intermodulation noise to be considered has been specified as a specific function of the effective amplifier back-off for each waveform.

B. Waveform configurations

The main waveform and simulation parameters are summarized in Table II for DVB and in Table III for NR. More details can be found in Section 5.3 of [7]. In Table II, the allocated carrier bandwidths for both DVB-S2X and DVB-RCS2 are matched with typical configurations used by operators in high-throughput GEO systems, reflecting real-world deployment practices. In Table III, the PxSCH carrier bandwidth is set at 200 MHz, while the allocated bandwidth is determined by the number of allocated resource blocks (RBs). For the PDSCH, this allocation goes up to 132 RBs, corresponding to a 200 MHz bandwidth with a 120 kHz Subcarrier Spacing (SCS). For the PUSCH, it is set at 40 RBs, which is equivalent to 28.8 MHz with a 60 kHz SCS. These RB allocations are defined to closely approximate the bandwidths used in DVB-S2X and DVB-RCS2 systems, ensuring practical alignment for comparison.

The minimum Demodulation Reference Signal (DMRS) configuration is applied to minimize the overhead knowing that the simulated channel frequency selectivity is rather limited compared to the usual terrestrial mobile channel models. For Modulation and Coding Scheme (MCS) indexes 0–9, Phase Tracking Reference Signal (PTRS) is disabled due to ineffective phase tracking under low SNR conditions. PTRS density increases progressively with higher MCS

[1] The practical DVB-S2X receiver does not implement the coarse frame detection in time and frequency usually performed prior to entering in "Locked State". It implements Least Mean Square (LMS) equalization, fine frequency recovery, coarse phase recovery, amplitude correction and phase tracking.

[2] The practical DVB-RCS2 receiver implements timing recovery, frame detection, frequency recovery and phase tracking.

[3] The practical PxSCH receiver does not implement the coarse time and frequency acquisition and compensation steps. It is assumed these steps have been performed upstream through cell acquisition in DL or UE NTN self-compensation in UL. The receiver implements channel estimation and equalization based on DMRS as well as Common Phase Error (CPE) correction based on PTRS.

indexes to facilitate the demodulation of symbols transmitted with MCS more vulnerable to phase noise.

Table II. Waveform and simulation parameters considered for DVB-S2X and DVB-RCS2.

	DVB-S2X	DVB-RCS2
Carrier Bandwidth	210 MHz	24 MHz
Roll-off	5%	20%
Pilots	Enabled	Enabled - Pilots density is defined per burst ID
Nb. of information bits per code block	From ~15000 up to ~55000	From ~1000 up to ~5000
Frame Error Rate/Packet Error Rate (FER/PER) target	1e-3, 1e-5	1e-3, 1e-5
Min nb. of simulated errors	100	100

Table III. Waveform and simulation parameters considered for NR PDSCH and NR PUSCH.

	NR PDSCH	NR PUSCH
Carrier Bandwidth	200 MHz	200 MHz
Nb. of allocated RBs	7 up to 132	40
Code Block Size	~ $K_{cb}/2$	Variable
DMRS	Unique configuration with minimal density.	
PTRS	Four configurations with variable density depending on RB allocations and MCS index	
SCS	120 kHz	60 kHz
HARQ (Hybrid Automatic Repeat Request)	Disabled	Disabled
Nb. of information bits per code block	From ~1200 up to ~4600	From ~400 up to ~8400
Block Error Rate (BLER) target	1e-3, 1e-5	1e-3, 1e-5
Min nb.. of simulated errors	10^4	10

The PDSCH allocation in terms RBs is configured such that the TB size gets very close to half the maximum NR Code Block (CB) size (K_{cb}) in terms of information bits before channel coding. In this study, broadband traffic is assumed leading to high data rate to be achieved and large chunk of data to be delivered at each transmission. In these conditions, TB segmentation shall be performed resulting in CB size varying between $K_{cb}/2$ and K_{cb}. Note that the demodulation performance degrades when the CB size decreases. However, the induced required SNR degradation for a given MCS to achieve the same BLER target assuming a CB size of $K_{cb}/2$ instead of K_{cb} is about 0.2 dB. This remains very close to the best achievable performance while covering the worst case configuration that can happen when TB segmentation is performed.

Regarding PUSCH configuration, the same fixed number of RBs is considered for all the MCS indexes. This is motivated by the desire to compare DVB-RCS2 and NR PUSCH waveforms in a context where the transmission band is fixed in advance due for instance to operational constraints (e.g. uplink equivalent power flux density limits at the satellite inputs). The CB size is mainly driven by the RB allocation and the MCS selection. Therefore, this allocation restriction leads in a substantial amount of information bits in a TB for the most efficient MCS indexes. In this case, TB segmentation is performed which leads to a CB size ranging between $K_{cb}/2$ and K_{cb}. For the rest of the MCS indexes for which TB segmentation is not required, the CB size varies between few tens of bits and K_{cb}. The induced SNR degradation due to the CB size decrease is approximately 4.1 dB for $K_{cb}/64$, 2.5 dB for $K_{cb}/32$, 1.8 dB for $K_{cb}/16$, 0.9 dB for $K_{cb}/8$, 0.5 dB for $K_{cb}/4$, and 0.2 dB for $K_{cb}/2$.

The same FER/PER/BLER targets are considered for the sake of the comparison. However, it is worth mentioning that the number of information bits per packet or frame or block is never identical when comparing the technologies. Therefore, the packet error rates experienced at the higher layers will not be the same. SLS [9] [10] make it possible to quantify this type of effect to take it into consideration in the comparison.

C. Spectral efficiencies computation

The MCS (5G) / MODCOD (DVB) rate is defined as the number of information bits transmitted per symbol (and per subcarrier in the case of NR) taking into account only the effective code rate i.e. after rate matching and the modulation order associated to the selected MCS/MODCOD. However, it is necessary to derive a spectral efficiency metric defined in terms of information bits per second per Hertz for the sake of comparison. To do so, it is necessary to take into account the waveform specificities such as:

- For NR PxSCH: the occupancy of DMRS and PTRS which are essential to the receiver for synchronization and demodulation, the Cyclic Prefix (CP) length which is an essential feature of NR waveform to deal with multipath channel and enable one tap equalization and the standardized guard bands occupancy.
- For DVB-S2X: the Base Band (BB) framing efficiency taking into account the BB header overhead, the Payload (PL) framing efficiency taking into account the pilots and the PL header overhead, the carrier roll-off which characterizes the spectral occupancy of the carrier and the guard bands, which are usually required between adjacent DVB-S2X carriers due to operational constraints.
- For DVB-RCS2: the frame Packet Data Unit (PDU) Cyclic Redundancy Checksum (CRC) size, the Burst framing efficiency taking into account the pilots, preamble and postambule overhead, the guard times which are necessary to avoid inter-user interference between successive burst transmissions, the carrier roll-off which characterizes the spectral occupancy of the burst transmission and the guard bands introduced between adjacent independent Multi-Frequency Time-Division Multiple Access (MF-TDMA) communication channels.

$$SE_{5G}=\beta \times(1-\alpha_{DMRS}-\alpha_{PTRS})\times(1-\alpha_{CP})\times(1-\alpha_{CRC})/(1+\alpha_{GB}) \quad (1)$$

where SE_{5G} represents spectral efficiency of NR, β denotes the MCS rate, α_{DMRS} and α_{PTRS} are the weights associated to the DMRS and PTRS symbols occupancy in the PxSCH resource grid, α_{CP} corresponds to the weight of the CP in the OFDM symbol, α_{CRC} is the weight of the CRC in the CB before channel coding, and α_{GB} is the weight of the guard bands.

[4] The number of simulated errors is reduced compared to the DVB simulations to compensate for the significantly larger number of NR configurations to be covered. Ultimately, this keeps simulation time to a reasonable level, but introduces a degradation in the accuracy of BLER measurements compared to DVB.

$$SE_{S2X} = \beta \times(1-\alpha_{BB})\times(1-\alpha_{PL})/(1+\alpha_{RO}+\alpha_{GB}) \quad (2)$$

where SE_{S2X} represents spectral efficiency of DVB-S2X, β denotes the MODCOD rate, α_{BBF} corresponds to the weight of the BB header overhead, α_{PL} represents the weight of pilots and PL header overhead, α_{RO} is the carrier roll-off, and α_{GB} is the weight of the guard bands.

$$SE_{RCS2} = \beta \times\delta\times(1-\alpha_{CRC})\times(1-\alpha_{GT})/(1+\alpha_{RO}+\alpha_{GB}) \quad (3)$$

where SE_{RCS2} represents spectral efficiency of DVB-RCS2, β and δ correspond to the MODCOD rate and the burst framing efficiency, α_{CRC} is the weight of the PDU CRC, α_{GT} represents the weight of the guard times w.r.t. to the total slot duration, α_{RO} is the carrier roll-off, and α_{GB} is the weight of the guard bands.

IV. Physical Layer Simulation Results

The results obtained using the simulators, based on the specified assumptions, are summarized in this section. Note that all numerical values related to MCS/MODCOD rate, spectral efficiency and demodulation performance are also reported in Section 5.5 of [7].

This section analyzes the performance of each waveform i.e. NR PDSCH, NR PUSCH, DVB-S2X, DVB-RCS2 which are illustrated in Fig. 1, Fig. 2, Fig. 3 and Fig. 4 respectively.. The common legend is the following:

- The **green solid curve with triangles** represents demodulation performance in terms of MCS/MODCOD rate, expressed in bit/symbol, under channel Type AWGN conditions assuming a perfect receiver implementation. This curve reflects only the Forward Error Correction (FEC) and modulation schemes performance for each waveform.
- The **blue solid curve with squares** represents demodulation performance in terms of spectral efficiency, expressed in bit/s/Hz, also under channel Type AWGN conditions assuming a perfect receiver implementation. This curve captures the additional effects of spectral occupancy and framing efficiency (pilots overhead, encapsulation loss, guard bands, …).
- The **red solid curve with circles** represents demodulation performance in terms of spectral efficiency, expressed in bit/s/Hz, under channel Type A conditions with a practical receiver implementation. This curve reflects the combined effects of implementation loss, impairments degradation, framing efficiency, and spectral occupancy.

These figures highlight the following impacts:

- Impact of framing efficiency and spectral occupancy (Impact A) that can be quantified by comparing the **green curve** with the **blue curve**.
- Impact of Implementation losses and impairments degradations (Impact B) that can be quantified by comparing the **red curve** with the **blue curve**.
- Combination of impacts A and B (Impact C) that can be quantified by comparing the **red curve** with the **green curve**.

Each figure provides also an example of the quantification of these impacts in terms of spectral efficiency loss and SNR degradation.

These analyses are conducted for both the Forward direction (DVB-S2X vs NR PDSCH) and the Return direction (DVB-RCS2 vs NR PUSCH) by considering a PER/FER/BLER target of 1e-5. Impact A is agnostic of the considered target error rate. Impact B quantification is very similar for the target error rates of 1e-3 and 1e-5. Finally, to ensure a fair analysis, the same NR PxSCH MCS rate range and DVB MODCOD rate range has been considered. These MCS/MODCOD ranges were selected to cover a SNR range which is in line with the reference scenario. This approach provides an initial comparative trend between the two technologies.

A. Forward direction: DVB-S2X vs NR PDSCH

Fig. 1 and Fig. 2 illustrates the impact of framing efficiency and spectral occupancy, as well as the combined effects of implementation loss, impairments degradation, framing efficiency and spectral occupancy on NR PDSCH and DVB-S2X waveforms, respectively. The following analysis quantifies the related losses of spectral efficiency and SNR degradations.

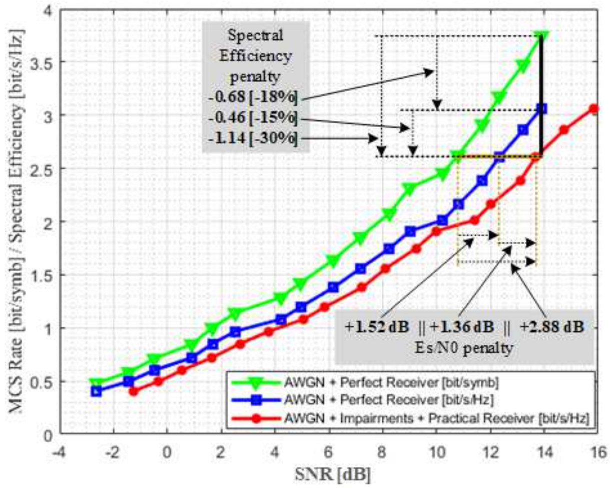

Fig. 1. [**NR PDSCH**] – Analysis of the Impact A, Impact B and Impact C

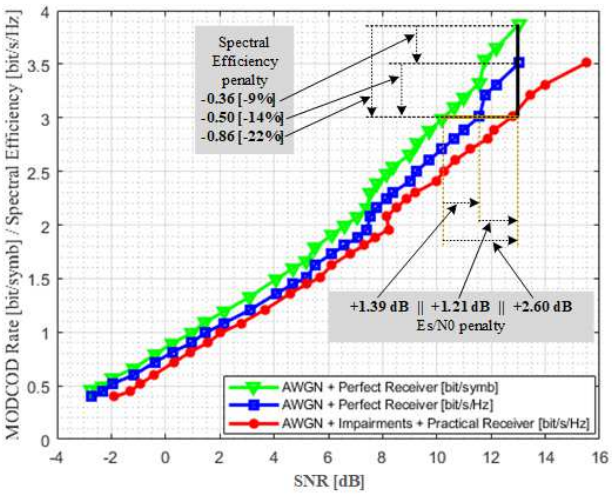

Fig. 2. [**DVB-S2X**] – Analysis of the Impact A, Impact B and Impact C

When comparing the **green solid curve with triangles** to the **blue solid curve with squares**, the following observations are made. For a given SNR level, DVB-S2X exhibits a spectral efficiency loss of 9%, whereas NR PDSCH shows a spectral efficiency loss ranging from 15.0% to 18.0%. Conversely, for a given spectral efficiency, DVB-S2X experiences a SNR degradation ranging from 0.4 dB to 1.4 dB, while NR PDSCH shows a SNR degradation ranging from 0.7 dB to 2.3 dB. This analysis indicates that DVB-S2X offers better framing efficiency and spectral occupancy compared to NR PDSCH. The significant impact of framing efficiency and spectral occupancy on NR PDSCH is attributed to the higher reference symbol overhead, especially at higher MCS indexes, where the PTRS overhead becomes significant. Additionally, the loss in efficiency due to the CP further contributes to this degradation.

The comparison between the **blue solid curve with squares** and the **red solid curve with circles** reveals SNR degradations from 0.7 to 1.9 dB for NR PDSCH, whereas DVB-S2X experiences a slightly lower SNR degradations, ranging from 0.5 to 1.7 dB, to enable a given spectral efficiency level. Conversely, for a fixed SNR level, NR PDSCH shows a spectral efficiency loss of 5% to 15%, while DVB-S2X exhibits a loss ranging from 4% to 14%. This shows that DVB-S2X suffers less of the effects of implementation loss and impairments degradation w.r.t. NR PDSCH. This can be partially attributed to the nature of the NR PDSCH receiver architecture. Indeed, the NR receiver operates on a slot-by-slot basis depending on network grants, with each slot being demodulated independently, without any information from previous slots. In contrast, the DVB-S2X receiver implements a continuous frame demodulation process, in which each symbols contributes to loop-based tracking algorithms, providing more stability and reducing implementation losses.

When comparing the **green solid curve with triangles** to the **red solid curve with circles**, the following observations are made. For a fixed SNR level, DVB-S2X shows a spectral efficiency loss between 13% and 22%, whereas NR PDSCH shows a spectral efficiency loss ranging from 28% to 33%. On the other hand, when considering a given spectral efficiency, DVB-S2X incurs a SNR degradation ranging from 1.0 and 2.6 dB, while NR PDSCH exhibits a SNR degradation ranging from 1.7 and 3.5 dB. This confirms that DVB-S2X suffers less of the combined effects of implementation loss, impairment degradation, framing efficiency, and spectral occupancy. w.r.t. NR PDSCH.

The performances of the two technologies in terms of framing efficiency and spectral occupancy (Impact A), implementation loss and impairments degradation (Impact B), as well as the combined effects of implementation loss, impairments degradation, framing efficiency, and spectral occupancy (Impact C), are summarized in Table IV for the forward link (DVB-S2X and NR PDSCH).

Table IV. Summary of forward link analyses

	Metric	S2X	PDSCH
Impact A	***Spectral Efficiency Loss***	9%[5]	15% to 18%
	SNR Degradation	0.4 to 1.4 dB	0.7 to 2.3 dB
Impact B	***Spectral Efficiency Loss***	4% to 14%	5% to 15%
	SNR Degradation	0.5 to 1.7 dB	0.7 to 1.9 dB
Impact C	***Spectral Efficiency Loss***	13% to 22%	28% to 33%
	SNR Degradation	1.0 to 2.6 dB	1.7 to 3.5 dB

[5] There is a slight variation of less than 1%, but only the whole numbers are shown in the tables.

B. Return direction: DVB-RCS2 vs NR PUSCH

Similar to Fig. 1 and Fig. 2, Fig. 3 and Fig. 4 enable the same type of analysis, but for NR PUSCH and DVB-RCS2 waveforms respectively. The analysis of the RTN link follows the same methodology as for the FWD link. The results for the RTN link are summarized in Table V. It has been observed that NR PUSCH is less affected by framing efficiency and spectral occupancy compared to DVB-RCS2. The substantial impact on DVB-RCS2 is mainly driven by the pulse shape filter roll-off of 20%. However, NR PUSCH suffers from higher implementation losses and greater sensitivity to impairments.

Table V. Summary of return link analyses

	Metric	RCS2	PUSCH
Impact A	***Spectral Efficiency Loss***	20% to 29%	19%[5]
	SNR Degradation	1.6 to 3.9 dB	1.4 to 3.0 dB
Impact B	***Spectral Efficiency Loss***	0.0%[5]	6% to 15%
	SNR Degradation	0.0 to 0.2 dB	0.2 to 1.1 dB
Impact C	***Spectral Efficiency Loss***	20% to 29%	23% to 31%
	SNR Degradation	1.6 to 3.9 dB	1.8 to 3.2 dB

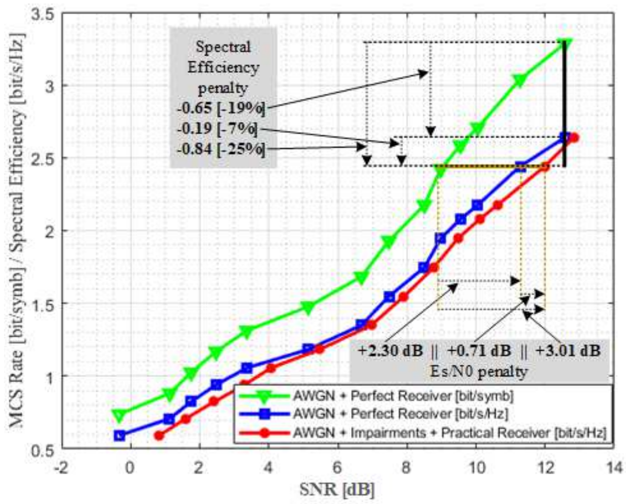

Fig. 3. [**NR PUSCH**] – Analysis of the Impact A, Impact B and Impact C

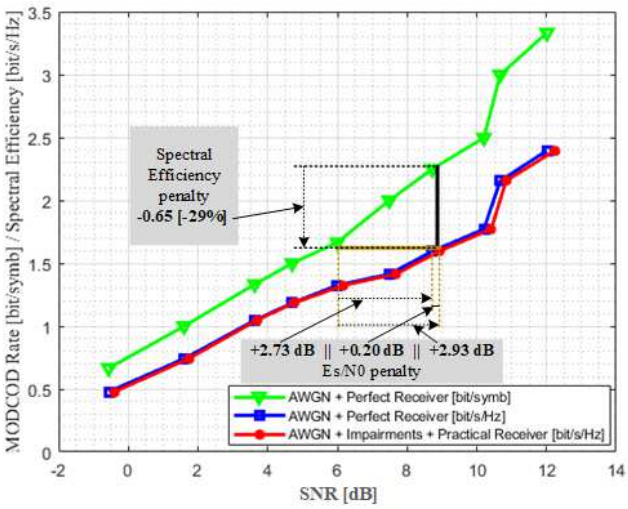

Fig. 4. [**DVB-RCS2**] – Analysis of the Impact A, Impact B and Impact C

V. Comparison between 5G and DVB Physical Layers

In addition to the analyses presented in section IV, this section aims to examine the performance gap observed between the technologies depending on the channel type and the target error rate considered.

The legend of the figures presented in this section is defined as follows:

- The **green solid curve with triangles** represents demodulation performance in terms of spectral efficiency of NR PxSCH for a BLER target of 1e-3.
- The **blue solid curve with squares** represents demodulation performance in terms of spectral efficiency for a BLER target of 1e-5.
- The **red solid curve with stars** represents demodulation performance in terms of spectral efficiency of DVB-S2X and DVB-RCS2 for a FER/PER target of 1e-3
- The **black solid curve with plus** represents demodulation performance in terms of spectral efficiency for DVB-S2X and DVB-RCS2 for a FER/PER target of 1e-5.

Each figure provides also an example of the estimation of spectral efficiency loss and SNR degradation.

A. Channel Type AWGN – Perfect Receiver Implementation

Fig. 5 presents a comparison between DVB-S2X spectral efficiency and demodulation performance with respect to NR PDSCH spectral efficiency and demodulation performance in channel Type AWGN conditions, assuming a perfect receiver implementation. Better performance is observed for DVB-S2X with respect to NR PDSCH, regardless of the target FER/BLER. The observed SNR degradations for NR PDSCH, in order to achieve the same level of spectral efficiency, ranges from 0 to 2 dB for a FER/BLER target of 1e-3, and from 0 to 2.5 dB for a FER/BLER target of 1e-5. Conversely, for a given SNR level, NR PDSCH experiences a spectral efficiency loss ranging from 0% to 17% for a FER/BLER target of 1e-3, and from 0% to 26% for a FER/BLER target of 1e-5. These performance gaps are primarily attributed to the FEC and modulation scheme performance, the reference symbol overhead, along with other sources of spectral efficiency loss, which are more pronounced for NR PDSCH than for DVB-S2X. This is especially the case with higher MCS indexes where the PTRS overhead becomes significant. Moreover, it appears that FEC curves are steeper for DVB-S2X than for NR PDSCH (see Fig. 6). The design of the concatenated DVB-S2X coding scheme based on Low-Density Parity-Check (LDPC) code and Bose–Chaudhuri–Hocquenghem code (BCH) enables very steep FEC curves. Therefore, when the required SNR remains almost at the same level for DVB-S2X between a FER target of 1e-3 and 1e-5, a significant SNR increase is observed in the case of NR PDSCH.

Fig. 7 is similar to Fig. 5, but it compares the performance between DVB-RCS2 and NR PUSCH. From Fig. 7, it can be observed that NR PUSCH outperforms DVB-RCS2. The SNR degradation observed for DVB-RCS2, in order to achieve the same spectral efficiency, ranges from 0 to 2.5 dB for a PER/BLER target of 1e-3, and from 0 to 1.7 dB for a PER/BLER target of 1e-5. For a given SNR level, DVB-RCS2 shows a spectral efficiency loss between 0% and 23% for a PER/BLER target of 1e-3, and between 0% and 18% for a PER/BLER target of 1e-5. These performance gaps are attributed to the higher spectral occupancy of the DVB-RCS2 waveform, which is driven by the roll-off configuration of 20%, compared to the NR PUSCH waveform.

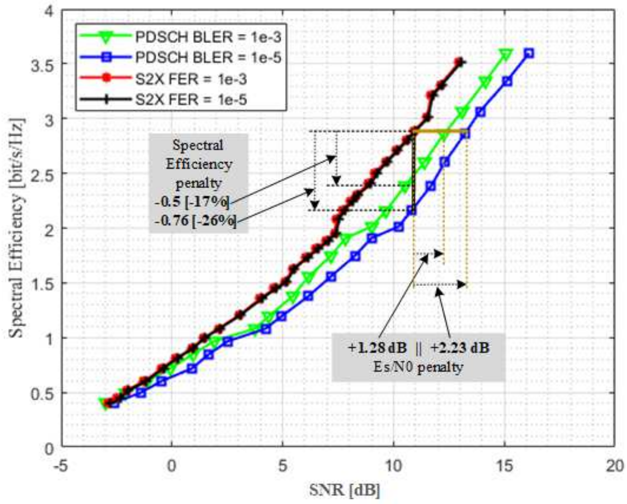

Fig. 5. Comparison of **DVB-S2X and NR PDSCH** required SNR assuming channel Type AWGN

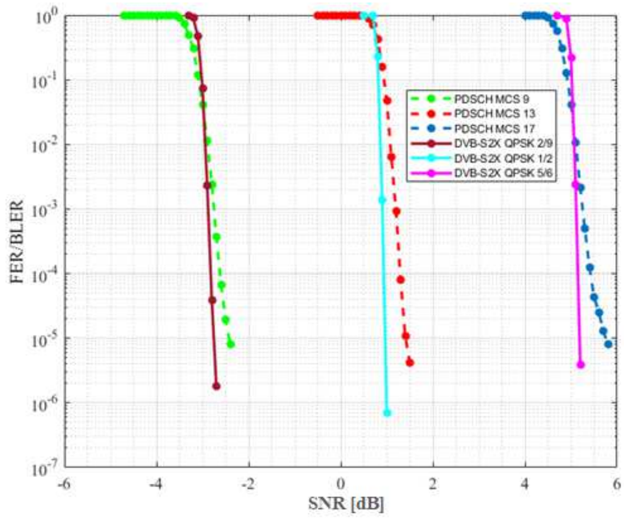

Fig. 6. FER/BLER vs SNR curves for **DVB-S2X** and **NR PDSCH**

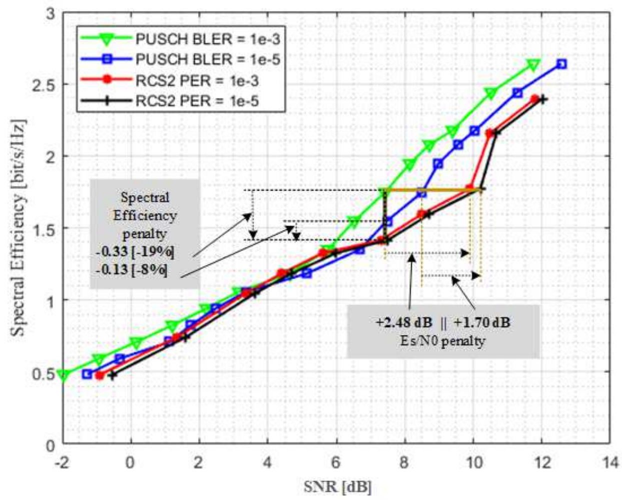

Fig. 7. Comparison of **DVB-RCS2 and NR PUSCH** required SNR assuming channel Type AWGN

B. Channel Type A – Practical Receiver Implementation

Fig. 8 presents a comparison between DVB-S2X spectral efficiency and demodulation performance with respect to NR PDSCH spectral efficiency and demodulation performance in channel Type A conditions, assuming a practical receiver implementation. These curves reflect the additional impacts of implementation losses and impairments degradations on both technologies. As expected, the resulting demodulation performances have been degraded with respect to channel Type AWGN and perfect received conditions for both technologies since all the required SNR values have increased to achieve the same level of spectral efficiency. It can be observed that DVB-S2X remains more efficient than NR PDSCH, regardless of the target FER/BLER. The observed SNR degradation for NR PDSCH w.r.t. DVB-S2X, in order to achieve the same level of spectral efficiency, ranges from 0 to 3 dB for a FER/BLER target of 1e-3, and from 0 to 3.2 dB for a FER/BLER target of 1e-5. When considering a fixed SNR level, NR PDSCH shows a spectral efficiency loss ranging from 0% to 21% for a FER/BLER of 1e-3, and from 8% to 25% for a FER/BLER of 1e-5. These performance gaps are partially attributed to the NR receiver architecture, as discussed in Subsection IV.A.

Fig. 9 is similar to Fig. 8, but compares the performance between DVB-RCS2 and NR PUSCH. Based on Fig. 9, it can be observed that NR PUSCH generally outperforms DVB-RCS2. More precisely, there is no significant performance gap between DVB-RCS2 and NR PUSCH for spectral efficiencies below 1.4 bit/s/Hz. However, for spectral efficiencies above 1.4 bit/s/Hz, NR PUSCH shows superior performance compared to DVB-RCS2. The SNR degradation required to achieve the same level of spectral efficiency varies from 0 to 2.4 dB for a PER/BLER target of 1e-3, and from 0 to 1.6 dB for a PER/BLER target of 1e-5. In terms of achievable spectral efficiency for a given SNR level, DVB-RCS2 experiences a loss ranging from 0% to 19% for a PER/BLER target of 1e-3, and a loss between 0% and 17% for a PER/BLER target of 1e-5. These observations confirm that the degradations due to implementation losses and impairments are more pronounced for NR PUSCH than for DVB-RCS2, as highlighted by Impact B in Table V.

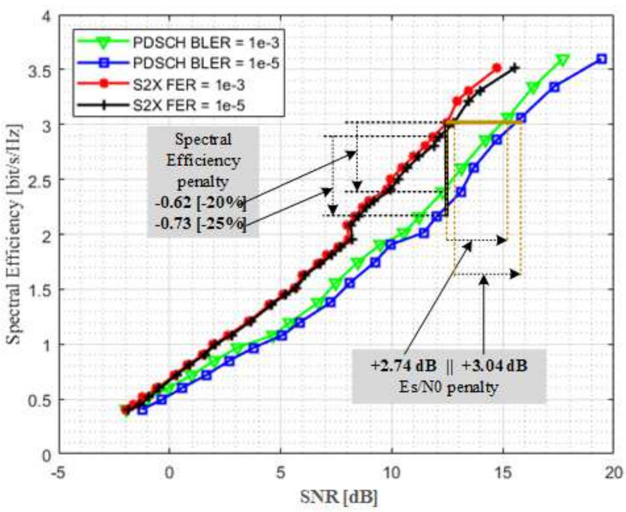

Fig. 8. Comparison of **DVB-S2X and NR PDSCH** required SNR assuming channel Type A

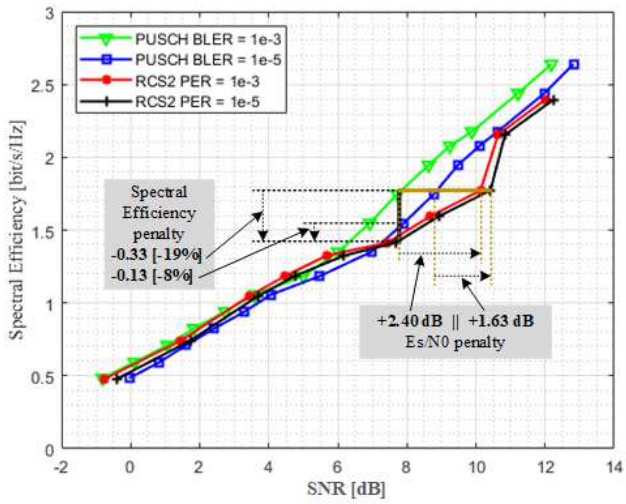

Fig. 9. Comparison of **DVB-RCS2 and NR PUSCH** required SNR assuming channel Type A

C. Forward link overall demodulation performance gap

The overall demodulation performance gap has been estimated by calculating the average spectral efficiency assuming a uniform weight distribution of the considered MCS/MODCODs.

The results are summarized in

Table VI. The FWD link demodulation performance comparison shows an average spectral efficiency gain of 15% and 20% in favor of DVB-S2X for a FER/BLER of 1e-3 and 1e-5 respectively assuming channel Type AWGN with perfect receiver implementations. These gains become 20% and 26% for a FER/BLER of 1e-3 and 1e-5 respectively assuming channel Type A conditions with practical receiver implementations. As already mentioned in the previous sections, these gains are explained by three major causes:

- The performance gap between the 5G NR LDPC coding scheme and the DVB-S2X concatenated BCH and LDPC coding scheme. The combination of LDPC with BCH results in steeper FEC curves for FER below 1e-3. Additionally, the number of information bits per CB is significantly higher for DVB-S2X than for NR.
- The reference symbol overhead and other sources of spectral efficiency loss (e.g. CP overhead) which are higher for NR PDSCH than for DVB-S2X.
- The higher impairments sensitivity and implementation losses for NR PDSCH.

The significant performance gap results from major technology design differences and therefore does not come as a surprise. DVB-S2X has been natively developed to address high latency ultra-reliable broadband satellite telecommunications with very small aperture terminals. By contrast, 5G NR standard has been opportunistically extended to support NTN. It comes with core features designed to address primarily low latency mobile communications in multipath fading environments with a particular attention to the terminal battery consumption. Some of these core features like CP duration or FEC coding scheme may not be the best suited for broadband satellite communications.

Table VI. Overall demodulation performance gap between DVB-S2X and NR PDSCH

Error rate	FER/BLER = 1e-3		FER/BLER = 1e-5	
Technology	***S2X***	***PDSCH***	***S2X***	***PDSCH***
Channel Type AWGN – Perfect Receiver	1.83	1.56 **(-15%)**	1.83	1.47 **(-20%)**
Channel Type A – Practical Receiver	1.73	1.38 **(-20%)**	1.68	1.24 **(-26%)**

D. Return link overall demodulation performance gap

In the same way, the overall demodulation performance gap has been evaluated for the RTN link.

The results are reported in

Table VII. They show an average spectral efficiency gain of 11% and 7% in favor of NR PUSCH for a PER/BLER of 1e-3 and 1e-5 respectively, assuming channel Type AWGN conditions with perfect receivers. When assuming channel Type A conditions with practical receivers, an average spectral efficiency gain of 3% in favor of NR PUSCH is observed for PER/BLER of 1e-3. However, an average spectral efficiency gain of 3% in favor of DVB-RCS2 this time is obtained for a PER/BLER of 1e-5. These results are explained by the combination of the following considerations:

- The performance advantage of NR PUSCH due to its lower spectral occupancy compared to DVB-RCS2.
- The higher steepness of FEC curves for DVB-RCS2 compared to NR PUSCH for BLER/PER below 1e-3.
- The lower impact of implementation losses and impairments degradations on DVB-RCS2 compared to NR PUSCH.

Eventually, having a less characterized performance gap in the RTN link is partially attributable to the fact that both technologies are based on MF-TDMA and burst based demodulation.

Table VII. Overall demodulation performance gap between DVB-RCS2 and NR PUSCH

Error rate	PER/BLER = 1e-3		PER/BLER = 1e-5	
Technology	***RCS2***	***PUSCH***	***RCS2***	***PUSCH***
Channel Type AWGN – Perfect Receiver	1.41	1.58 **(+11%)**	1.41	1.51 **(+7%)**
Channel Type A – Practical Receiver	1.40	1.45 **(+3%)**	1.40	1.36 **(-3%)**

VI. Conclusions

The physical layer demodulation performance comparison on the FWD link has showed an average spectral efficiency decrease from 15 to 26% for NR PDSCH with respect to DVB-S2X depending on the study cases and the FER/BLER targets considered. This performance gap may be reduced by further optimizing the NR DMRS and PTRS configuration for each MCS index to obtain the best compromise between induced overhead and level of degradation due to impairments and channel estimation inaccuracy. Additionally, considering NR receiver enhancements such as taking advantage from past periodical transmissions of reference signal like Synchronization Signal Block (SSB) or Channel State Information – Reference Signal (CSI-RS) to feed data aided algorithms may also help. Finally, improving the channel estimation and phase tracking algorithms may also reduce the experienced implementation losses.

Assuming a fixed transmission bandwidth of approximately 25 MHz, the RTN link analysis has showed equivalent performance for both NR PUSCH and DVB-RCS2 with a slight advantage for one or the other depending on the scenario.

Finally, the physical layer comparison is not self-sufficient and shall be completed with System Level Simulations [9] [10] implementing physical layer abstraction models. These simulations shall take into consideration the physical layer packet sizes mismatch, the non-linear amplification impacts as well as higher layer aspects such as control plane signaling effects and achievable scheduling efficiency.

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