Technology Trends for Ka-Band Broadcasting Satellite Systems

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Abstract. This paper provides an overview of the technology trends pertinent to Ka-band broadcasting satellite systems. Starting from the state-of-the-art digital broadcasting systems, we present technology trends that can further expand the use of Ka-band satellite broadcasting and improve the performance and efficiency. In particular, it is shown that the combination of DVB-S2X features offer significant advances and opportunities to service providers. This is true particularly in geographical areas that are subject to severe atmospheric attenuation.

Keywords: Ka-band broadcasting · Multi-beam satellites · Channel bonding · Variable coding and modulation · Simulcasting

1 Introduction

The Direct to Home (DTH) broadcasting today is by far the largest market in the satellite communications sector. The capability of broadcasting satellites to rapidly setup services and provide multitude of TV channels at relatively low cost and to a large number of subscribers have resulted in a significant growth of the DTH market in the past two decades.

Despite the past success, the opportunity for steady growth of the DTH market in the future is under threat. In many parts of the world consumers are rapidly changing their habits when viewing television, going from passive consumption of delivered content to more on-demand interactive experience. The use of a second screen such as a tablet allows interactions with peers or searching for relevant information while viewing the video content. There is a growing demand for multiple video streaming into a household. These trends are expected to continue, creating new businesses opportunities for highly customized unicast video content distribution. Such services have been creating fierce competition against conventional direct satellite broadcasting services.

On the other hand, the quality of video-on-demand is moving from standard definition quality of high-definition. More bandwidth demanding video contents such as Ultra- High Definition (UHD) and 3D TV create new opportunities for direct broadcasting satellite, particularly targeting home viewing screens.

The cost competitiveness of satellite broadcasting can be maintained or improved through different technical advances. New video compression techniques such as HEVC [1] along with more sophisticated transmission schemes such as DVB-S2X [2]

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are promising technologies to reduce the required bandwidth per channel. The use of Ka-band broadcasting can help reducing the cost of the bandwidth and allow higher multiplexing gain especially for UHD content broadcasting.

Technical solutions using variable coding and modulation and scalable video coding can provide different quality of service and graceful degradation of the broadcast content. The use of front-end processing together with multiple LNB's can improve the effective antenna size and help maintaining the alignment. New system-on-chip design approach integrating the RF front-end and the baseband processing functionality will allow simultaneous access to full spectrum while lowering the power consumption and possible integration of functionality at the front-end [4].

The satellite video distribution can also be integrated with micro content delivery networks for multi dwelling houses, apartments or neighborhoods and allow the possibility of providing local content. This will help off-loading from the Internet backbones the delivery of bandwidth demanding contents while maintaining many interactivity features that are demanded by users.

The use of new generation of hybrid broadband/broadcast satellite can allow more efficient use of on-board resources and gradual migration from one type of service to the next. However, given the number of existing satellite fleets and their expected lifetime, it is important to rely on ground/user segment technical advancement allowing more efficient use of conventional broadcasting in the next 5 to 10 years while new generation of satellite being designed and put in service.

In this paper we particularly focus on the opportunities and challenges of Ka-band broadcasting. By defining some study cases, we present technology trends both at the space and ground segments that can enable cost-effective content delivery using Ka-band broadcasting satellites even in geographical areas that are subject to severe atmospheric attenuation.

2 Ka-Band Broadcasting: Opportunities and Challenges

Satellite broadcasting in so called "Reverse BSS" (17/24 GHz) [5] Ka-band frequencies is a well-established technology in North America, contributing significantly to the satellite broadcasting business revenue especially for the HDTV program offerings [6].

The deployment of Ka-band broadcasting satellites is also gaining momentum in other regions of the world. Recent advancements in the regulatory situation in ITU Region 1 and 3, as defined in [7], have contributed to this progress. Complementing the original Ka-band broadcasting frequency allocation of 21.4-22.0 GHz by Word Radiocommunication Conference (WRC) in 2007, during WRC-12 a new feeder link (uplink) frequency band was allocated to Ka-band broadcasting (24.65-25.25 GHz). This further improved the feasibility of the frequency planning for Ka-band broadcasting satellite systems in ITU Region 1 and 3.

Current examples of commercially operated Ka-band broadcasting satellites are EUTELSAT 25B at the 25.5°E orbit providing Ka-band broadcasting system coverage to the Middle East and North Africa, Nilesat 201 Satellite with Ka-band coverage of North Africa [8]. Both satellites provide commercial broadcasting services in Ka-band that complements the Ku-band broadcasting content.

The Ka-band broadcast technology provides the means for enhanced TV integrated services where the Ka-band frequency can complement the existing Ku-band services by providing a higher quality video content in addition to the standard quality content offering of Ku-band services. This could be realized by deploying dual-band receivers at the user premises. Technologies such as multi-tuner set-top boxes and dual Ka/Ku band LNBs are today's reality [8].

In some regions including Europe and Far East Asia, the deployment of Ka-band broadcasting faces challenges caused by severe atmospheric attenuation. This could impose a large link margin that would hamper the efficiency and cost-effectiveness of such systems. This issue is recognized and discussed also in recent work as reported in [9]. In the remaining of this paper, we present system and air interface solutions that can address this issue and facilitate the use of Ka-band broadcasting services even in the presence of atmospheric fading conditions.

3 DVB-S2X for Broadcasting

A technical module of DVB (Digital Video Broadcasting) took the mandate to extend DVB-S2 in order to achieve higher spectral efficiencies without introducing fundamental changes to the complexity and structure of DVB-S2. The outcome of this development was approved by DVB in March 2014 as DVB-S2 Extension (herein referred to as DVB-S2X) and was published as Part II of the ETSI Standard [2].

There are number of new features introduced in DVB-S2X, each targeting a particular improvement in the efficiency, flexibility and applicability of the standard to the core or emerging market segments. This paper is concerned with the direct to home broadcasting. The goal is to examine and quantify at system level the benefits offered by the features of DVB-S2X, individually or collectively, in a set of representative system scenarios relevant to Ka-band broadcasting. As a starting point, an overview of the relevant features of DVB-S2X [2] that are considered in our analyses is provided below.

3.1 Broadcasting with Differentiated Channel Protection

A major difference of DVB-S2X compared to DVB-S2 is that it supports the Variable Coding and Modulation (VCM) technique as a normative feature for the broadcasting profile. The VCM can provide different level of signal protection by time sharing different Modulation and Coding (MODCODs) in each physical layer frame [10]. This allows satellite operators to adjust transmission robustness according to the service availability they wish to guarantee, and to differentiate services according to the quality of service requirements. The use of VCM in conjunction with simulcast can be used to guarantee service continuity in the presence of a heavy atmospheric fading, while at the same time offering a high quality service in the absence of rain attenuation. By allowing a tolerable degradation in the picture quality during a heavy atmospheric fading, it is possible to significantly increase the overall system spectral efficiency.

At the receiver, it is assumed that the two streams corresponding to the same content are video decoded independently. However, the time synchronization between the two streams is maintained such that the output stream for the same content can switch seamlessly between the two.

Compared to a scalable video coding with two or more layers of coded content, the use of simulcasting of low and high quality streams offers a simpler video coding and decoding solution and possibly a lower overhead (if the required bit rate for the lower quality stream is considerably lower than that of higher quality stream). It should be noted that the cost of simulcasting, in terms of overhead depends on the assigned bit rates per two video streams.

3.2 Channel Bonding

The DVB-S2 system was designed to carry a single or multiple MPEG Transport Streams (or generic continuous streams) over a single satellite transponder. In a conventional DTH application, HDTV multi-program and MPEG-4 video encoding allows for multiplexing a sizeable number (5-6) of programs per transponder. This could be increased taking into account Statistical Multiplexing gain as shown in Fig. 1. The DVB-S2X aims to integrate with HEVC video coding and UHDTV (four times the definition of HDTV). Assuming that an UHDTV signal requires four times the transmission capacity of HDTV for the same compression system, and that HEVC doubles the compression efficiency versus MPEG-4, we roughly estimate 20 Mbits/s bit rate requirement per each UHD program. This would reduce the number of supported UHD to 2 or 3 programs per transponder, and the statistical multiplexing gain would be significantly reduced (less than 12 %, assuming Fig. 1 is applicable to UHDTV and HEVC), thus not allowing the transmission of an additional program.

In order to increase the statistical multiplexing gain for UHDTV, S2X implements “channel bonding”, that is merging the capacity of two or three transponders to transport a single stream. This functionality is available only for multi-tuner receivers,

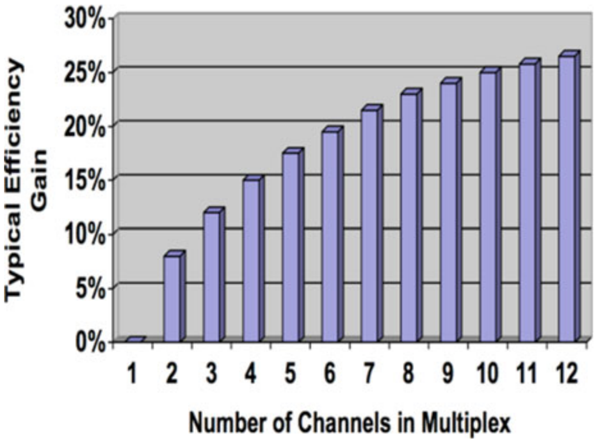

Fig. 1. Statistical multiplexing gain for increasing number of bonded channels (from [11]).

which are anyway finding their way in the market also to implement other functionalities. It should be noted that channel bonding requires simultaneous reception of signal from two or more transponders.

3.3 Higher Order Modulation for Broadcasting Applications

DVB-S2X supports as a normative feature 16APSK (as well as 32APSK) modulation for broadcasting applications. The use of higher order modulations combined with VCM are particularly advantageous for Ka-band broadcasting systems [1], as 16APSK allows a higher spectral efficiency for users in clear sky along with a more protected MODCOD under heavy fading conditions. This physical layer configuration can ensure the target service availability by allowing a graceful degradation of the service quality following the VCM concept.

3.4 New MODCODs and Finer SNR Threshold Granularity

The increasing demand for broadband satellite services has pushed for a more efficient utilization of resource, namely available power and spectrum. Multi-carrier operation is usually envisaged for this configuration, implying that the High Power Amplifiers (HPA) non-linearities can be considered quasi-linear. The new DVB-S2X standard includes additional MODCODs optimally designed to operate on a linear channel and in the presence of phase noise. Furthermore, the additional MODCODs brought as main advantage a finer granularity in the SNR threshold, reducing the gap between thresholds from 1-1.5 dB of the DVB-S2 to 0.5 dB.

3.5 Smaller Pulse Shaping Filter Roll-off Values

The new standard allows for the usage of sharper roll-off values, i.e 15 %, 10 % and 5 %, in addition to the DVB-S2 20 %, 25 % and 35 %. As shown in [3], for DTH applications these narrower roll-offs do not seem to offer significant performance advantage (at least for the channel model that has been considered), while for VSAT networks some performance improvements at system level are expected.

4 Multi-beam Ka-Band Broadcasting

In order to assess the comparative performance of the DVB-S2X with respect to DVB-S2, a broadcasting satellite system deploying the Ka-band broadcasting frequency allocation (21.4-22.0 GHz) is considered.

The satellite is assumed to be located at 10°E of the geostationary orbit providing broadcasting services to eight linguistic beams covering Europe as shown in Fig. 2. The frequency plan associated with 8 beams is defined according to a 4 colour scheme as shown in Fig. 3. The frequency plan allows for a frequency re-use factor of 2 while maintaining reasonable level of carrier to interference ratio.

The Ka-band satellite payload is assumed to have 40 active Ka-band transponders (5 transponders per beam) with single carrier per transponder. The TWTA power amplifier per transponder is assumed to radiate 200 W power at the peak, which agrees with the near term available HPA technology. A nominal bandwidth of 54 MHz per IMUX/OMUX filters and an adjacent frequency spacing of 60 MHz between transponders are assumed. Hence, each beam consists of 5 carriers with a total bandwidth of 300 MHz.

As a benchmark, a Ku-band broadcasting satellite at the same geostationary orbit with a similar DC power envelope of 15 kW is considered, which typically allows to accommodate up to 64 Ku-band transponders, each with a 120 W TWTA power amplifier.

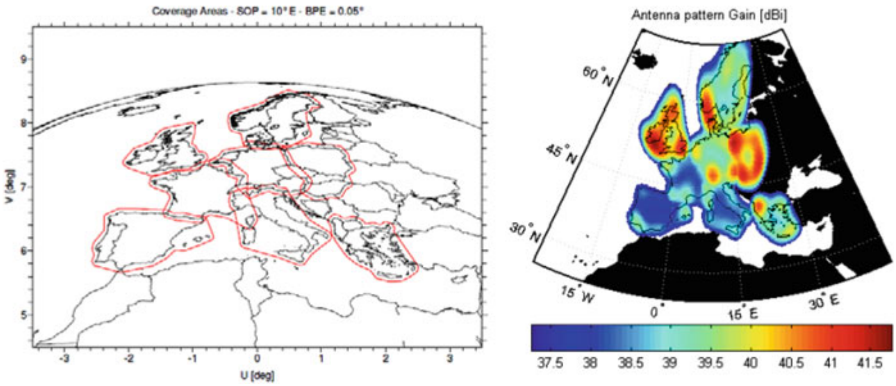

Fig. 2. Broadcasting satellite with 8 linguistic beams in BSS Ka-band

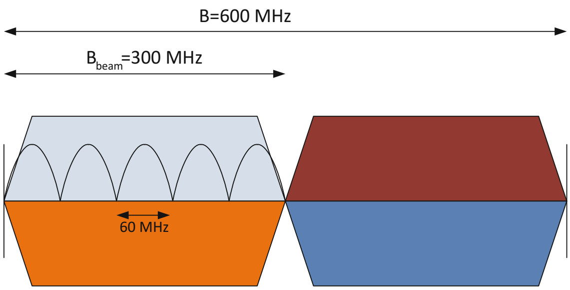

Fig. 3. Frequency Plan – Multi-beam Ka-band

4.1 Receiver Architecture Assumptions

The performance comparison between DVB-S2 and DVB-S2X is based on the following assumptions concerning receiver technologies:

DVB-S2 Legacy Receivers: Implementing DVB-S2 air interface according the broadcasting profile with no added capability to tolerate inter-symbol interference (ISI).

Such receivers are assumed to operate only in CCM mode with QPSK or 8PSK modulation scheme and no capability of digital channel bonding.

DVB-S2 Enhanced Receivers: Implementing DVB-S2 air interface broadcasting profile (similar to the legacy receivers). Additionally, the enhanced receivers are assumed to be capable of mitigating interference caused by band limited channel (e.g. using baseband equalizers) that would allow increasing the symbol rate. It should however be noted that the MODCOD selection is constraint by the broadcasting profile of DVB-S2. The physical layer performance results are shown in [3].

DVB-S2X Enhanced Receivers: Implementing DVB-S2X air interface broadcasting profile and capable of equalizing the linear distortions caused by the band-limited channel. Such receivers are assumed to support digital channel bonding (up to three BBFRAMEs), 16APSK modulation and MODCODSs according to DVB-S2X broadcasting profile. The physical layer performance results are shown in [3].

4.2 Video Service Quality

The target service availability in each scenario is 99.9 % of the time over the entire coverage area. For a DTH service based on DVB-S2 air interface, this service availability is applied directly to each video stream (HD or UHD). For DVB-S2X that is supporting VCM, the service availability of 99.9 % is provided by two video quality levels associated with each video streams as follows:

- The HD service availability of 99.0 %, complemented by a lower quality stream (MPEG-4 coded at 1.0 Mbits/s) of the same program with a service availability of 99.9 %.
- The UHD service availability of 99.0% (or 97.0 %), complemented by a lower quality stream (HEVC coded at 2.0 Mbits/s) of the same video content with a service availability of 99.9 %.

The higher quality (HQ) and lower quality (LQ) streams are decoded independently but the receiver is assumed to be able to maintain the synchronization between the two streams and switch between the two to maintain the quality and service availability.

4.3 Comparative Performance Assessment

Figure 4 shows two locations within the coverage area for which the outage probability as function of atmospheric attenuation for geographical locations is plotted based on ITU-R Rec. P.618 [12]. It is noted that the more severe propagation conditions of the Mediterranean location compared to the North European one are counter balanced by the higher elevation of the former location compared to the latter.

Several study cases are defined to establish a benchmark performance according to the existing DVB-S2 solutions as well as enhanced solutions according to DVB-S2X specifications. The definition and justification of each study case is outlined below. A summary of key parameters associated to the each study case is provided in Table 1.

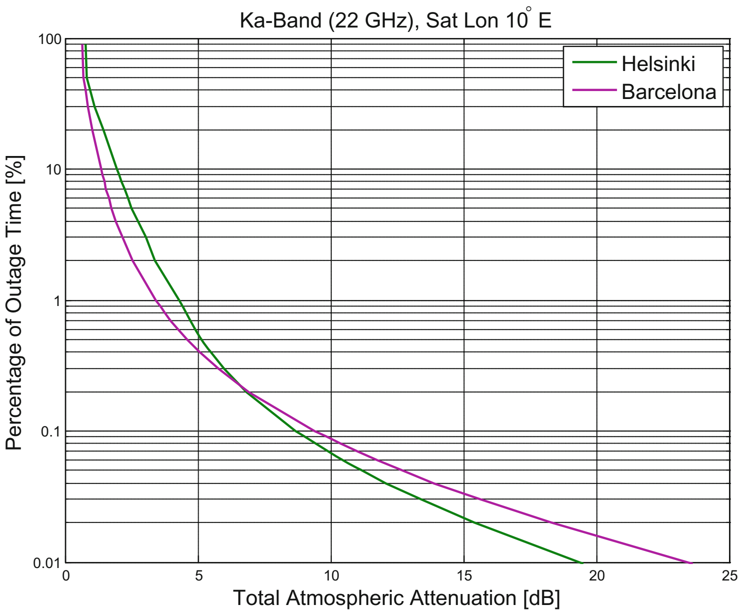

Fig. 4. Examples of atmospheric attenuation statistics in Ka-band

Study Case 1: Ku-band reference system with DVB-S2 and legacy receiver.

This study case serves as a benchmark, outlining the expected performance of legacy DVB-S2 receivers in a conventional Ku-band system with a single beam and wide coverage over Europe using a broadcasting satellite with the same envelope DC power of 15 kW. The payload consists of 64 transponders in Ku-band. Considering the transponder bandwidth and the transponder spacing, a baud rate of 30 MBaud is considered for this study case. The target service case is the broadcasting of UHD quality television channels with an average rate of 20 Mbits/s per channel. The target availability for each channel is 99.9 %.

Study Case 2: Ku-band reference system with DVB-S2 and enhanced receiver.

This study case is similar to Study Case 1 except for the receiver capability of mitigating ISI. In this case, the receiver remains compliant with DVB-S2 protocol according to the broadcasting profile while allowing for the optimization of the symbol rate.

Study Case 3: Ku-band reference system with DVB-S2X with channel bonding.

In this study case, DVB-S2X receivers with channel bonding and CCM transmission mode are considered. Similar to Case 1 and 2, UHD video quality with 99.9 % service availability is assumed.

Study Case 4: Ka-band system with DVB-S2 and enhanced receiver.

This study case examines the use of DVB-S2 together with an enhanced receiver and HEVC video decoder to deliver UHD video quality content to the end users in

Table 1. A summary of parameters for Study cases

Study Case Parameter	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Scenario	Ku-band benchmark			Ka-band Multi-beam		
Transponder Frequency Spacing (MHz)	40	40	40	60	60	60
Transponder Bandwidth (MHz)	36	36	36	54	54	54
Total Number of Transponders	64	64	64	40	40	40
Aggregate bandwidth (MHz)	2560	2560	2560	2400	2400	2400
Number of Carriers per transponder	1	1	1	1	1	1
Air Interface (DTH Profile)	DVB-S2	DVB-S2	**DVB-S2X**	DVB-S2	**DVB-S2X**	**DVB-S2X**
Receiver Assumptions	Legacy	Enhanced	Enhanced	Enhanced	Enhanced	Enhanced
Transmission Mode	CCM	CCM	CCM	CCM	**VCM**	**VCM**
Video CODEC	**HEVC**	**HEVC**	**HEVC**	**HEVC**	**HEVC**	**HEVC**
Average bit Rate per stream (Mbits/s)	20	20	20	20	20 (HQ) 2 (LQ)	20 (HQ) 2 (LQ)
Availability	99.9 %	99.9 %	99.9 %	99.9 %	**99.0 %** 99.9 %	**97.0 %** 99.9 %

Ka-band multi-beam broadcasting satellite system. A service availability of 99.9 % is targeted. The DVB-S2 receiver in this case operates in CCM transmission mode.

Study Case 5: Ka-band system with DVB-S2X.

This case examines the use of DVB-S2X air interface and enhanced receiver that supports VCM in broadcasting profile. The receiver is equipped with HEVC decoder to receiver two classes of video qualities; UHD at 99.0 % service availability and a lower quality video HEVC coded at 2 Mbits/s to complement the UHD stream at 99.9 % service availability.

Study Case 6: Ka-band system with DVB-S2X and 97.0 % UHD availability.

This is similar to Study Case 5 except for the service availability of the UHD quality TV program that is relaxed to 97.0 %. It is meant to investigate the sensitivity of the results on the availability required.

Table 2 provides a summary of the key link budget assumptions for each study case.

Table 3 presents a summary of the performance results for cases studied. For each case, the effective bit rate per transponder as well as the total number of video channels delivered by the broadcasting satellite in this example scenario is reported. It can be noted that:

Table 2. A summary of key link budget parameters

Study Case Link budget parameters	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Scenario	Ku-band benchmark			Ka-band Multi-beam		
EIRP at Saturation (dBW)	53.5	53.5	53.5	60.7	60.7	60.7
OBO (dB)	0.5	0.3	0.3	0.3	0.5	**1.5**
Fade Margin for 99.9 % availability (dB)	3	3	3	9.4	9.4	9.4
Fade Margin for 99.0 % availability (dB)	N/A	N/A	N/A	N/A	3.4	N/A
Fade Margin for 97.0 % availability (dB)	N/A	N/A	N/A	N/A	N/A	2.2
User Terminal minimum antenna size (cm)	65	65	65	65	65	65
Terminal G/T (dB/K) for 99.9 % of the time	12.7	12.7	12.7	15.5	15.5	15.5
Terminal G/T (dB/K) for 99.0 % of the time	N/A	N/A	N/A	N/A	15.7	N/A
Terminal G/T (dB/K) for 97.0 % of the time	N/A	N/A	N/A	N/A	N/A	16.2
C/N0 (dBHz) for 99.9 % of time	83.7	83.7	83.7	82.5	82.5	82.5
C/N0 (dBHz) for 99.0 % of time	N/A	N/A	N/A	N/A	87.5	N/A
C/N0 (dBHz) for 97.0 % of time	N/A	N/A	N/A	N/A	N/A	89.3
Adjacent Satellite C/I (dB) (Note 3)	13	13	13	22	22	22
Co-Channel Interference (dB) (Note 4)	N/A	N/A	N/A	20	20	20
C/(N+I) (dB) for 99.9 % of the time	7.7	7.1	7.1	5.2	5.1	4.1
C/(N+I) (dB) for 99.0 % of the time	N/A	N/A	N/A	N/A	10.5	N/A
C/(N+I) (dB) for 97.0 % of the time	N/A	N/A	N/A	N/A	N/A	11.1
Baud Rate (MBaud)	30	**34**	**34**	51	51	51
MODCODs	8PSK3/5	**QPSK 5/6**	**QPSK 5/6**	QPSK 2/3	8PSK 5/6 (HQ) QPSK 2/3 (LQ)	16APSK 2/3 (HQ) QPSK 3/5 (LQ)
Required Threshold (dB)	6,6	**5,7**	**5,7**	3,6	10,4 (HQ) 3,6 (LQ)	10,8 (HQ) 2,8 (LQ)
Link Margin (dB)	1.1	**1.4**	**1.4**	1.6	1.5	1.3

Table 3. A summary of performance results

Study Case Parameter	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Scenario	Ku-band benchmark			Ka-band Multi-beam		
Transponder IMUX/OMUX Bandwidth (MHz)	36	36	36	60	60	60
Total Number of Transponders	64	64	64	40	40	40
Symbol Rate (MBaud)	**30**	34	34	54	54	54
Air Interface (DTH Profile)	DVB-S2	DVB-S2	**DVB-S2X**	DVB-S2	**DVB-S2X**	**DVB-S2X**
Receiver Assumption	Legacy	Enhanced	Enhanced	Enhanced	Enhanced	Enhanced
Transmission Mode	CCM	CCM	CCM	CCM	**VCM**	**VCM**
Average bit rate per video stream (Mbits/s)	20	20	20	20	20 (HQ) 2 (LQ)	20 (HQ) 2 (LQ)
Assigned MODCODs	8PSK 3/5	QPSK 5/6	QPSK 5/6	QPSK 2/3	8PSK 5/6 (HQ) QPSK 2/3 (LQ)	16APSK 2/3 (HQ) QPSK 3/5 (LQ)
Effective bit rate per transponder (Mbits/s)	54.3	56.5	56.5	67.9	118.1	122.4
Digital Bonding (Note 1)	N/A	N/A	**Yes**	N/A	**NO**	**NO**
Fractional number of video streams per transponder (Note 2)	2.7	2.8	2.8	3.4	5.4	5.6
Statistical multiplexing gain	8 %	8 %	23 %	12 %	16 %	16 %
Effective number of video streams per transponder	3	3	10/3 (Note 3)	3	**6**	**6**
Total number of video streams (TV channels) delivered by the satellite	64x3=192	64x3=192	64 × 10/3 ~ 213	40 × 3=120	40 × 6=240	40 × 6=240

Note 1: For DVB-S2X (CCM), the channel bonding can be applied to up to 3 transponders.
Note 2: this ratio does not include the statistical multiplexing gain.
Note 3: For DVB-S2X CCM, the effective number of video streams is computed for every 3 transponders to take into account the digital channel bonding gain.

- The use of DVB-S2 enhanced receivers (Study Case 2) compared to the legacy receivers (Study Case 1) does not offer any improvement in terms of the number UHDTV channels for this particular system and only provides a marginal improvement (4 %) in terms of the throughput per transponder.
- DVB-S2X channel bonding used in the Ku-band (Study Case 3) offers around 11 % increase in the number of UHDTV channels compared to DVB-S2 (Study Case 2).
- The use of DVB-S2 enhanced receiver with UHD video quality in Ka-band (Study Case 4) shows a significant reduction (37 %) in the number of video streams compared to a Ku-band broadcasting satellite with the same 15 kW DC power envelope (Study Case 2.2). This confirms that Ka-band broadcasting should be realized with DVB-S2X.
- The use of DVB-S2X enhanced receiver with UHD video quality in Ka-band can offer a significant increase in the number of channels compared to DVB-S2 in

Ka-band. The increase in the number of UHD channels is around 100 % (Study Cases 5 or 6) compared to DVB-S2 (Study Case 4). It is worth highlighting that this result is achieved with the same overall power consumption and with fewer HPAs on board.

5 Concluding Remarks

Satellite broadcasting services in Ka-band are readily available in many regions of the world. In this paper, we presented solutions based on multi-beam satellites and new features of DVB-S2X to offer Ka-band broadcasting services even for geographical areas with high atmospheric fading.

For the broadcasting services, the use of the channel bonding feature of DVB-S2X allows for a reasonable gain in the number of offered TV channels on conventional transponders. The performance improvement of the channel bonding is attributed to the statistical multiplexing gain due to the aggregation of two or three multiplexing streams (as opposed to one that is supported by DVB-S2).

The use of VCM together with simulcasting allows for significant improvement in number of channels while maintaining the service availability. In particular, in such scenarios, the use of VCM together with simulcasting, would allow up to 100 % increase in the number of offered TV channels, compared to similar services without VCM (conventional DVB-S2).

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