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HDTV SATELLITE BROADCASTING IN THE EHF DOMAIN: FEASIBILITY STUDY AND QUALITY ASSESSMENT

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Abstract

In this work we propose a simulation-based feasibility study for the efficient exploitation of W band (75-110GHz) for high quality HDTV broadcasting applications. In order to obtain a reliable and realistic simulation environment, we have considered the DVB-S2 standard specifications, introducing the typical W-band impairments such as phase noise, rain attenuation, as well as non-linearities. For testing purposes, we have adopted common High-Definition benchmark video sequences, so as to evaluate the H.264 video quality as a function of the available bit-rate on the channel. During the simulation phase we have taken into account adaptive techniques like ACM (Adaptive Coding and Modulation) and scalable video coding (SVC). Eventually, we have evaluated the achieved results in view of implementing future broadcasting services in the EHF domain. Simulation results have demonstrated the suitability of W-band to efficiently support a reliable HDTV service with an increased number of available channels if compared to DVB-S2 standard using K_u and K_a band. The large bandwidth availability should also improve the system flexibility in terms of trade-off between spectral efficiency and video quality.

Index Terms

DVB-S2, HDTV, Satellite Broadcasting, Adaptive Code Modulation, EHF.

I. INTRODUCTION

The introduction of digital TV transmission has allowed for a consistent increment of degrees of freedom thanks to adaptive modulations, joint source and channel coding, scalable source coding, as well as adaptive error concealment, which have permitted a more efficient bandwidth usage. As also stated in [1], the set of crucial parameters that characterize the TV broadcasting service are represented by (i) orbital position, (ii) transponder bandwidth, (iii) power coverage, and (iv) service availability.

In addition, we have also to take into account the desired output of the transmission, both in terms of perceived quality, and in terms of available channels delivered to the users.

Recently, the TV broadcasting standardization bodies have been concentrating on the DVB. In particular the DVB-S system is based on Quadrature Phase Shift Keying (QPSK) modulation couple with convolutional channel coding, and concatenated with Reed-Solomon coding. The satellite channels for DVB-S have been identified in the Ku-band (11-14 GHz). The Ku band exhibits favorable atmospheric attenuation conditions, as also reported by the intensive tests carried out during the five-year SIRIO measurement campaign (1978-1982) [2]. The last evolution of the DVB-S standard is represented by DVB-S2, now recognized as ITU-R and ETSI standard [3]. DVB-S2 extended the DVB-S functionalities to include higher-order modulations and adaptive coding and modulation (ACM). DVB-S2 has been designed to fulfill the requirements of different types of applications, including (i) broadcasting of standard definition and high-definition TV (SDTV and HDTV), (ii) interactive services including Internet access, (iii) professional applications (e.g. news gathering), as well as (iv) data content distribution and Internet trunking.

The question that naturally comes to mind is whether K_u and K_a-band frequency spaces are compatible and large enough to efficiently support the constantly increasing number of high-quality digital TV and HDTV channels as required by the market. In such a framework, recent experiments of satellite

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Extremely High Frequency (EHF) communications [4] like ALPHASAT, DAVID and WAVE, are exploring unexploited spectrum portions in the EHF domain in order to find additional bandwidth resources for broadband satellite communications. The analysis carried out in literature [5], [6], [7] evidenced two favorable frequency windows for EHF satellite transmission, i.e. Q-V band (30-50 GHz) and W-band (75-110 GHz).

A preliminary work about optimization of DVB-S2 links in W-band has been recently proposed in [8]. Simulations including rain fading and amplifier nonlinearities have been performed in order to select the proper thresholds for the different Adaptive Coding and Modulation (ACM) modes considered by DVB-S2 standard.

Our work aims at providing an improvement with respect to the previous work of [8], by extending the analysis to the transmission and the reception of the coded digital TV signal. In this paper, we simulate a complete end-to-end satellite W-band link for DVB-S2 broadcasting that includes phase noise, amplifier nonlinearities, and rain fading. We also address the issue of evaluating the impact of link attenuation and distortion on the digital signal, measuring the quality of the video received at the destination. Besides assessing the performance achievable by the DVB-S2 standard in a W-band transmission scenario, it is also necessary to propose realistic solutions to improve the quality of the received video signals in presence of heavy channel attenuation. The proposed study will consider the increased bandwidth availability naturally provided by W-band with respect to K_u and K_a band, in order to design an effective transmission link.

The paper is structured as follows: Section 2 describes the DVB-S2 W-band satellite broadcasting system, Section 3 is devoted at presenting the DVB-S2 physical layer simulation, and Section 4 details the video coding procedures adopted for efficient HDTV broadcasting in the framework of DVB-S2 standard. Section 5 introduces the simulation strategies chosen to model and simulate the impairments in the W-band link. Experimental results will be shown in Section 6, while concluding remarks are drawn in Section 7.

II. SYSTEM DESCRIPTION

The analysis we present here provides a qualitative evaluation of the performances of an HDTV broadcasting application with reference to the downlink channel (the "high bit-rate forward link" in Fig. 1) of a geostationary satellite operating in the EHF domain, and in the W-band in particular. Fig. 1 briefly summarizes the typical structure of a DVB-S2 system in the ACM configuration.

The most attractive feature of the W-band compared to other frequency bandwidths such as the K_u-band, consists of the larger bandwidth availability. Once demonstrated that the strong limitations due to the atmospheric attenuations can be overcome using state-of-art error resilience tools, we can devise a possible frequency plan for the W-band and compare it with a K_u-based system: given the example of the ASTRA 1H satellite for broadcast services [10], the typical transponder bandwidth for K_u transmission is about 33 MHz and the overall bandwidth availability is about 1GHz; estimating an overall bandwidth of about 15 GHz or even more for the W-band, a reasonable bandwidth allocation for a single transponder can be in the range of about 500 MHz. This turns out to be an evident advantage, first of all in terms of number of channels per transponder but also because it allows employing a higher bit-rate for the TDMA, thus limiting the typical problems related both to the narrower transponder of the K_u band and to the FDMA systems (e.g. intermodulation interference, high back-off levels and so on).

As a reference system for the link budget equation we used the data provided in [11] (included for the sake of completeness in Table I) for a geostationary high-bit-rate satellite system, transmitting on a W-band downlink.

III. DVB-S2 PHYSICAL LAYER SIMULATION

The physical layer we have adopted represents a satellite broadcasting system operating on a W-band link. The block diagram of the transmitter section is shown in Figure 2. The system has been implemented using the software MATLAB SIMULINK 2007. The simulation model, shown in Figure 3 is based on

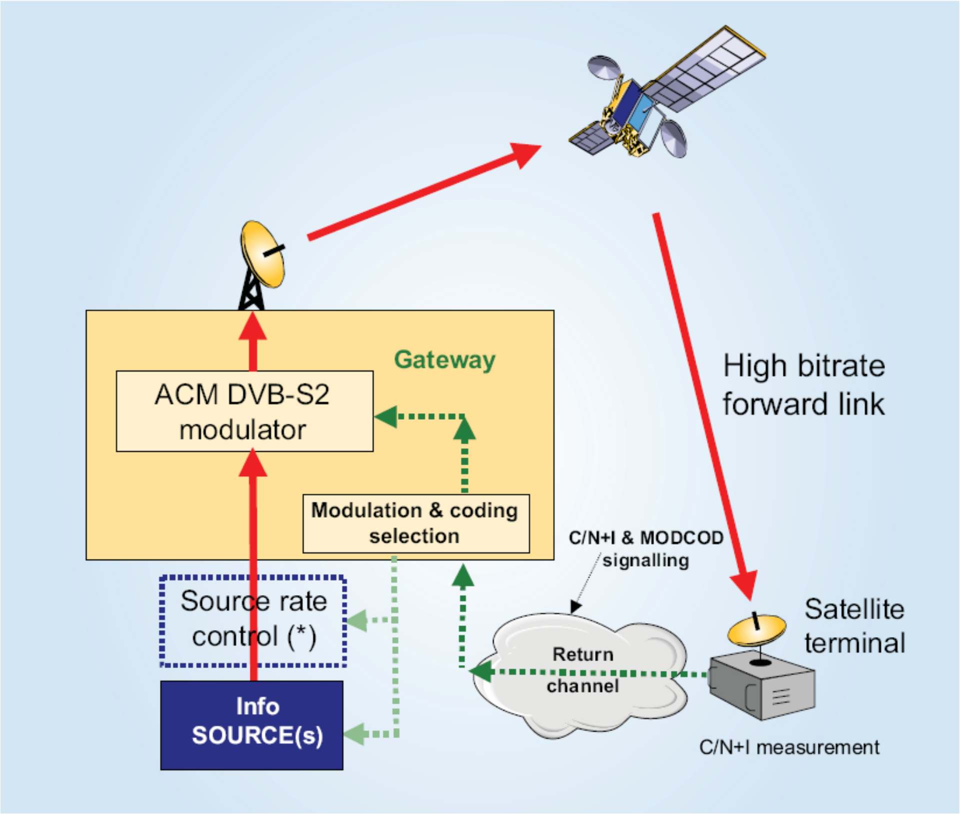

Fig. 1. Scheme of the DVB-S2 broadcasting system (courtesy by [9])

Parameter	Numeric value
Frequency	92 GHz
RF Power	20 dBW
TX terminal EIRP	80 dBW
Free-space loss	222.75 dB
RX terminal gain	57.1 dB
RX noise temperature	29.6dB°K
RX G/T	26.6dB°K
Pointing loss	1.6 dB

TABLE I
LINK BUDGET FOR A DOWNLINK GEO TRANSMISSION IN W-BAND

the specifications of the DVB-S2 standard and it also includes the behavior of both the channel and the hardware impairments.

More specifically, let us start with the description of the block diagram in Figure 2. The generated input bits are buffered into the BBFRAME (K_{BCH} bits), which provides a length vector suitable for the BCH encoder. The next step, in compliance with the DVB-S2 standard [12], consists of the FEC encoding: first a LDPC (Low-Density Parity Check) inner code is applied (n_{LDPC}, k_{LDPC}), which is then concatenated with a BCH (Bose-Chaudhuri-Hocquenghem) outer code (N_{BCH}, K_{BCH}).

The main part of the encoding task is performed by means of LDPC codes, which are linear block codes characterized by sparse parity check matrices $H_{(n-k)\times n}$. Each block of k information bits is encoded with a codeword of size n that can have two different lengths: 64800 bits for normal applications, or 16200 bits for applications operating with critical delays. The aim of the BCH encoder, is instead to avoid the presence of the typical error floor generated in presence of low error rates (which is particularly difficult, sometimes impossible, to measure accurately), in order to guarantee an additional low-complexity

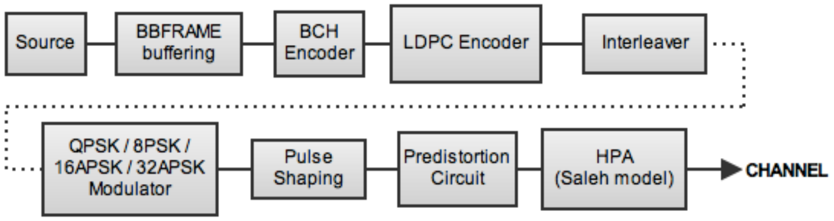

Fig. 2. Block diagram of the transmitter section

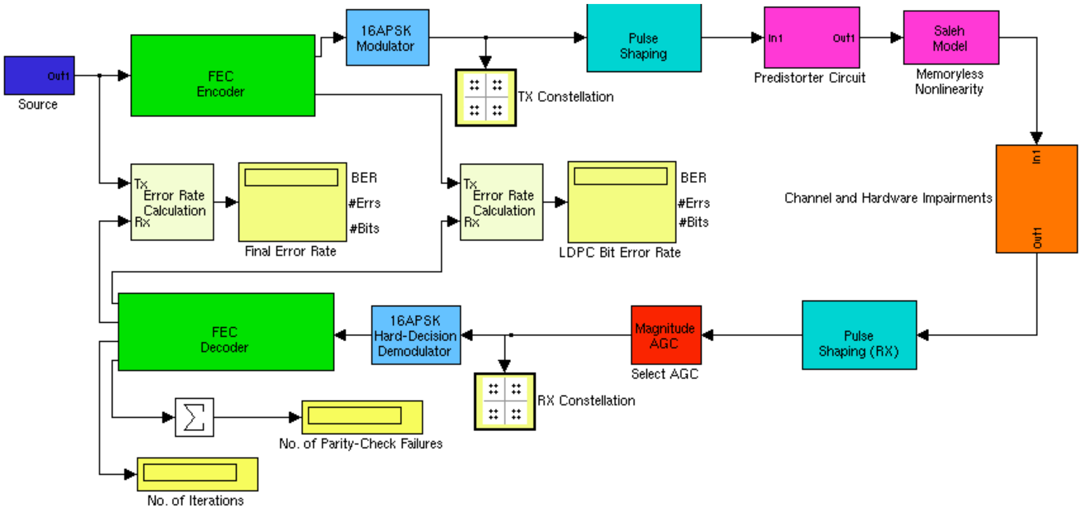

Fig. 3. Transmitter/Receiver Sections simulated in MATLAB SIMULINK.

protection margin. For this reason, the corresponding blocks are placed after the BBFRAME block and the inner parameters are automatically configured based on the selected code-rate for the transmission. After the FEC section, the standard provides the insertion of a bit interleaver (except for the QPSK case) so as to separate from each other, bits mapped onto the same transmission signal.

Regarding the modulation block, there are four modes available for the transmission. The most typical configurations for broadcasting applications are QPSK and 8PSK, common because of their high performance when dealing with nonlinear amplifiers driven near saturation; 16APSK and 32APSK ensure instead a much greater spectral efficiency, but are mainly considered for professional applications due to their high requirements in terms of SNR.

In the next block we find the pulse shaping section: here square-root raised cosine baseband filters are applied to shape the “ideally impulsive” signal to transmit, thus reducing the bandwidth occupation in the frequency domain. The main parameter to configure in the RRC filters section is the roll-off factor, which basically sets the shape of the filter and consequently influences its bandwidth. In our simulations we choose to set the roll-off factor to 0.35, but values 0.20 and 0.25 are also possible as specified by the DVB-S2 standard. Furthermore, this block is also devoted to managing the quadrature modulation and the related RF signal generation, although for our simulation we simplified it to a baseband system. Moreover, considering the selected roll-off factor and a transponder bandwidth equal to 500 MHz (according to our model assumptions), we can calculate the available symbol-rate in the system, given by $R_S = BW/(1+\text{roll-off})$, and then equal to 370 Mbaud/s.

The final part of the transmitter model depicted in Figure 2 refers to the non-linear amplifier (HPA) and to the pre-distortion circuit. These two blocks have been added according to the fact that the power amplifier nonlinearities are modeled using the memoryless Saleh model [13], which gives us the input-output relations both for amplitude (AM/AM conversion)

$$A(r) = \frac{k_1 k_2 \alpha_1 r}{1 + \beta_1 k_1^2 r^2} \tag{1}$$

and phase (AM/PM conversion) [8].

$$\Phi(r) = \frac{k_1^2 \alpha_2 r^2}{1 + \beta_2 k_1^2 r^2} \tag{2}$$

According to Eq. (1) and (2), r is the magnitude of the input signal, simulation values k_1 and k_2 are set to 4 and 30, respectively, while α_1, β_1, α_2 and β_2 are taken to be 2.1587, 1.1517, 4.0033 and 9.1807, respectively.

The pre-distortion circuit placed ahead of the amplifier is composed by an amplitude compensator (only needed for 16APSK and 32APSK modulations), a phase compensator (to make up for phase shift in constellations) and an attenuator (to ensure that the amplifier is not driven into saturation). In particular, the latter is given by:

$$k_3 = \frac{G}{k_1 k_2} = \frac{\alpha_1}{2 k_1 x_{max} \sqrt{\beta_1}} \tag{3}$$

that corresponds to the ratio of the obtained gain (about 29 dB, depending on x_{max}) to the maximum possible gain when β_1 is zero (about 41 dB). Thus, using a pre-distorter that calculates the reverse transfer function of the Saleh equation, it is possible to reach a consistent amount of gain at the output of the amplifier with a reasonably low level of distortion.

As far as the receiver is concerned, it is mainly composed of the specular blocks of the transmitter, with the only exception of the AGC (Automatic Gain Control) positioned before the demodulator, needed to adjust the input gain.

IV. VIDEO CODING AND VIDEO QUALITY ASSESSMENT

The DVB-S2 system does not impose any restriction in terms of video coding standards to be adopted for video delivery. For this work, in accordance to the current state of art in video coding, we have chosen H.264/AVC [14], because of the high performance with respect to its predecessors.

As we stated at the beginning of this paper, one of the main purposes of this work is to evaluate the transmission of HDTV video streams in a particular range of the frequency spectrum. We have thus analyzed four different HD sequences, using different configurations of the encoder (x264 - an open source software for video encoding in H.264 [15]), and evaluating the obtained video quality by measuring the SSIM index (Structural Similarity Index Metric) [16], a full-reference objective metric that better correlates the visual artifacts to the human visual perception, with respect to more common metrics such as the Peak Signal to Noise Ratio (PSNR).

The selected HD sequences are in 720P format and analyzed at both 25 and 50 fps. Given the difficulties of finding uncompressed HD sequences, for testing purposes we have used HD movie trailers, already compressed in H.264 format at high quality. The reason that lead us to the choice of movie trailers, is that they can reasonably well approximate the average statistics of an entire movie, so that we can work with relatively short sequences with a good approximation of the full length movies.

The sequences we have chosen for simulation are:

- **Cartoon** - a movie trailer from a famous cartoon produced by Disney Pixar, rich of details and colors, duration 2 min 23 sec, resolution 1280×720;
- **Action movie** - a movie trailer containing some fast and particularly critical (for the encoder) scenes, duration 1 min 58 sec, resolution 1280×608;
- **Movie** - a trailer from a typical movie with slow/medium motion scenes, duration 2 min 30 sec, resolution 1280×544;
- **Action scene** - an additional video extracted from a pretty fast and complex two minute scene of a movie, in order to have a “worst case” sequence to test, resolution 1280×532.

A first set of tests has been carried out in order to analyze the video quality and the output bit-rate as function of the quantization parameter of the x264 encoder.

A second set of tests is then carried out to evaluate the video quality (given by the average SSIM index) of the sequences, as function of the target bit-rate, assigned through the rate-control parameter of the x264 encoder. As we can see from Table II, for each sequence we analyze a set of different values for the bit-rate, that lead us to the definition of two main target groups, the low bit-rate one (1000 to 2500 Kbit/s) and the high bit-rate one (8000 - 9000 Kbit/s).

Target bit-rate (Kbit/s)	**SSIM (25 *fps*)**	**SSIM (50 *fps*)**
Movie		
1000	0.9764	0.9752
1500	0.981	0.9803
2000	0.9836	0.9831
2500	0.9856	0.9852
8000	0.9957	0.9954
9000	0.9964	0.9961
Cartoon		
1000	0.9717	0.9674
1500	0.9808	0.9773
2000	0.9854	0.9825
2500	0.9882	0.9858
8000	0.9972	0.9965
9000	0.9975	0.9972
Action movie		
1000	0.9695	0.9678
1500	0.978	0.9766
2000	0.9829	0.9816
2500	0.9861	0.9849
8000	0.9975	0.9968
9000	0.9978	0.9975
Action scene		
1000	0.8972	0.8918
1500	0.9217	0.9174
2000	0.9369	0.9333
2500	0.9474	0.9443
8000	0.9905	0.9882
9000	0.9931	0.9908

TABLE II
ANALYSIS OF THE VIDEO QUALITY (SSIM INDEX) FOR DIFFERENT TARGET BIT-RATE

MOS	**SSIM**
5 (excellent)	>0.99
4 (good)	≥ 0.95 & < 0.99
3 (fair)	≥ 0.88 & < 0.95
2 (poor)	≥ 0.5 & < 0.88
1 (bad)	< 0.5

TABLE III
MAPPING OF SSIM INDEX TO MOS SCALE

From the results of Table II, we can do a first assessment of the video quality for the different bitstreams, but we first have to find the correlation between the SSIM metric and a subjective scale using MOS (Mean Opinion Score). Therefore, given the difficulties of recruiting a considerably large number of users for the subjective experiment, we have adopted the “SSIM to MOS” mapping illustrated in [17] as shown in Table

III. As we can see from the cross analysis of Table III and II (Figure 4), when any of the four sequences is encoded using a high bit-rate, the average SSIM index is always greater than 0.99 (except for the action scene at 50 fps where SSIM is 0.9882, reasonably rounded up to 0.99). This means practically that the final video quality is excellent; a different situation is shown for the low bit-rate videos instead, where for the movie trailer sequences we always obtain slightly lower values, between 0.96 and 0.99, whereas for the worst case represented by the action scene the SSIM values goes from 0.89 till a maximum of about 0.95, corresponding to the "fair" quality of the MOS scale. Going back to the broadcasting application, this basically implies that when a high bit-rate is available on the channel, the H.264 encoder can guarantee an excellent video quality for any kind of sequence, even for the fast or complex ones; when the bit-rate available is lower, meaning 1000 - 2500 Kbit/s, a good video quality is guaranteed on the average, but for critical scenes the quality could have peaks of lower (but still fair) quality. Another interesting thing to notice from Table II is the really low variation on the average SSIM index between 25 fps and 50 fps sequences, which in practice means that the presence of doubled frames generated in order to fulfill the broadcasting requirements of the EBU (European Broadcasting Union) about the 720p/50 format do not have an perceptual impact on the final quality of the video (in case of cinematographic movie).

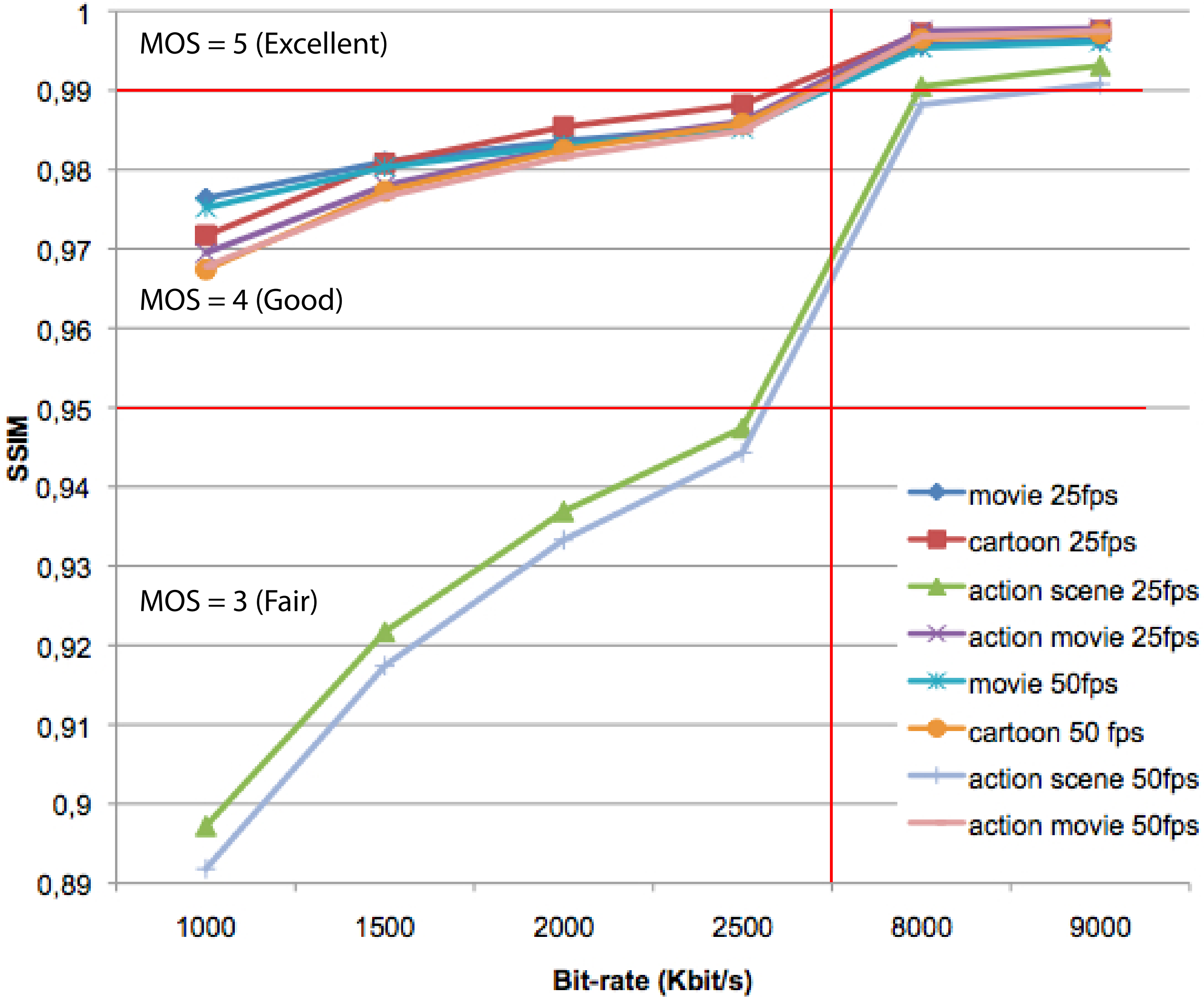

Fig. 4. Average SSIM index as a function of target bit-rate

Given the feature of the DVB standard in handling a High Priority and a Low Priority stream, it is worth mentioning that the videos could be delivered using a layered encoding strategy, such as provided by the H.264/AVC extension called SVC (Scalable Video Coding), that we considered for our evaluations on the possible broadcasting scenarios (in Section VI) [18]. Scalable video coding enables in practice to broadcast the whole stream, giving though the possibility to the end-user to decode only a subset of relevant information, depending on the channel availability or the device features. In other words, we assume to encode our HDTV video stream using a "quality scalability" and to achieve this we considered a main bitstream consisting of an High Priority (HP) subset stream, transmitted by the DVB-S2 system using a highly protective mode and therefore having a smaller bit-rate, and of a Low Priority (LP) subset stream that can be transmitted using a lower degree of protection. What we expect in the decoding phase is to experience an excellent video quality when the whole bitstream (both HP and LP streams) is received correctly at the decoder, and a fairly good quality instead when only the HP stream is available at the receiver.

V. SIMULATION STRATEGIES

In our system we simulate a 500 MHz transponder in the W-band satellite link, in order to measure the service availability of the channel both in terms of service time and bit-rate. In addition, we also investigate the number of HDTV channels that could be transmitted as the bit-rate capacity varies.

The most important task of the simulator for the characterization of the satellite link and the related hardware problems, is in modeling the channel and the RF device impairments. We have identified three main processing blocks to achieve this goal: the first one simply adds the atmospheric attenuation due to rain events, the second is the AWGN noise block, and the third one manages the additional phase jitter due to phase noise and thermal noise. Rain attenuations, and more in general atmospheric attenuations, is probably the most critical impairment in this particular frequency domain. In fact, as also demonstrated by the work proposed in [7], the presence of fog, haze, clouds, rain, and snow, can cause very strong attenuations depending on the wavelength, and this is one of the main reasons why operative bands for telecommunications, like the W-band, are chosen in specific ranges typically situated in "transmission windows", namely a frequency range in which the attenuation is minimum. The atmospheric attenuation data we considered in our work are taken from the simulation results obtained in [11] by using a N-state Markov chain model based on data interpolated from lower frequency statistics. This attenuation data are reported in Figure 5 as a function of the service-time percentage during a rain event, and will be essential further on to evaluate the QoS of the broadcasting system.

As mentioned in the previous paragraph, the second block is the AWGN block. The configuration of the block is easily achieved by setting the signal-to-noise ratio, formulated as E_S/N_0 (energy per symbol to noise ratio), which can be calculated from the carrier-to-noise ratio C/N_0. This value is given by the budget link for a downlink GEO transmission in W-band, as described in [11], and reported in Table I. The resulting C/N_0 is 112.5 dB and given the 370 Mbaud/s symbol-rate, we obtain a final E_S/N_0 of about 26.8 dB. The last block is represented by the phase and thermal noise of the RF devices operating at high frequencies, and returns at the output a residual phase jitter in the constellation. This block should be actually part of the receiver system but we put it instead in the "impairments part" because it strongly contributes to the satellite link characterization. Phase noise is a very important impairment factor in transmission systems working in the EHF domain and it is typically associated to the non-ideal behavior of oscillators and up/down-converters, which cause signal distortions and variations to the oscillation period. The jitter creates a phase instability on the oscillator that generates, as a consequence, random shifts in the carrier frequency. We have modeled the phase noise jitter as indicated in [19] and reported for completeness in Eq. 4

$$\sigma_\phi = \sqrt{2\int_{B_L}^{R_s/2} S_\phi(f)\,df} \tag{4}$$

where σ_ϕ is the residual phase noise jitter (in radiants) at the output of a generic carrier recovery loop, B_L is the loop bandwidth, R_S is the symbol-rate, and S_ϕ is the power spectral density of the phase noise in rad^2/Hz.

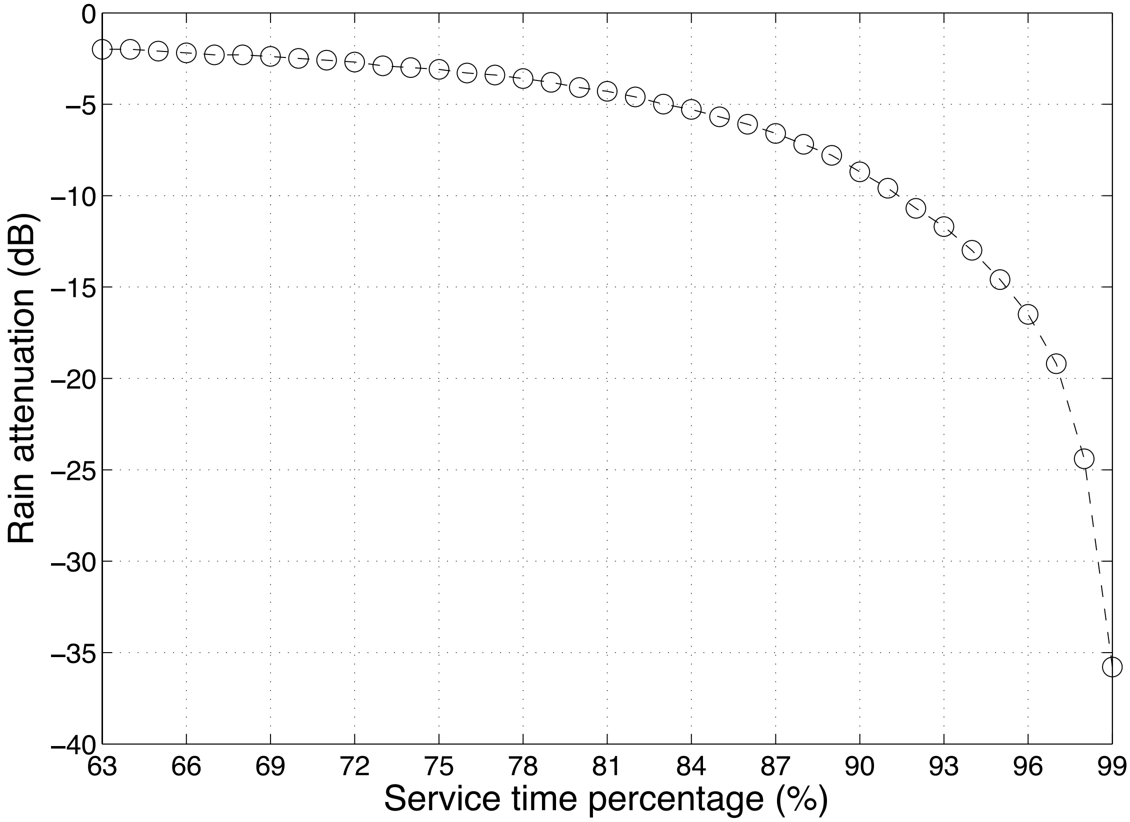

Fig. 5. Cumulative distribution function of the additional rain attenuation

To calculate σ_ϕ we considered the phase noise mask given by a commercial Gunn[1] oscillator, operating at 91.25 GHz (Figure 6). Based on the known symbol-rate (fixed to 370 Mbaud/s in our model), on the phase noise mask that we just saw, and on a loop bandwidth that we can reasonably set to 1 MHz, we can consequently calculate the phase noise jitter, that turns out to be about 2 degrees. We should also add to this jitter the thermal noise contribute, which is mostly influenced by the SNR and by the rain attenuation considered in our model, as shown in Eq. 5:

$$\sigma_\tau \cong \sqrt{\left[\frac{2E_s}{N_0} \cdot \frac{R_s}{B_L}\right]^{-1}} \tag{5}$$

where E_s/N_0 is the SNR computed including the rain attenuation factor. The total phase jitter σ_{TOT} can now be computed as:

$$\sigma_{TOT} = \sqrt{\sigma_\phi^2 + \sigma_\tau^2} \tag{6}$$

Based on our simulations we obtain the values reported in Table IV: here, as already stated, σ_{TOT} mainly depends on SNR and, therefore, on rain attenuation.

VI. RESULTS AND SCENARIOS

As explained in the previous sections, the purpose of our simulations is to find for each DVB-S2 mode (that is the combination of modulation and LDPC code-rate) the bit error rate (BER) of the channel, given

[1] provided by Rheinmetall Italia S.p.A.[4]

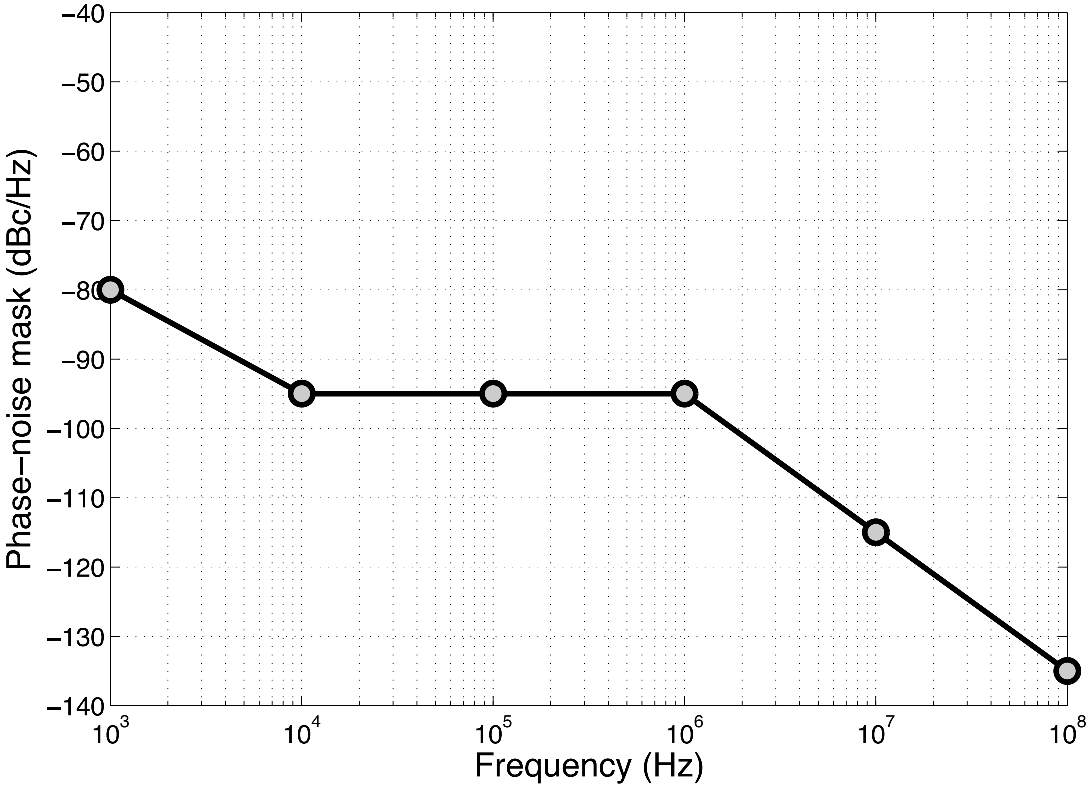

Fig. 6. Phase noise mask of the solid state oscillator operating at 91.25 GHz

Attenuation	0 - 17 dB	18 - 24 db	25 - 29 dB	30 - 32 dB
Phase jitter	3°	4°	5°	6°

TABLE IV
TOTAL PHASE JITTER AS FUNCTION OF THE RAIN ATTENUATION

a fixed SNR, in presence of a rain attenuation that varies from 0 to 32 dB (according to the percentage of service time shown in Figure 5).

Furthermore, in our results we refer to *available* bit-rate only when the BER is Quasi Error Free (QEF). This practically means that if the BCH block is able to correct even the error floor left by the LDPC decoder, we can reasonably assume a BER<< 10^{-8}; on the contrary, if the BCH cannot correct the residual error floor, BER is always greater then 10^{-6}, which is not acceptable for HDTV services.

In Figure 7 the values for the available QEF bit-rate on the channel are represented as function of rain attenuation, whose cumulative distribution has been shown in Figure 5 It is clear from the plot that by increasing the attenuation value, the transmission system is required to use more protective code-rate and less efficient constellations, in order to maintain a QEF transmission. As a consequence, the bit-rate decreases when the percentage of service time goes up. In particular, we can observe that for a 3dB attenuation (74% service time) the available QEF bit-rate using a 32APSK 9/10 is about 1663 Mbit/s, for a 6dB attenuation (86% service time) the 16APSK 9/10 provides 1330 Mbit/s, for 9dB (90% service time) the 8PSK 9/10 provides 997 Mbit/s, for 15dB (95% service time) the QPSK 9/10 provides 665 Mbit/s, and so on up to 27dB attenuation (about 98.2% of service time) where the last mode available, the QPSK 1/4, can provide 182 Mbit/s QEF bit-rate.

Given the fixed bandwidth of the transponder (500 MHz), the roll-off factor (0.35) and the consequent symbol-rate (370 Mbaud/s), we obtain for our system the aforementioned bit-rate availability depending on the channel condition. Based on this bit-rate values we can now select the number of HDTV channels that can be broadcast on the satellite channel. Based on these considerations, we can devise the following broadcasting scenarios, depending on the DVB-S2 transmission mode.

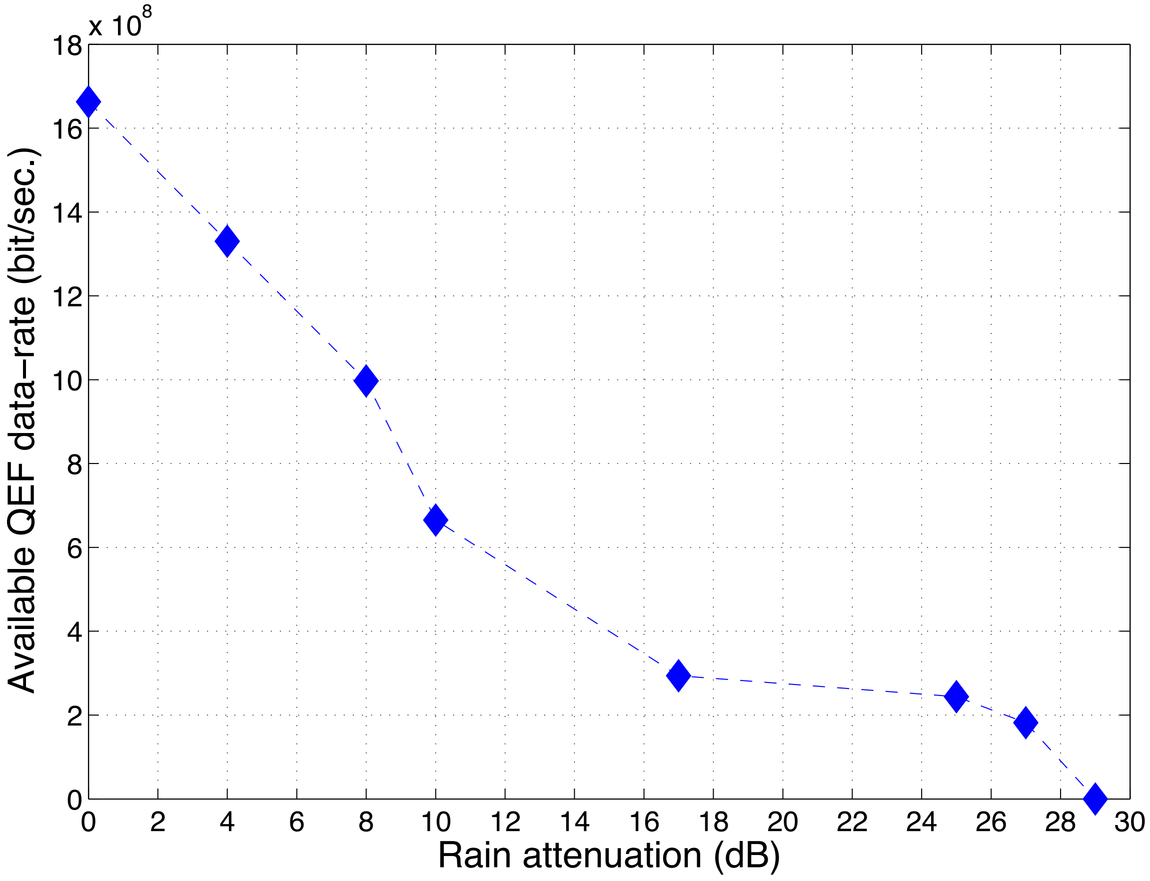

Fig. 7. Available bit-rate (Mbit/s) on the channel in QEF condition as a function of rain attenuation (dB)

A. Scenario 1: Constant Coding and Modulation - CCM

In a typical scenario of home satellite TV broadcasting, the DVB-S2 mode is fixed (CCM modality) and therefore both service time percentage (in presence of rain) and bit-rate availability are also fixed. Thus, given the number of channels in the transponder, it is possible to calculate the available bit-rate for each channel and also estimate the video quality of the HDTV transmission. In our system, and considering such scenario, we can first of all select a suitable value for the service time, considering the cumulative distribution function shown in Figure 5; after that, based on the corresponding attenuation value, we need to find the most suitable DVB-S2 mode so as to obtain the maximum QEF bit-rate available. Going back to the figures shown in Table II about the relationship between video quality and channel bit-rate, we can consider a 8 Mbit/s bit-rate per channel to obtain an excellent video quality. This configuration would result in the availability of 83 channels service time percentage of 95% and up to 30 channels for 98% of service time percentage, as shown in Figure 8.

To improve the performance of the broadcasting system we introduced in our work two innovative features: in one scenario we considered the already mentioned Scalable Video Coding (SVC), which would allow us encoding a single HDTV stream into different subset bitstreams, each one with different video quality and priority, exploiting on the channel side the Variable Coding and Modulation (VCM) mode of the DVB-S2; in the second scenario we employ the Adaptive Coding and Modulation (ACM)

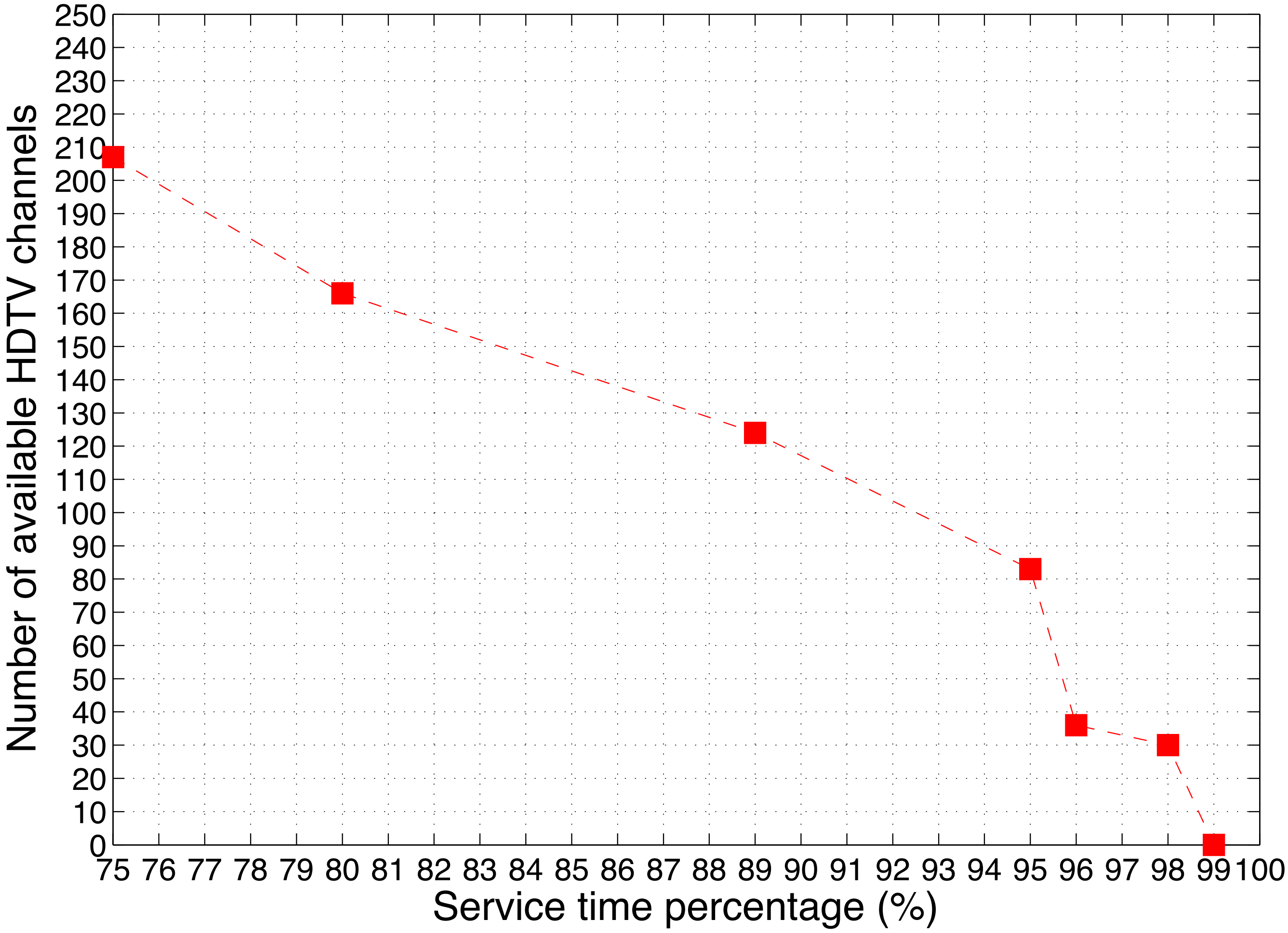

Fig. 8. Available bit-rate (Mbit/s) on the channel as a function of service time percentage; the number of possible channels is also indicated for single channel bit-rates of 8 - 9 Mbit/s

technique specified in the DVB-S2 standard [12], which consists in the exploitation of a return channel aimed at providing a feedback channel to inform about the quality of the link, thus letting the system adapt the transmission modes dynamically so as to maximize the quality perceived by the end-user.

B. Scenario 2: Variable Coding and Modulation - VCM

In the second analyzed scenario, we want to exploit the scalable video coding to improve the service availability, yet keeping a good number of channels. In practice, we generate two different subset bitstreams from the H.264 SVC coding process, where the first one contains the High-Priority (HP) stream, while the second on contains the Low-Priority (LP) stream that, once combined with the HP stream, gives as result an excellent video quality at the receiver. It is important to recall that in order to allow the transmission of different bitstreams using different DVB-S2 modes, we are required to exploit the Variable Coding and Modulation (VCM) modality provided by the standard itself.

In Table V we reported different possible configurations for our scenario: we started fixing the number of channels for the transponder and a bit-rate for each HP bitstream able to guarantee a good quality (1 - 1.5 Mbit/s satisfy this requirements according to Table II); then we calculated the bandwidth occupation due to the HP streams transmitted using the QPSK 1/4 mode (the most protected mode that guarantees about 98.2% of the service time during a rain event) and considering the residual throughput available on the channel we evaluate the tradeoff between the LP streams transmission mode and the video quality of the total bitstream. In the case of Table V the selected mode (for LP streams) is the 32APSK 9/10 that guarantees QEF only for 74% of service-time but still lets us exploit the residual throughput of

Channels	HP stream	LP stream	Total stream
70	1.5	10.088	11.588
80	1.5	7.135	8.635
90	1	9.370	10.370
95	1	8.400	9.400
100	1	7.525	8.525

TABLE V
DIFFERENT BITSTREAMS (MBIT/S) FORMING THE HDTV VIDEO SIGNAL IN A BROADCASTING SYSTEM EMPLOYING THE SVC

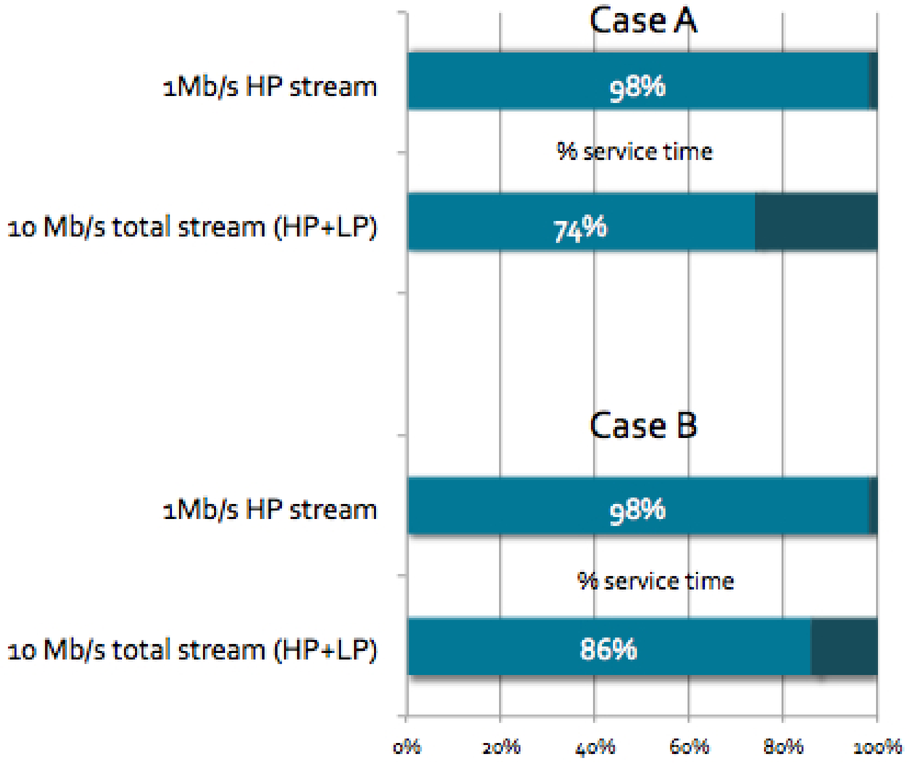

Fig. 9. Comparison between two different case of SVC scenario

the channel in a really efficient way, thus giving, for any of the configuration selected on the table, a satisfying LP stream bandwidth and, as a consequence, an excellent final video quality. Another way to manage the residual bandwidth for the LP streams could have been to choose a 16APSK 9/10 mode and, considering the 80 channels scenario, to use a 1 Mbit/s HP stream, a 9.343 Mbit/s LP stream and then a 10.343 Mbit/s total bitstream, thus allowing an excellent video quality for the 86% of the service time and still guaranteeing a quite good quality for 98.2% of the time. Finally, in Figure 9 we can see a visual comparison between this last 80 channel scenario (Case B), and the 90 channel scenario reported in table V (Case A) with an almost identical video quality for both the HP and the LP stream. Employing the SVC coding in satellite television broadcasting should allow to exploit the channel capacity with more flexibility, thus enabling to manage the service time in relation with the final video quality we want to guarantee during a rain event.

C. Scenario 3: Adaptive Coding and Modulation - ACM

The last scenario we evaluated refers to a professional broadcasting system aimed to distribute the HDTV contents to the local terrestrial transmitters. For this system we assumed the exploitation of a return channel as a feedback for the channel conditions, thus employing the ACM modality of the DVB-S2 standard in order to dynamically adapt the bit-rate availability of the transponder, as a countermeasure to the

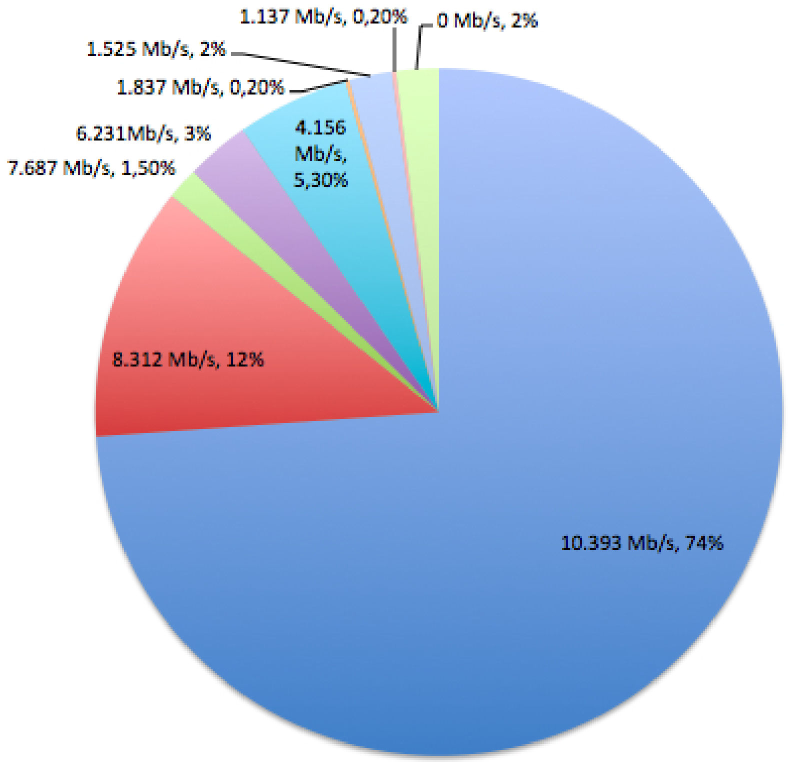

Fig. 10. Possible distribution of the single channel bit-rate values during a rain event (employing ACM)

attenuations of the satellite link. Given a fixed number of channels for this scenario, what happens is that for each attenuation level the system automatically switches to the most efficient mode able to guarantee a QEF bitstream, and thus every time the mode changes the available bitrate available to transmit for each channel changes accordingly, always ensuring the best video quality for the transmission. Considering a number of HDTV channels equal to 160, we show in Figure 10 a possible distribution of the values assumed by the single channel bit-rate during a rain event; as we can see, for most of the time (about 86%) we can assume an excellent video quality (bit-rate greater than 8 Mb/s), and also for the rest of the time the video quality can still be considered good in the average (bit-rate greater than 1.1 Mb/s).

To conclude, given the fact that an HDTV broadcast over W-band frequencies seems to be reasonably feasible, we can state that the number of channels available for a single 500 MHz W-band transponder is considerably higher than the average number of channels given by the typical 33 MHz Ku-band transponder (5 - 6 channels or less), and this is basically due to the huge amount of bandwidth available in this spectrum portion. Moreover, as we saw, broadcasting services can be further improved by using innovative techniques like scalable video coding and ACM modality, thus letting us exploit even better the channel availability to obtain more channels and higher video quality.

VII. CONCLUSIONS

In this paper, we have investigated the possibility of using the W-band for HDTV satellite broadcasting. The analysis includes the propagation issues and link impairments of a 92 GHz GEO satellite link. Three HDTV broadcast scenarios have been considered, according to the DVB-S2 standard: the Constant Coding and Modulation (CCM) scenario, the Variable Coding and Modulation (VCM scenario) and the Adaptive Coding and Modulation (ACM) scenario. Simulation results show that a HDTV broadcast service can be effectively supported by W-band transmission providing a maximum link availability of 98%. The estimated number of available HDTV channels varies on the basis of the selected technique for modulation and coding. The large bandwidth availability in the W-band allows for a more efficient management of the tradeoff between spectral efficiency and video quality so as to exploit in an optimized way the flexibility of DVB-S2, in particular when the ACM scenario is considered.

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