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# Next Generation High Throughput Satellite System

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***Abstract*— This paper aims at presenting an overview of the state-of-the-art in High Throughput Satellite (HTS) systems for Fixed Satellite Services (FSS) and High Density-FSS. Promising techniques and innovative strategies that can enhance system performance are reviewed and analyzed aiming to show what to expect for next generation ultra-high capacity satellite systems. Potential air interface evolutions, efficient frequency plans, feeder link dimensioning strategies and interference cancellation techniques are presented to show how Terabit/s satellite myth may turn into reality real soon.**

***Index Terms*—Terabit, HTS, multi-beam, broadband, IMT,**

## I. INTRODUCTION

Broadband satellite services are showing a significant grows year by year, thanks to the relevance of broadband satellite solutions in areas unserved or underserved by terrestrial network to promote social inclusion (2020 European Strategy [1]). The first generation broadband satellites such as iPSTAR, WildBlue I or SpaceWay 3 was providing total capacities up to 20Gbps in a first attempt to make satellite communications suitable for broadband market. The 2nd generation of Ka-band satellites (i.e. Ka-Sat, Viasat-1) is achieving an economy of scale thanks to higher Frequency Re-use factor (FR) allowed by multiple narrow satellite antenna beams and higher spectral efficiency modulation and coding schemes reaching total capacities from 70Gbps to 140Gbps. Further more Fade Mitigation techniques (FMT) such as Adaptive Coding and Modulation (ACM) allows to cope with the variable rain attenuations impairments characterizing the use of Ka-band. The challenge still remains for next generation systems, as IP traffic nearly doubles every two to three years [2]. In order to follow the trend of terrestrial networks in terms of peak data rates and service cost and to cope with the economic and technical demands of the market, it is necessary to further improve broadband satellite systems capacity and to reach or go beyond the Terabit/s satellite (as tackled in [3], [4]).

To remain competitive, the cost of satellite services shall drastically decrease (cost/Mbps). To achieve this goal, the logical way is to increase satellite capacity by both increasing the usable bandwidth and further improving system spectral efficiency.

When trying to improve system throughput, a trade-off exists between the increase of the satellite power in order to enhance spectral efficiency and the increase of usable bandwidth. In Fig.1, we compare the capacity increase in two cases: increase in power at constant bandwidth, thus improving spectral efficiency using higher ModCods (case 1), and proportional increase in power and bandwidth thus keeping the same ModCod (case 2). The increase in power and bandwidth leads to capacity gain 6.6 times greater than an equivalent increase in power at constant bandwidth. (DVB-S2 ModCod performances are considered [5]). Thus, it is clear that the first objective when trying to increase capacity is a quest for bandwidth. This has been a clear trend in the past decades, moving satellite operation frequencies up to Ka-band and beyond in order to make use of larger available bandwidths. Along the same line, Frequency Re-use strategies and optimized frequency plans in multibeam architectures play an important role when it comes to make the best possible use of bandwidth resources. Next, once spectral resources are maximized, increasing power is to be considered to optimize system performances by means of improving system EIRP, either enhancing antenna gain or further increasing transmitted power. In an attempt to identify what to expect for fixed

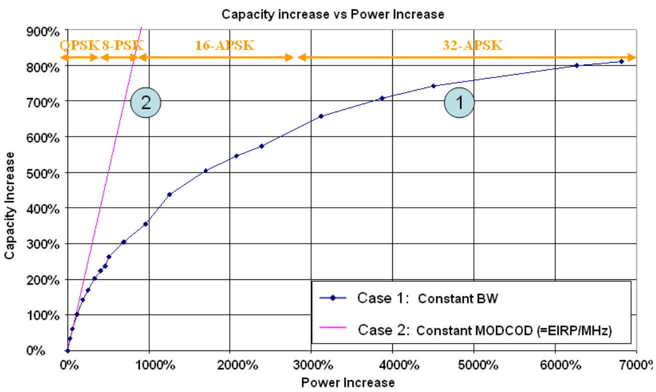


*Fig. 1. Capacity increase vs power increase for DVB-S2 standard performances*

broadband satellite systems in the coming years, this paper aims at identifying potential innovative system solutions that may lead us even beyond the challenging Terabit/s.

Section II tackles the state-of-the-art in terms of spectrum allocation for FSS services, the relevance of smart frequency plans and Frequency Re-use strategies, feeder link dimensioning, specifics on air interface and the promising Interference Mitigation Techniques. Further work and conclusions are presented in section III.

## II. WHAT'S NEW ON HTS BROADBAND SYSTEMS?

### A. *Spectrum allocation for FSS/HD-FSS*

As described in section I, system capacity increases linearly with the amount of available spectrum (at constant EIRP density values). This simple assessment is one of the key design drivers of broadband FSS systems. Frequency plan shall comply with the regulatory constraints as identified by ITU worldwide, CEPT in Europe and also the different national authorities. The second generation of HTS satellites achieves capacities in the range from 10Gbps to 100Gbps by using Ka-band, where more bandwidth is available and with fewer coordination issues (with respect to more exploited lower bands). However, only 2x500MHz is exclusively allocated for FSS which clearly is a limiting factor when trying to significantly improve total system capacity.

Nonetheless, as presented in [3], [4] and [6], the trend is going towards the use of full Ka for user links and shifting feeder link to higher bands such as Q/V-band. The main idea behind is to allocate the shared Ka-band spectrum to user links (otherwise occupied by feeder links), increasing the available downlink user bandwidth from 500MHz up to 2.9GHz per polarization. Fig 2 shows CEPT Ka-band downlink segmentation ([6], [8], [9], [10]). It should be noted the 2.9 GHz considered bandwidth takes advantage of the Ka-band extension (17,3GHz – 17,7GHz) allocated to FSS in primary basis only in Region 1. A 2.5GHz bandwidth is available for user uplink, with 1.2GHz exclusively allocated for FSS services.

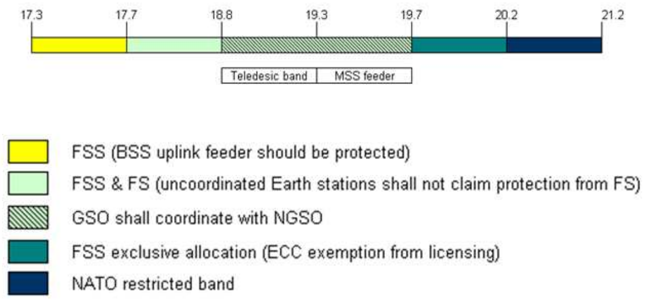


*Fig. 2. CEPT Ka-band downlink segmentation in 17.3 – 21.2 GHz*

Moving to Q/V-band for feeder links allows locating the gateways within the service area there non more risk of interference between feeder and user links. In addition, there is a larger amount of potentially available spectrum. On the other hand, the main limiting factor for the adoption of Q/V band is the fading due to atmospheric phenomena (mainly rain, but also clouds, gasses and scintillations), which is much higher compared to Ka and Ku bands. The lack of maturity of Q/V-band technology is also a limiting factor to fully exploit this band, even if more and more work is carried out by manufacturers to develop reliable and cost efficient equipment for next generation systems.

A total of 5GHz in uplink and 4GHz in downlink are available

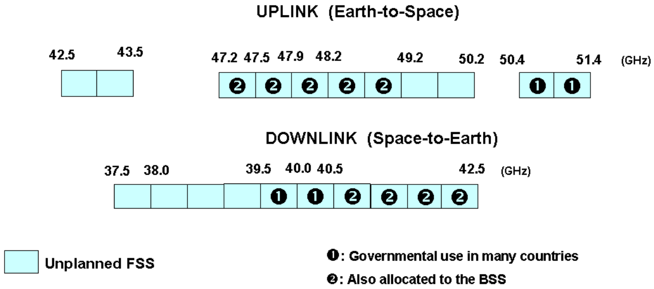


*Fig. 3. Q/V-band segmentation at ITU level*

in Q/V-band, as stated in [12] and depicted in Fig.3.

Considering the use of both circular polarizations (RHCP and LHCP), up to 10GHz are thus available per ground station for the feeder uplink.

### B. *Frequency Re-use and Frequency plan*

The allocated frequency band does not correspond to the only available system bandwidth resource. Multibeam coverage permits to reuse several times the same frequency/polarization sub-band and so allows increasing the usable bandwidth significantly by the same amount. The way to increase frequency resource seems unlimited by just increasing the number of beams, but it has a practical limit due to satellite antenna limitations in size, pointing accuracy and inter-beam isolation.

When it comes to select the appropriate FR pattern for broadband FSS systems, several trade-offs should be taken into account depending on system requirements knowing that in any case, there is no generic or unique solution. If the goal is to increase final user data rates, it seems logical to think capacity density per $Km^2$ must be increased. To reach this goal, we can reduce the beam width having narrower spot beams with higher gain (subject to antenna design and power limitations) or we search for FR patterns with the highest BW/beam allocation (or both). FR patterns of 3 or 4 colors are well-known conventional solutions which have been applied in recent real systems. The 3-color pattern considering systems with considerably smaller beam sizes, can be significantly penalized by inter-beam interferences and higher complex payload, even if more BW can be assigned to each beam. The 4-color pattern is also penalized by interference budget but

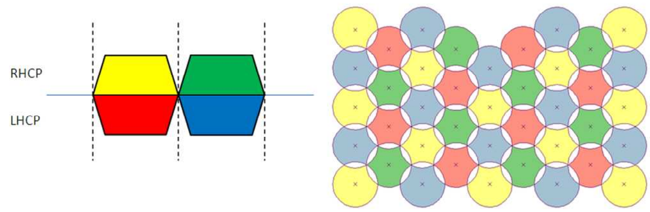


*Fig. 4. Generic 4-color frequency re-use pattern*

keeps the inter-beam minimum distance constant between all same-colored beams, band fragmentation process is simpler and thus, payload design less complex. Other patterns such as 6, 7 or 12 (or greater, as can be found in mobile terrestrial networks) allow getting a larger inter-beam isolation but have two main drawbacks. First, less bandwidth per beam is available, thus yielding to significant reduction in total system capacity, and in addition regarding spectrum regulation, operators may not be ready to consider sub-bands without any exclusive part of spectrum. With these constraints, efficient bandwidth fragmentation and payload design yield to increasing complexity compared to what can be gained in terms of interference budget and overall performance. In [3], [4] and [6], 4-color re-use pattern has been considered. It should be noticed antenna design capabilities (beam shape, lower side lobes, and pointing accuracy) play a key role when considering a specific FR pattern for a given system.

Other strategies such Interference Mitigation Techniques (IMT) for broadband satellite systems (discussed later in sub-section D) aim at improving further system capacity, thanks to full frequency re-use schemes enabled by terrestrial interference cancellation MIMO (Multiple Input Multiple Output) techniques.

Once FR pattern is established, the frequency plan must be carefully defined as it has a direct impact on payload design, feeder link dimensioning and overall system performance. In [5], a smart frequency plan is presented which aims at reducing the total number of GW stations by allocating part of Ka-band spectrum within the 27.5 – 30GHz band to the feeder uplink (in addition to the V-band spectrum already allocated to the feeder links). Thus, each GW station can serve more beams and this allows reducing substantially the total number of GW stations (significant issue in next generation HTS systems). In [4], the frequency plan presented aims to optimize the impact on payload design by reducing the number of forward link frequency converters. Half of beams have different BW assignation but the same EIRP density per beam is assured considering two classes of HPA on-board.

All in all, when it comes to define the optimal frequency plan, system requirements, payload complexity and regulatory constraints will be the key design drivers to come out with the most suitable solution.

### C. *Feeder link dimensioning*

As discussed in section A, in order to have a full Ka-band user link, feeder link must be shifted to Q/V-band so as to be able to locate all GW within the service area.

Operating at higher band implies fighting against much higher propagation impairments than in Ka or Ku bands. To ensure an acceptable overall link availability requirement (e.g. around 99.7%), feeder link availability larger than 99.9% should be considered. With such high availability requirement, the use of diversity techniques is the sole option as static margin for a single GW station should be larger than 15dB for Q-band and 22 dB for V-band (e.g. over EU) (see Fig. 5).

A feeder link sizing with such margins would lead to very high cost and possibly unrealistic solutions. Besides, as the number of beams increases and thus the total equivalent bandwidth, the number of feeder stations needed to serve all beams increases. Indeed, when coping with Terabit/s-like scenario, as seen in [3] and [4], several tens of feeder stations must be deployed. Hence, smart diversity techniques to cope with large fades should be considered to provide more efficient solutions than classical approaches with one-to-one redundancy for systems with a single or limited number of GW stations.

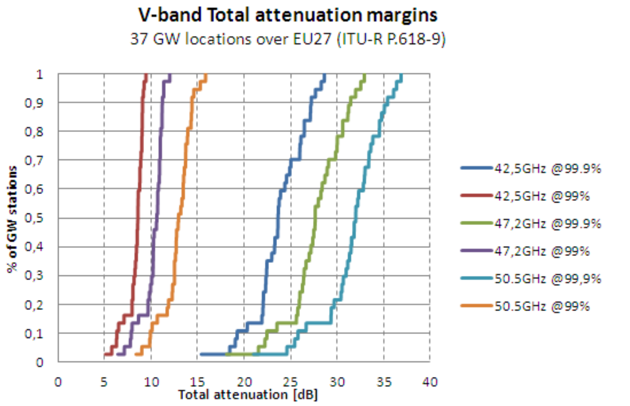


*Fig. 5. CDF Total attenuation of V-band frequencies (99% and 99,9% single GW availability for 42,5, 47,2 and 50.5GHz)*

Among site diversity techniques, one of the most interesting is N+P diversity, considered in [3], [4] and [6]. This technique allows achieving the desired availability by adding P redundant GWs to the N active ones. In case of propagation impairment of one of the active GW, all traffic is rerouted to one of the P diversity gateways and restored after the fading phenomena. The additional gateways are deployed far away enough from other gateways in order to ensure proper decorrelation of rain fade. Thus, all ground stations must be inter-connected by a terrestrial network to the backup GWs. As an example, this allows to obtain a system feeder link availability larger than 99.9% with single GW like availability of 99%, as described in [5]. As seen in Fig.5, this leads to a required attenuation margin more affordable, between 5dB and 15dB, even if still considerably large. Note that each beam is only served by a single GW at a time, either active or back-up.

Smart site diversity concept is a FMT technique based on the interconnection of a sub-set (or all set) of GW stations in order to allow efficient routing of feeder link traffic if site diversity is required to mitigate heavy rain fade occurring on a given feeder link. Compared to conventional site diversity a limited number of backup GWs is required. This concept was firstly introduced in [13], and has been revisited with the emergence of the Terabit/s concept (e.g. [14]). Three possible approaches for implementing smart diversity can be identified. The first one takes advantage of the spatial diversity by serving each beam with a pool of GW. When a feeder link becomes unavailable, only a part of beam capacity is lost and the impacted users are possibly reallocated within the resource managed by another GW (offering a graceful degradation mode, as shown in Fig.6). In this type of scheme, beams could to be served one after the other or simultaneously, which corresponds to time or frequency multiplexing approaches. In [14], full N-active smart GW diversity by means of frequency multiplexing has been analyzed based on the scheme shown in Fig.6.

The second approach also consists in serving each beam by a pool of GW. In this case, each GW link is oversized w.r.t. to clear sky requirements. When a fading event occurs on a given GW feeder link, the other GWs use their in-excess resource to substitute the faded one.

Finally, in the third approach, each beam is served nominally by a single GW. The GW link must be also oversized so as in case of a given GW feeder link outage, the other GW make use their extra resources to serve the unavailable feeder link as in the previous approach.

On-board connectivity, however, can become an issue as payload complexity increases significantly when each user beam is linked to more than a single GW. Besides, as the number of GW in the pool increases, a related reduction in carrier bandwidth is required, this may lead to payload collateral performance degradation (guard bands, channelization, sensitivity to payload noise, etc). In fact, a trade-off between connectivity requirements and payload complexity, using a large GW pool, and potential capacity loss using smaller pool should be considered for some of these approaches.

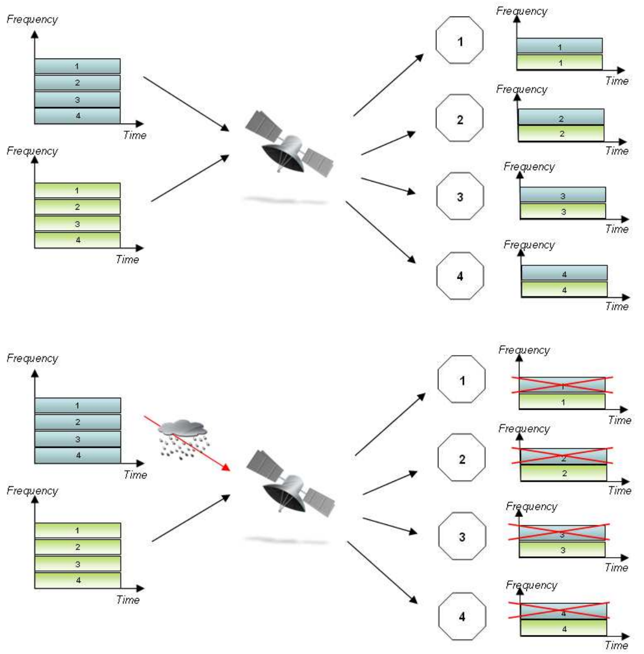


*Fig. 6. Smart Gateways techniques – First approach.Frequency multiplexing*

Further research needs to be done on these issues, as HTS systems will require a large number of GW stations, and cost-effective solutions, full-filling availability system requirements, are necessary to cope with those challenging scenarios.

### *D. Interference Mitigation Techniques*

Interference Mitigation Techniques based on MIMO information theory have been investigated and results show great potential in terms of overall enhanced capacity and performance when applied to broadband satellite systems. The aim of these techniques is to cope with the interference issues resulting from the increasing number of beam trend in HTS like scenarios, but also offers a more important benefit, that is allowing the implementation of full FR pattern. The analogy between Multi User MIMO –Broadcast channel and the FWD link in FSS system allows transposition of these terrestrial techniques to a satellite broadband framework. Receiver-based techniques have also been studied for the return link. As for the FWD link, an analogy also applies regarding MIMO – Multiuser Access Channel (MAC) (uplink from multiuser to one receiver) which can be associated to the so -called Multi-User Detection (MUD) techniques.

An initial study applying MU-MIMO precoding in broadband satellites systems was carried out in the frame of an ESA study. Precoding is defined as any kind of pre-processing applied to the signal at the transmitter in order to cancel the interference produced by the channel. In particular, these techniques are based on the joint encoding of all co-frequency carriers transmitted by a GW to the set of considered beams in order to minimize the mutual interference that each user will experience from the other co-channel beams. As the transmitter knows the interferer signals, is able to pre-substract them before transmission. Adding some form of ”pre-equalization”, thanks to Channel State Information (CSI) fed back from return link to the transmitter, user terminals are almost not affected. In theory, this technique could allow full frequency re-use provided that interference known at the transmitter can be pre-subtracted in principle. Practical implementation though, is not that simple.

The objective of that initial study, also summarized in [15] and [16], has been to assess performance gain through linear precoding which is, in all its forms, a sub-optimal MU-MIMO precoding technique derived from the capacity achieving Dirty Paper Coding (DPC - [17]). The potential of Precoding has been demonstrated, achieving significant spectral efficiency improvements, from 25% to 50%, more gain being achievable depending on the specific system assumptions. Other studies have been conducted at latter stage, proving the interest of joint precoding and on-ground beam forming [18] or techniques like Multibeam Opportunistic Beamforming (MOB) [19]. The later jointly extract Multi-user gain and MIMO benefits, choosing at each moment, the best user terminal to be served (better SNIR), not randomly as assumed in initial studies. Hybrid space-ground processing has been also assessed in [20], aiming at finding a better balance between performance and payload complexity. One of the main drawbacks of all linear techniques is the resulting large variation in transmitted signal Peak-to-Average Power Ratio (PAPR) which plays a role in the performance degradation due to HPA non-linarites.

Non-linear precoding techniques attempt to solve this problem adding additional signal processing [21], improving BER performances. For instance Tomlinson-Harashima precoding (THP) reduces the PAPR of the transmitted signal, at expenses of increased implementation complexity.

No matter which solution is considered, it is feasible in practice if the same GW manage the set of beams suffering from mutual interference. Otherwise, the transmitter would have no knowledge of signals transmitted in the other beams signals in order to carry out the encoding procedure. In the scope of Terabit/s satellite systems, a constraint may appear because of the high number of GW that are needed and the limited number of beams being served by each one. Being more specific, between 6 and 10 beams per GW, assuming frequency plans presented in section B. Nevertheless, as high capacity links between GW are already required to implement the smart diversity strategies, thus joint coding could be extended thanks to the cooperative joint processing among all GW. A full-frequency re-use scheme all over the service area could be considered, leading to a remarkable increase in system capacity.

Concerning the reverse link, two interesting studies have been carried out coping with ACI mitigation and IMT for wideband FSS satellite systems. Both studies are also related to the ESA study mentioned before. In [22], ACI mitigation in TDMA based satellite return link is assessed by means of Turbo-Interference Cancellation. The aim of this Iterative Interference Cancellation (IIC) technique is to reduce carrier spacing allowing to increase system throughput for a given bandwidth. No spatial processing exploitation is considered in this case so it can be also applied in single-beam systems. Results have shown spectral efficiency improvements up to 60% going down to spacings as low as 0.5Rs with respect to more conventional carrier spacing (e.g. 1.2Rs/1.3Rs considering spacings between carriers of 0.2/0.3 times the symbol rate). All processing is centralized at the GW station and thus, there is no impact in user terminal software/hardware.

In [23], MUD-IMT techniques specifically devised for multibeam system scenarios are described, thus exploiting spatial processing. In particular, two techniques are studied: the spatial MMSE (Minimum Mean Square Error) processing and Spatial MMSE-SIC (Successive Interference Cancellation). The principle is to jointly process all co-channel carriers received from the beams allocated to the same GW thus, allowing full FR strategies or cluster based ad-hoc frequency plans, as in precoding techniques for the FWD link. In the same way, only it is feasible if the same GW manage the set of interfering beams. Both techniques require precise channel estimation (CSI) as they are based on an optimal linear MMSE matrix filter (channel matrix H must be well-known). MMSE-SIC improve the spatial MMSE technique by cancelling successively the contribution of each well-demodulated/decoded UT from the received signal, beginning with the one having the highest SNIR. Thus, at each process step, the filter is recomputed and MMSE filtering shall only compute one UT at the time.

Reverse link IMT techniques show great potential and important spectral efficiency gains, being higher than 60% depending on the scenario considered. However, some aspects should still be refined as e.g. the optimization of packet scheduling algorithms, selection of appropriate decoding order of MMSE-SIC and improvements on system total availability.

IMT techniques applied to both Forward and Return link of multibeam FSS satellite systems have been overviewed in this section. Further research still needs to be done in this promising field which has the potential to significantly boost tomorrow's satellite performances. Some critical aspects though, should be carefully taken into consideration:

- PAPR of the transmit signal and the impact on single carrier HPA operation mode (large variations can imply operation with some output back-off and thus, carrier power reduction).
- Limited on-board power, mass and accommodation yields to limitation in terms of HPAs, when dealing with full-frequency re-use in large networks with multi-GW precoding
- Trade-offs between capacity and availability requirements
- Synchronization and time recovery issues before channel can be estimated and interference cancellation started.
- GW scheduler strategies modification to be in line with precoding techniques
- On-ground and on-board complexity considerations

### *E. Air Interface*

DVB-S2 air interface standard has been proven to be a reliable and effective solution for satellite broadcast/broadband systems. The introduction of efficient FMT techniques, such as ACM, allows optimizing the transmission parameters for each individual user, dependent on path conditions, enlarging the SNR dynamic range and so, being more adaptable to propagation phenomena and increasing the overall system spectral efficiency and availability. In the last year, recent advances and innovative techniques summarized in [24], are being proposed in DVB group in order to push further S2 performances (most of them applicable to RCS), aiming at a "DVB-S2 evolution" or a new DVB-S3. Some of these advances are presented in the following paragraphs.

*MODCODs extension*

Extending the SNIR range supported by DVB-S2 is of general interest, as the actual lowest modcod, corresponding to QPSK ¼, may be insufficient to cope with deep fading in Ka-band, even worst in Q/V and when operating HPA in multiple carrier. This can lead to unacceptable link availability figures. Different proposals have been presented in order to extent the lowest modcods: either by performing symbol or frame repetition or by designing lower FEC codes. Another approach, in the frame of mobile SAT communications, is presented in [25] which could be considered in DVB-S2 modcod extension. It introduces a new FMT concept called Adaptive Coding, Spreading and Modulation (ACSM) which can accept SNIR values as low as -22dB. Of course, that would entail a PL header enhancement in order to be robustly demodulated at the lowest SNIR value with minimum overhead impact. On the other extreme of the dynamic range, 64-APSK is the natural candidate to enhance point-to-point professional applications. For mass market in next generation HTS, this extension on the higher end will not have a major impact, since it is difficult to close the link budget required to run that type of high order modulation scheme considering typical user aperture sizes (~60-70cm).

Another direction to improve performances would be offering smaller modcod SNR threshold granularity. In fact, quite irregular distance in terms of energy per bit can be observed with current DVB-S2 modcods (from few tenths of dB up to about 1.4dB, over linear channel). Gaps may be even wider considering synchronization impairments and non-linearity impact. Introducing more FEC code rates to fill these gaps would certainly increase capacity gain, although the impact of ACM margins should be further analyzed.

*Smaller Roll-off waveforms*

Standard solution today uses a transmit carrier roll-off of 20%. Aiming to increase the spectral efficiency, one straightforward solution is to reduce DVB-S2 roll-off factor down to 10% or even 5%. This can lead to spectral efficiency improvements from 10% to 15% with respect to the current standard. Some low roll-off solutions are already available on the market and it is expected to integrate them into the standard soon, as no major impact in the standard is involved.

*Wideband carrier operation*

DVB-TM-S2 group has been working lately on wideband satellite transponders aiming to increase baud rates up to 200/500 Mbaud. This proposal aims to achieve more efficient payload operations, being able to work in a single-carrier mode or reducing OBO requirements on wideband HPAs. Indeed, HPAs are typically optimized to work at saturation where better efficiencies can be obtained. In legacy systems, carriers of typically 36MHz or 72MHz have been usually considered mostly due to technological limitations in user terminal chip-sets processing capabilities. Recently, Wideband HPAs in Ka-band are being developed, achieving reasonable efficiencies with amplifiable bands from 1GHz up to 3GHz. However, operating this wideband HPAs with such “narrow” carriers certainly requires significant OBO which degrades total power budget. Thus, even though a certain OBO will still be required working with wideband carriers on wideband HPA, an improvement on HPA efficiency can be expected.

Working with high baud rates (200/500 Mbaud) implies user terminals must be capable to demodulate and decode large carriers. In fact, one of the main drawbacks being identified is the FEC decoding. In actual DVB-S2, each user terminal must decode all physical layer frames in order to reach either the generic stream or the MPEG-stream, carrying their own specific packets. As no state-of-the-art (neither mid-long term) chipset is capable to decode in real-time the proposed wide carriers, “time-slicing” approach is being considered in order to tackle the problem. This means user terminals have only to entirely decode certain PL frames (PL slice), identified by a stream identifier (SID) coded within PL header.

These solutions entails modifications of the standard, still being under investigation by DVB-TM, as PL header must be coded robustly enough and carry some more information than the actual header.

*Time and Frequency packing*

Time and frequency packing techniques aim to increase spectral efficiency by compressing in time and frequency the signaling waveform. This is achieved by reducing the spacing in both time and frequency domains between adjacent signals. Hence, controlled ISI and ICI interferences are introduced but at the same time making a better use of the available time and frequency resources.

The time-only variant signaling technique, also known as “Faster than Nyquist” (FTN) was developed in the 70s but there had not been extensive work either developing algorithms for FTN or realization on devices for practical usage until recently. Initially, this applied to a single carrier system with pulses overlapping with each other in time. Later it was extended to multicarrier systems (e.g. OFDM) where the least required spacing (following Nyquist transmission for ISI free transmission) could be violated both in frequency and time.

In order for these techniques to be effective, a receiver able to cope with possibly very large interferences is assumed. Indeed, the main drawback of these techniques relies on the complexity of the receivers. In [27], a time-frequency packing technique is proposed with a low-complexity receiver (based on successive interference cancellation principle) and it is demonstrated that orthogonal signaling can be largely suboptimal from the spectral efficiency point of view, above all, for low order constellations (e.g. QPSK). Indeed, considering DVB-S2 evolution framework, time-frequency packing provides a gain that could enable the adoption of low-order modulation formats for higher spectral efficiency values: all QPSK, 8-PSK and 16-APSK ModCods could be replaced with ModCods based on QPSK showing better performances (more robust to non-linear effects and to synchronization errors, although PAPR increases). Despite these promising results, the application of these techniques must be further studied in order to reduce receiver complexity, to design demodulator, synchronization and equalization algorithms to limit the bit energy loss and optimize signaling scheme on a linear and no-linear channel (and for a large range of spectral efficiencies present in DVB-S2), among others.

## III. CONCLUSION

In this paper we have reviewed the state-of-the-art on HTS system features, techniques and innovative solutions which have the potential to further enhance broadband satellite systems performance to reach or go beyond the so-called Terabit/s satellite.

Moving feeder links to Q/V-band allows user links to fully use Ka-band, thus achieving a step forward in total system spectrum availability. However, feeder link dimensioning becomes much more complex, as tens of GW stations must be deployed to serve hundreds of narrow spot beams. In order to ensure the required system availability, smart diversity techniques become a must to counteract heavy propagation impairments in Q/V-band. The use of appropriate FR schemes and optimized frequency plans is of vital importance to further optimize spectral resources and payload complexity.

Due to the increased number of beams and the reduction of their size, promising IMT techniques attempt to bring solutions in order to cope with more and more interference limited scenarios and open the possibility to full FR schemes and other new scenarios which can significantly boost overall system capacity.

Finally, the possibility to get closer to Shannon limit, further improving air interface, has been also tackled. Innovative techniques and appropriate modifications are being currently studied to push further S2 performances, going resolutely towards a new DVB-S3.

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