VALIDATION OF DVB-S2 SYSTEM PERFORMANCES WITH ACM

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Abstract

This paper presents the results of in-depth validation of a DVB-S2 [1-3] system with ACM, using a laboratory demonstrator developed under a European Space Agency Artes 5 contract “ACM Modem” [4]. The reference scenario used to define the test cases consists of a multi-beam Ka-band satellite system, representative of future systems to provide broadband access by satellite at a low cost and with high service availability, made possible with the DVB-S2 standard. The demonstration platform is based on a commercial gateway and terminal, which modulator and demodulator have been adapted to include DVB-S2 and ACM functionalities and detailed test points, a two-way satellite channel emulator, IP traffic generators and analysers and a control & monitoring station for test automation.

1 Introduction

The recent emergence of satellite multi-beam systems for broadband services have emphasised the importance of optimising the physical layer efficiency. In this perspective, the introduction of DVB-S2 with ACM feature has been a key factor for reducing the cost per transmitted bit – and increasing the number of subscribers per satellite transponder – whilst improving the link availability. For these reasons, most broadcast and interactive satellite systems, including proprietary implementations, are moving to DVB-S2 technologies.

The main objective of the ACM Modem test campaign is to characterise and evaluate the performance of DVB-S2 and ACM links in a large number of configurations. After detailed measurements of the physical layer performance, to determine in particular the QEF thresholds and the effect of various satellite channel impairments onto the link, the tests have focussed on the performance of ACM under a large number of fading conditions and different ACM loop configurations. The results show that significant gains are obtained with ACM and error free links can be achieved in the presence of fading in Ka-band. The impact of TWTA non-linearities has been evaluated with and without pre-distortion techniques. The link performance in the presence of phase noise has been measured for each modulation and coding rate of the standard. It has also been verified that applications with different QoS rules could be correctly transmitted end-to-end when ACM is activated.

2 Reference System

The reference system is based on the DDSO study [5], describing a middle term multi-beam Ka-band satellite system. The system is dimensioned with 100 user beams of 0.4°, with a four colour scheme, on a European coverage (Figure 1). It provides broadband services to consumers and professional / SME users with different classes of terminals. The market targets 3% of the population, with 1000 to 2000 active users per beam simultaneously. The terminals are managed by 7 gateways across Europe, using an extended 2 GHz bandwidth in dual polarisations.

Figure 1: user links beam coverage seen from satellite

The forward link consists of 45 Mbaud DVB-S2 carriers with ACM. The return link uses DVB-RCS signals with FMT (adaptive coding and dynamic rate assignment).

Multi-dimensional simulations have been run to calculate the link budget geographical and time statistics, in order to assess the potential gain of ACM in terms of spectral efficiency and link availability.

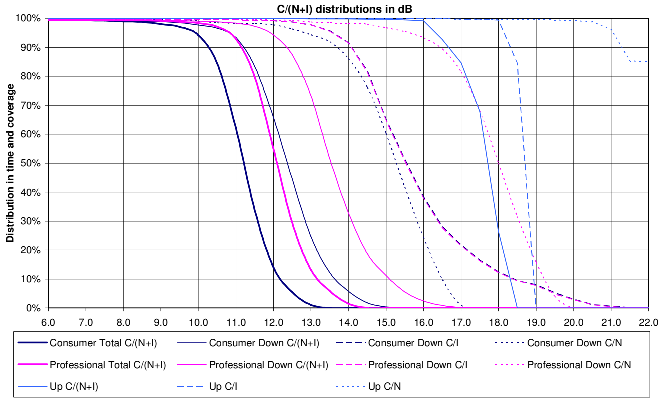
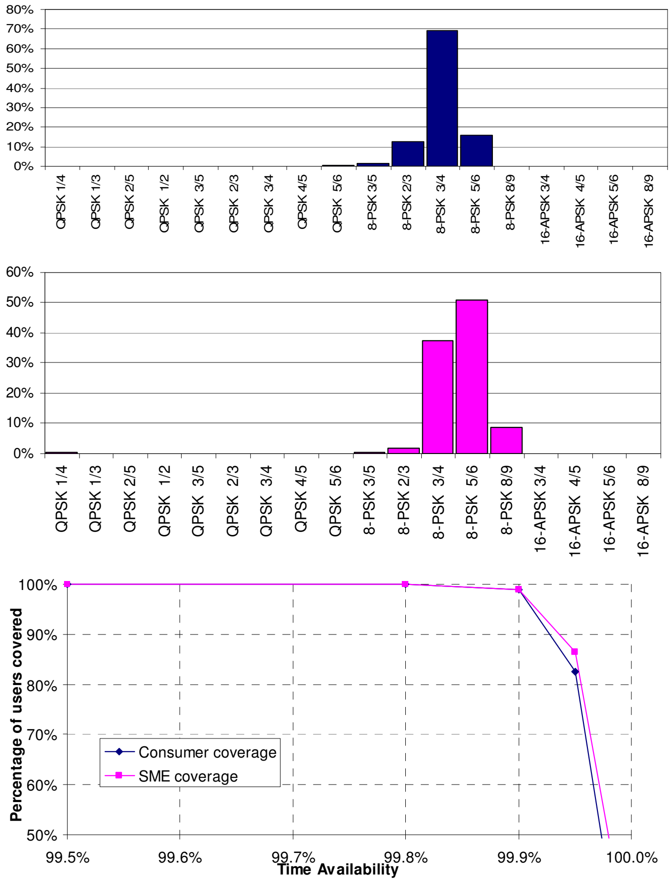


Figure 2: Forward link budget CDF



Figures 3-5: ACM usage histograms and link availability

The simulation results show that:

- Most of the link budget C/N+I CDF values (Figure 2), are concentrated on a 3 dB range
- Consequently, the number of Modcod activated on the forward link can be reduced from 28 down to 4 values (see Figures 3 & 4 histograms) with a limited loss of 2% in terms of spectral efficiency. Having a reduced set of Modcod simplifies the gateway design and improves the forward link encapsulation efficiency.
- Link availability (Figure 5) is very high overall thanks to Modcod 1 low C/N+I threshold at -2 dB

3 Test-bed Description

The ACM Modem demonstrator has been developed by an industrial consortium led by Nera, together with Fraunhofer IIS, DLR, TurboConcept and Astrium.

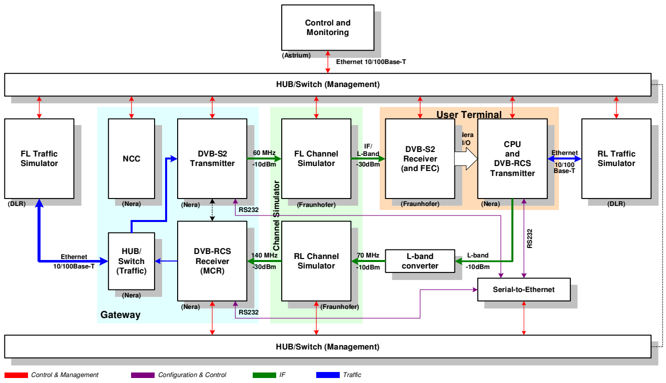


Figure 6: ACM Modem demonstrator architecture

The test-bed is based on the Nera gateway product. Several components have been specifically developed for the project:

- DVB-S2 modulator and demodulator
- ACM functions in the forward link equipment
- IP traffic generator and analyser
- Channel simulator for emulating propagation delay, thermal noise, phase noise, interferers, satellite non-linearities, and fading profiles (pre-calculated C/N+I time series applied in real time)
- Control and monitoring station for test conduction

The demonstrator (Figure 7) includes many test features:

- Demodulator and decoder detailed statistics on frame-by-frame basis
- Display of demodulator received I&Q constellations
- Emulation of other terminals with dummy ACM frames
- Random IP traffic generation with different models
- Test scripting language for automation

Figure 7: ACM Modem demonstrator

4 Test Configuration

The configuration of the test-bed is based on the reference system scenario.

Main settings of the forward link DVB-S2 signal:

- Symbol rate: 10 Mbaud
- Roll-off factor: 25%
- Pilot symbol: activated
- Frame size: normal (64800 bits)
- Modcod available: full set of 28 Modcod defined in the DVB-S2 standard (QPSK 1/4 to 32-APSK 9/10)
- Number of Modcod activated: 4 (reduced set) or 22 (basic set excluding 6 sub-optimal Modcod)
- Mode: CCM or ACM
- ACM margins: fixed (identical for all Modcod), variable (calibrated per Modcod) or adaptive (margin reduced until an error event occurs, then reset)
- Classes of service: signalling, high priority and best effort
- IP traffic: web browsing, file transfer, video streaming, voice, telnet, background traffic

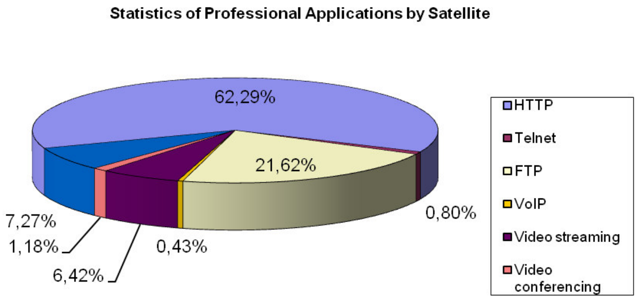


Figure 8: typical traffic data rates

The return link is configured with DVB-RCS signals. AC+DRA mechanisms are activated. Dynamic terminal interference is generated by the channel simulator.

The link budget contributors (thermal noise, intra-beam interference, other types of co-channel and adjacent channel interferers) are configured in the channel simulator, as well as the TWTA non-linearity profiles and phase noise masks.

Several C/N+I time series corresponding to various types of fading events have been generated. More than the actual C/N+I value, their variations in time are particularly important for stimulating the ACM loop. The weights represent the time of occurrence of each event.

Type of event	Weight
Clear sky	50%
Light fading	30%
Moderate fading	18%
Extreme fading	1.9%
Deep fading	0.1%

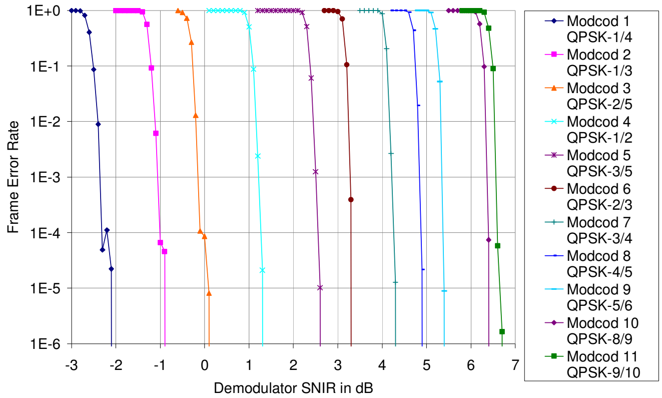
Table 1: Fading events

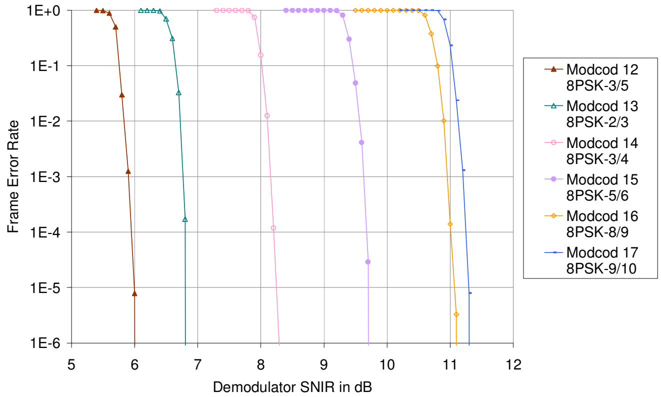
5 Test Results

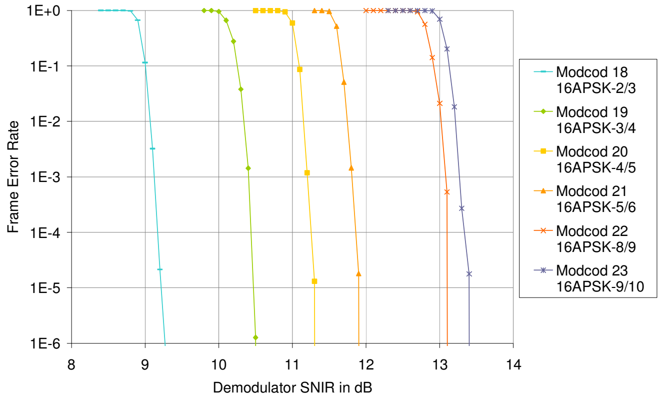
5.1 Performance in CCM mode

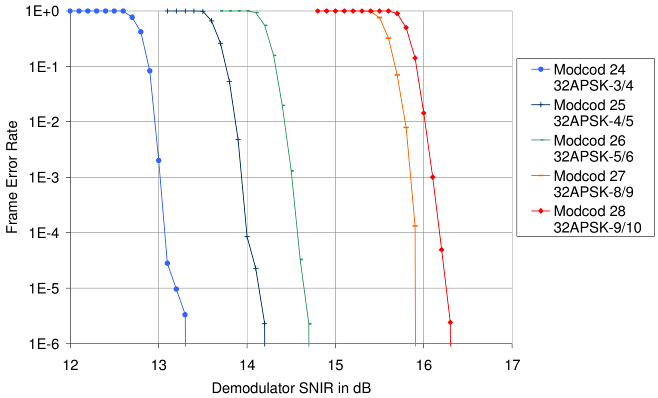
The modem performance has first been measured in CCM mode without channel impairment. Each Modcod has been tested for a target frame error rate of 10^{-6}, which corresponds to the QEF point – approximately 1 error per hour.

The frame error rate vs. Es/No curves are very steep because of the long LDPC codes (64800 bits). This can be interpreted as a pseudo binary behaviour: either the link budget is sufficient to correctly receive the frames, and no error occurs, or the link budget is below the Modcod threshold, and many errors occur due to uncorrectable frames. However, in the presence of high phase noise, an error floor effect has been measured on several Modcod (8-PSK 2/3, 16-APSK 2/3, etc), presumably coming from a weakness of these LDPC codes.









Figures 9-12: Frame error rate vs. Es/No for each Modcod

The modem performance compared to the DVB-S2 standard is summarised in Table 2. The measured Es/No degradation comes from the modem implementation.

Modulation	Degradation
QPSK	0.39 dB
8-PSK	0.53 dB
16-QPSK	0.54 dB
32-QPSK	0.81 dB

Table 2: Es/No degradation at QEF depending per modulation

5.2 Performance in ACM mode

When activating ACM functions, margins have been added for possible variations of the C/N+I values as perceived by the demodulator, during the ACM loop time (1 second). C/N+I variations are mostly coming from the atmospheric conditions in Ka-band and from the demodulator C/N+I measurement accuracy. The calculation of the Modcod consists of the CCM thresholds previously calibrated, plus ACM margin, plus satellite channel margin. The ACM loop changes the Modcod when the up or down threshold is crossed. In order to limit the number of Modcod changes, an offset of 0.3 dB has been added on the up threshold compared to the down threshold, resulting in a hysteresis effect.

On the “extreme fading” time series plotted on Figure 13, it can be observed that the C/N+I up and down variations across 1 second intervals depend on the C/N+I itself. In other words clear sky conditions are more stable that bad weather.

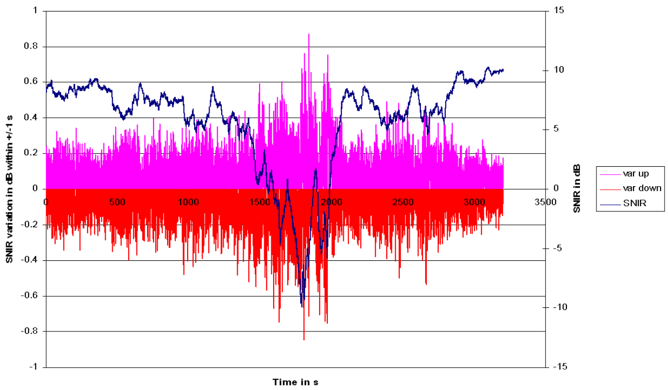


Figure 13: C/N+I time series and variations

Figure 14 illustrates the behaviour of the ACM loop under a deep fading event. After relatively stable conditions, where a few Modcod transitions occur, C/N+I drops sharply and Modcod changes quickly down to the most robust Modcod QPSK 1/4. Conditions become even worse during the 16th minute, where the link is lost. C/N+I then globally improves with up and down variations, and the link is eventually back to the initial conditions. During the fading event, the ACM loop correctly adapts to the link both on up and down transitions. No outage event occurs, in that C/N+I is always above Modcod threshold. The demodulator unlocks when C/N+I is below -2 dB, which should be considered as part of the link unavailability (i.e. the beyond 99.9% domain).

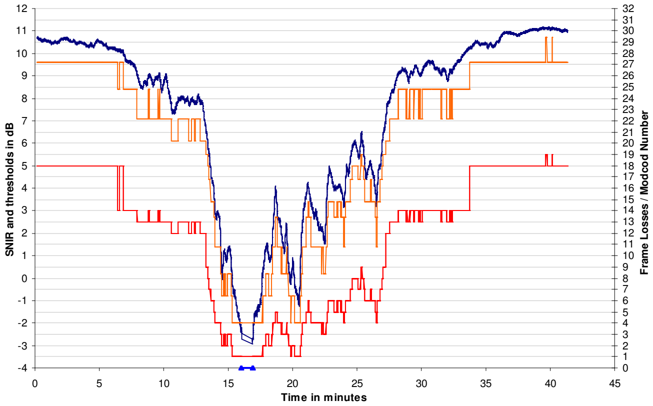


Figure 14: ACM loop adaptation to a deep fading event
Legend: top curve = C/N+I in dB, bottom curve = Modcod number, middle curve = corresponding threshold in dB

ACM performance tests have been run on the combination of time series (5 fading event), Modcod set (basic or reduced) and ACM margins (3 types). Results are presented the three following figures.

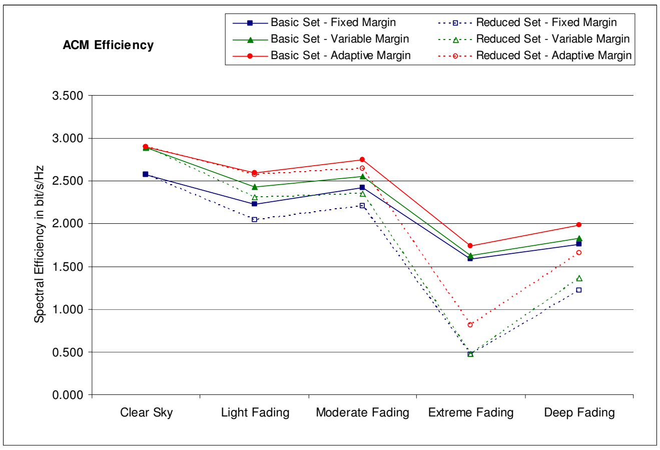


Figure 15: Spectral efficiency in bit/s/Hz

Spectral efficiency is primarily a function of the type of event, and secondly of the Modcod set and type of ACM margin. A fixed margin per Modcod significantly reduces the overall performance, so it is worth calibrating the ACM margin per Modcod.

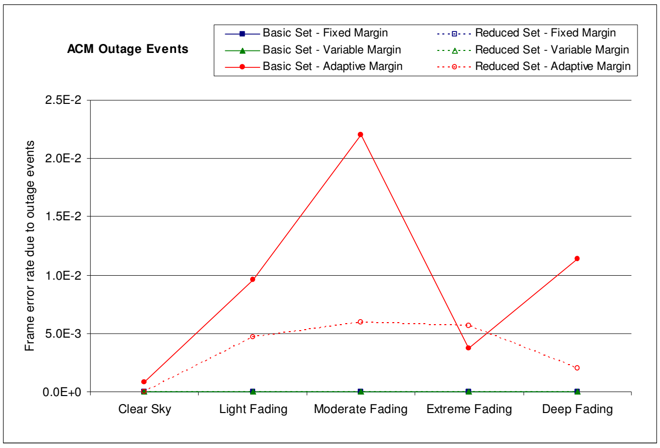


Figure 16: ACM outage events

With fixed and variable margins, assuming they are correctly calibrated, no outage event is encountered. With adaptive margin, frame errors appear when the ACM threshold becomes lower than the CCM threshold. This effect could be limited by a better estimation of the distance to QEF and by putting a low limit on the threshold.

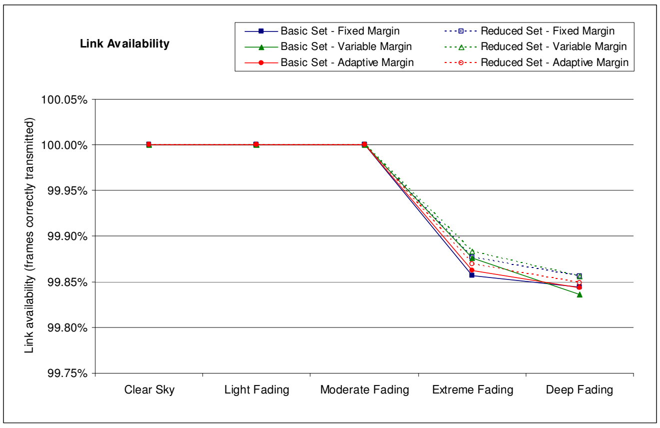


Figure 17: link availability

Link availability is equal to 100% for the 3 first types of fading events tested. It is around 99.85% for the extreme and deep fading events, because C/N+I becomes lower than QPSK 1/4 threshold.

The main results obtained are summarised below:

- With 22 Modcod activated and variable ACM margins, under clear sky conditions, no frame loss occurs and the gain of spectral efficiency is equal to +130 % compared to CCM Modcod 7 (corresponding to 99.9% availability) and to +53 % compared to CCM Modcod 12 (99.7% availability)
- Compared to an ideal ACM loop which would react immediately and without any up/down margin, the measured loss of efficiency of ACM implementation with variable margin is 2.4%
- The measured loss of efficiency when quantising the number of Modcod from 22 to 4 is between 3% and 5%
- With fixed and variable margins, frame error rate due to ACM outage event is below 10^{-7}, which demonstrates that the ACM margins are correctly set
- With adaptive margins, spectral efficiency increases by 3 to 5%, at the cost of a higher frame error rate

5.3 Impact of satellite non-linearities

The impact of satellite TWTA non-linearities with one carrier per transponder has been evaluated on the two AM/AM and AM/PM characteristics of the DVB-S2 standard annex H.7: non-linearised model B1 (Figure 18) and linearised model B2.

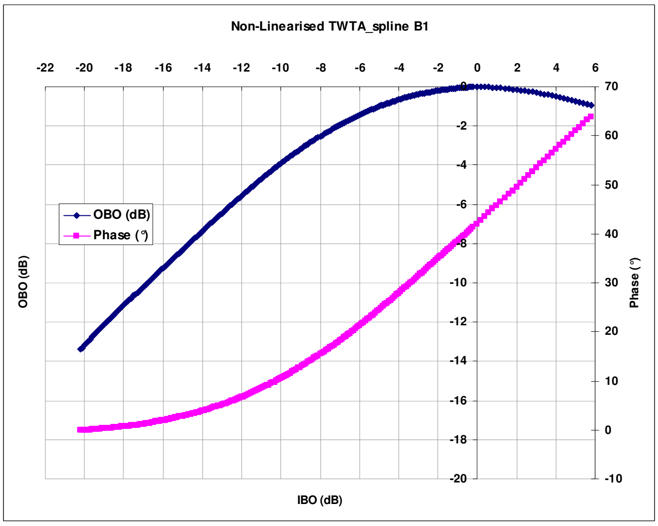


Figure 18: non-linearised TWTA model B1

In order to mitigate the effect of non-linearities and operate close to saturation, pre-compensation has been tested. It is implemented in the forward link modulator with a static memory-less algorithm, calibrated on the characteristics of the TWTA. The pre-compensation function is illustrated by the I&Q constellations (Figure 19).

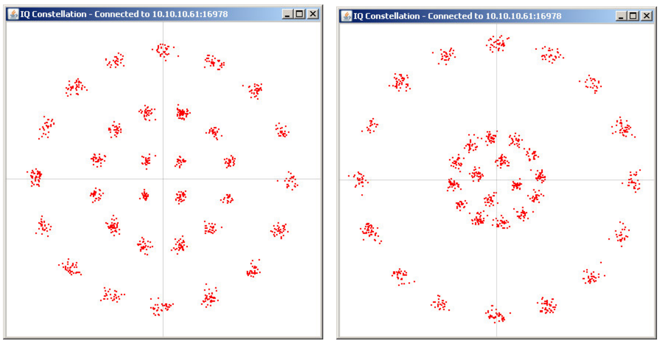


Figure 19: 32-APSK modulation respectively without and with non-linearity pre-compensation

The tests consist in measuring Es/No degradation at QEF, coming from the non-linearities. Because operating below saturation decreases the signal useful power, the metric chosen to calculate the total degradation is equal to the degradation plus the OBO. Figure 20 shows the total degradation measurements for 16-APSK 3/4.

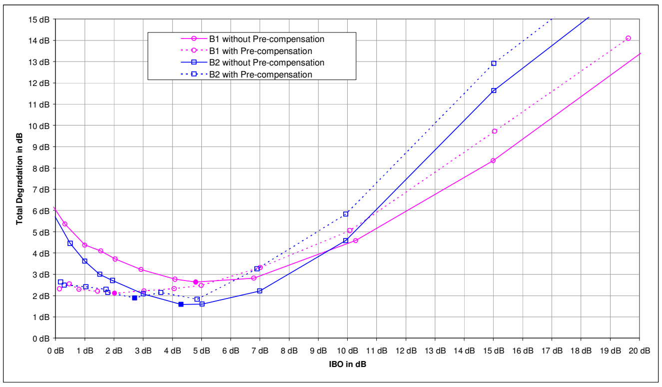


Figure 20: non-linearities total degradation for 16-APSK 3/4

On each curve, there exists an optimum operating point which minimises the total degradation. It is the result of a trade-off between non-linearity distortion and distance from saturation. The total degradation at optimum point for each configuration tested is summarised in Table 3.

	Nonlinearised TWTA model B1			Linearised TWTA model B2		
Modcod	Without precomp	With precomp	Precomp gain	Without precomp	With precomp	Precomp gain
QPSK 1/2	0.2 dB	0.2 dB	0.0 dB	0.2 dB	0.2 dB	0.0 dB
8-PSK 2/3	0.6 dB	0.6 dB	0.0 dB	0.4 dB	0.4 dB	0.0 dB
16-APSK 3/4	2.6 dB	2.1 dB	0.5 dB	1.6 dB	1.9 dB	-0.3 dB
32-APSK 4/5	4.9 dB	7.0 dB	-2.1 dB	3.0 dB	Demod unlock	

Table 3: total degradation at optimum operating point

Interpretation of the results:

- In QPSK and 8-PSK, the TWTA can be operated very close to saturation, because the symbols are on a single circle.
- In 16-APSK, the performance is degraded by the distortions of the outer circle. Pre-compensation gives a 0.5 dB gain for the non-linearised case.
- In 32-APSK, the signal is significantly degraded by non-linearities. The worst degradation is in the case of a non-linearised TWTA. Pre-compensation does not give any advantage in either case. A more sophisticated algorithm with memory would presumably improve the results.

5.4 Impact of phase noise

Several phase noise masks based on the DVB-S2 standard have been tested. Their impact has been measured on each Modcod, by comparing Es/No degradation at QEF with and without phase noise.

Frequency	100 Hz	1 kHz	10 kHz	100 kHz	1 MHz	> 10 MHz
Typical mask	-25	-50	-73	-93	-103	-114
Critical mask	-25	-50	-73	-85	-103	-114
Typical mask +5 dB	-20	-45	-68	-80	-98	-109

Table 4: phase noise masks

The results show that Es/No degradation increases with the level of modulation and coding, i.e. with protection level. The "typical mask +5 dB" significantly worsens the performance.

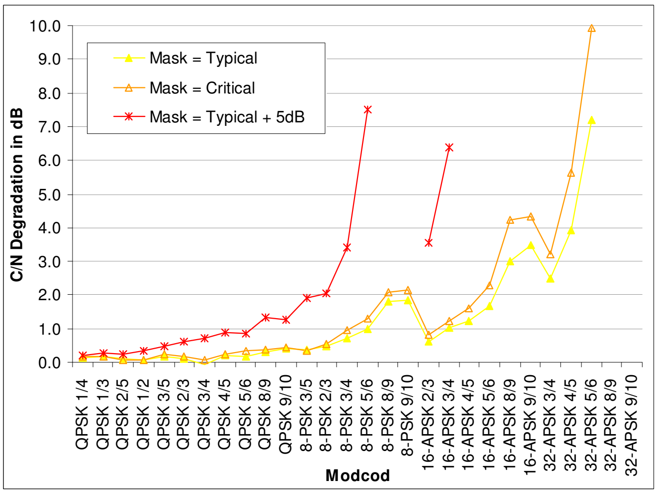


Figure 21: Degradation as a function of phase noise, modulation and coding

5.5 Applications test

An important aspect is to characterise the behaviour and performance of applications together with the variable link capacity coming from ACM. When the capacity is sufficient to transport the applications data rate, then no degradation is measured at IP level: no packet loss, no impact on end-to-end delay and jitter. When the capacity is reduced by 40% compared to the application nominal data rate due to a fading event, through ACM, the impact on the applications depends on the protocol used:

- UDP protocol: approximately 40% of the packets are lost at IP level, also causing delay variations, with different effects on the applications:
  - VoIP is inaudible in reduced capacity. Therefore high priority QoS must be applied to VoIP applications to avoid losing packets.
  - Video-conferencing: for applications able to adapt the video compression to the reduction of capacity, such as Skype, the conference is maintained with a lower quality. For other applications, video frame losses are encountered.
  - Video-streaming: MPEG-4 video is still perceptible under faded conditions, although slightly annoying. MPEG-2 performance is worse at 40% packet losses, provoking artefacts and frozen images.
- TCP protocol: retransmission mechanisms minimises application errors. An impact is measured on delay:
  - FTP: low PER (6x10^{-4} for 1 GByte transfer), slow start and rate adaptation.
  - HTTP and email: download time is typically 45% longer than in guaranteed capacity.

The performance of applications at IP level, together with ACM, is illustrated by Figure 22. In normal conditions, the link is error free. When congestion occurs, due to an ACM change to a more robust Modcod, packets are being lost and the throughput delay increases due to a saturation of the gateway transmit queues.

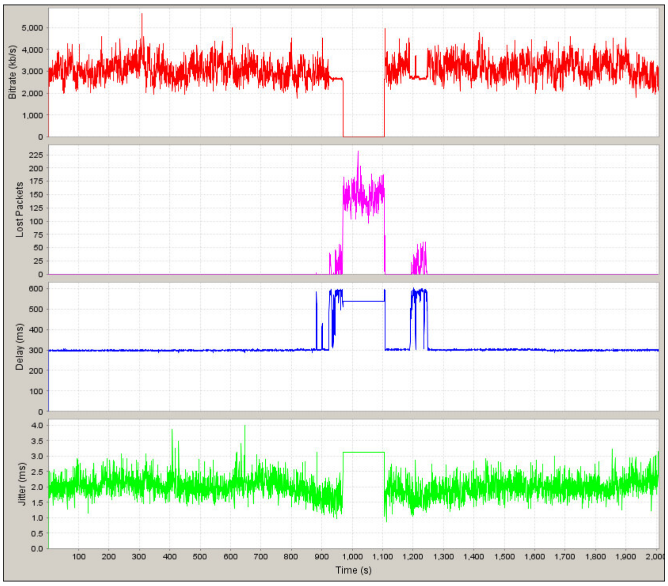


Figure 22: Video streaming application IP statistics during a deep fading event (with congestion) measured with Astrium RIO tool

The correct behaviour of the QoS mechanisms has been verified by transmitting higher priority VoIP traffic together with low priority background traffic. When congestion occurs, VoIP transmission is maintained without any degradation, whilst background traffic packets are dropped.

6 Conclusions

The extensive test campaign performed on the ACM Modem test-bed has demonstrated the importance of DVB-S2 and ACM technologies for the future generation of satellite broadband system, and confirms previous assessment performed by simulations [6]. ACM mechanisms can be implemented at a reasonable cost and complexity on ground segment equipment, especially since DVB-S2 chips with ACM are now produced in mass. The spectral efficiency is largely improved when moving from CCM to ACM, as well as the link availability. In order to optimise the efficiency of ACM, it is important that the terminal has access to an accurate and reliable Es/No estimator for calculating the distance to QEF. It has been shown that a DVB-S2 carrier can be operated close to saturation in QPSK, 8-PSK and 16-APSK, which also improves the overall efficiency of the system.

The next step is to perform test campaigns on real links, which is the object of the on-going ESA project "DVB-S2 Satellite Experiment" [7].

Acknowledgements

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