CGMS-34, EUM-WP-19
Prepared by EUMETSAT
Agenda Item: I/2
Discussed in WG I

STATUS OF EUMETST HIGH RATE DCP PROTOTYPING

This document provides an overview of the prototyping activities performed by EUMETSAT for optimising performances for a High Rate DCP System using the Meteosat Second Generation satellites. The optimisation process has considered all relevant satellite channel impairments. Its design has focused on Bandwidth Efficient Modulation schemes (as per CCSDS recommendations) and it is also proposing a Forward Error Correction mechanism that shall allow improving system performance while decreasing power requirements on the Data Collection Platform side.

The document also briefly summarises the status of the special studies performed by EUMETSAT for a potential overlay DCP system using Code Division Multiple Access –CDMA- through the same DCP transponder.

STATUS OF EUMETST HIGH RATE DCP PROTOTYPING

1 INTRODUCTION

The primary mission of the satellite is the generation of multi-spectral radiometer images of the Earth from the geostationary orbit. The Data Collection Service (DCS) is a secondary service supported by the satellite with dedicated UHF to L-band transponder in the satellite payload for this. The DCS allows users to collect environmental data from sensors in remote locations on the Earth and to transmit that data via the DCS transponder to be received at a central facility. The Meteosat DCS can be shared by a large number of users as the satellite communications band is separated in to multiple FDMA channels and users are assigned pre-defined transmission timeslots in the corresponding FDMA channel. The current DCS standard defines the signal transmission parameters for the Data Collection Platforms (DCPs), which was devised some 25 plus years ago, and uses a PM/SP-L modulation scheme with a data rate of 100bps.

With the development of the Meteosat Second Generation (MSG) programme, the DCS has been enhanced with larger channel capacity of the satellite. However, to take full advantage of the DCS improvements with the introduction of MSG, EUMETSAT wanted to investigate the feasibility of introducing DCPs transmitting at higher data rates than the old standard. One of the distinctive characteristics of the Meteosat satellites is that they are spin stabilised. The satellite communications antennas used for the DCP signals (in UHF and L-Band) are consequently electronically de-spun (EDA). These EDAs cause phase and amplitude ripple to be introduced onto the DCP signals, with the rate of ripple related to the spin rate of the satellite which is 100 rpm and the different EDA designs. Therefore, whichever modulation scheme is to be used for the high rate DCP transmission, it has to be able to cope with the effects of the EDAs.

An initial assessment of the current DCS standard, defined in the 1970/80s, showed that the DCS could be enhanced by improving the following characteristics:

- increase **bandwidth efficiency** in order to reduce adjacent channel interference while increasing the data rate and keeping the number of channels,
- increase **power efficiency** by using a suppressed carrier modulation scheme,
- increase **link availability** by introducing forward error correcting techniques that will enable the system to work with better BER even at lower Eb/No levels and,
- increase the **amount of transmitted information** per DCP message by increasing the data rate and timing accuracy and redefining the DCP message format so as to reduce unnecessary overhead.

For covering all these aspects, EUMETSAT is performing a series of technical studies that started in 2003 with identification of MSG suitable spectral efficient modulation schemes (or BEM –Bandwidth Efficient Modulation-). Based on the selected BEM scheme, the activities continued with the design and development of a set of prototypes (transmitter and receiver) that allowed proof of concept verifications at Lab level. They were also deployed at the MSG Primary Ground Station site and real life tests with MSG-2 were conducted. Based on the outcome of all these activities, EUMETSAT has refined the specifications of the system and is entering a pre-operational pilot phase. This phase includes the development of a new set of prototypes (TX and RX sides) that will incorporate all improvements identified during previous phases. In parallel, EUMETSAT has also explored the possibility of overlaying a CDMA based system through the same operational DCP transponder.

1 SELECTION OF SPECTRAL-EFFICIENT MODULATION SCHEME

The study started with the selection of the candidate modulation schemes to be considered. The list was selected among the suggested modulation schemes in CCSDS Recommendation 413 (CCSDS 413.0-G-1), which addresses the use of bandwidth efficient modulations for high-rate spacecraft telemetry. The selected modulation schemes that were considered for evaluation are listed below:

- GMSK with BT = 1,
- GMSK with BT = 0.5,
- GMSK with BT = 0.25, and
- SRRC pre-filtered ($\alpha = 0.5$) OQPSK

The 8QPSK Trellis-coded modulation scheme used by NOAA in their new HRDCP system was discarded because a previous study concluded that it was not adequate to the spinning characteristics of MSG spacecrafts (CGMS-XXVIII EUM-WP-29).

The performances of the four candidate modulation schemes were evaluated by using a MATLAB/Simulink model that reproduced the DCS communication link with the perturbations the signals will encounter in a real scenario, which are listed below:

- non-linear power amplifier introducing AM/AM and AM/PM ripple,
- single and multiple adjacent channel interference,
- MSG-like satellite transponder including de-spun antenna,
- signal multipath and,
- additive white Gaussian noise channel.

The simulations focused on the effects of the satellite de-spun antenna as it is known they introduce an important degradation in the link performance. These effects were modelled by the introduction of a given phase and amplitude ripple on the signal at the output of the satellite transmitter. Three different scenarios were evaluated:

- MSG1 – Measured ripple on MSG-1 during IOT.
- Nominal – Nominal specified ripple on the MSG DCP transponder (as per system design specifications).
- Degraded – Degraded satellite mode ripple on the MSG DCP transponder (as per system design specifications).

The ripple values for each one of these scenarios are summarised in Table 1.

The comparison between the candidate modulation schemes was based on the observed performance degradation in terms of BER vs Eb/No that suffered each modulation scheme for each one of the disturbances listed before. The degradation was measured by comparing the Eb/No value at which BER = 1E-4 and 1E-6 was achieved to the theoretical BPSK performance. These initial simulations were run at 300 bps without encoding and 1500 bps with convolutional encoding (R = ½, K = 7). The results are shown in Table 2, Table 3 and Figure 1.

	Frequency Components	AM Ripple	PM Ripple
MSG-1	26.7 and 53.4 Hz	1.5 dBpp	20ºpp
Nominal	26.7 and 53.4 Hz	4.1 dBpp	20ºpp
Degraded	26.7 and 53.4 Hz	7.6 dBpp	40ºpp

Table 1 – *Parameter for EDA ripple.*

	GMSK (BT = 0.25)	GMSK (BT = 0.5)	GMSK (BT = 1)	SRRC-OQPSK
AWGN channel	0.72 dB[1] 0.66 dB[2]	0.46 dB 0.30 dB	0.46 dB 0.24 dB	0 0
Non-linear amplifier	0.76 dB 0.85 dB	0.38 dB 0.26 dB	0.38 dB 0.21 dB	0.16 dB 0.2 dB
Multipath	0.77 dB -	0.37 dB -	0.39 dB -	0.15 dB -
EDA MSG-1	1.40 dB 1.62 dB	0.78 dB 0.93 dB	0.66 dB 0.67 dB	0.57 dB 0.94 dB
EDA Nominal	1.78 dB 1.99 dB	1.13 dB 1.41 dB	1.00 dB 1.21 dB	0.90 dB 1.36 dB
EDA Degraded	3.54 dB > 4 dB	3.05 dB > 4 dB	2.77 dB > 4 dB	3.10 dB 3.71 dB

Table 2 – Summary of measured BER degradation for each perturbation and modulation scheme for the 300 bps, uncoded case.

Results summarised in Table 2 show that SRRC-OQPSK is generally less degraded by the perturbations than GMSK when considering a signal that is not convolutionally encoded. But results in Table 3, with a convolutionally encoded signal, show that GMSK outperforms SRRC-OQPSK when taking into account the effects of the non-linear amplifiers or signal multipath, but shows a clear misperformance when considering satellite EDA effects.

When considering the effects of adjacent channel interference, displayed in Figure 2, the narrower bandwidth of GMSK modulation with respect to SRRC-OQPSK is beneficial in reducing the observed degradation, but the performance of all modulation schemes is quite similar when the channel separation is greater than 3 KHz.

[1] This value corresponds to the degradation observed at **BER = 1E-4**.
[2] This value corresponds to the degradation observed at **BER = 1E-6**.

	GMSK (BT = 0.25)	GMSK (BT = 0.5)	GMSK (BT = 1)	SRRC-OQPSK
AWGN channel	-0.11 dB -0.01 dB	-0.34 dB -0.15 dB	-0.39 dB -0.21 dB	0.09 dB 0.10 dB
Non-linear amplifier	-0.08 dB 0.08 dB	-0.38 dB -0.26 dB	-0.34 dB -0.31 dB	0.23 dB 0.35 dB
Multipath	-0.16 dB -	-0.36 dB -	-0.41 dB -	0.19 dB -
EDA MSG-1	> 4 dB > 4 dB	0.95 dB 1.49 dB	0.54 dB 1.17 dB	0.37 dB 0.46 dB
EDA Nominal	> 4 dB > 4 dB	1.17 dB 1.99 dB	0.86 dB 1.43 dB	0.57 dB 0.83 dB
EDA Degraded	> 4 dB > 4 dB	> 4 dB > 4 dB	> 4 dB > 4 dB	1.71 dB 2.40 dB

***Table 3** – Summary of measured BER degradation for each perturbation and modulation scheme for the 1500 bps, convolutionally encoded case.*

Therefore, although in some cases GMSK outperforms SRRC-OQPSK, it was considered that SRRC-OQPSK was better suited to the spinning characteristics of MSG spacecrafts because of its better performance in degraded de-spun satellite antenna conditions.

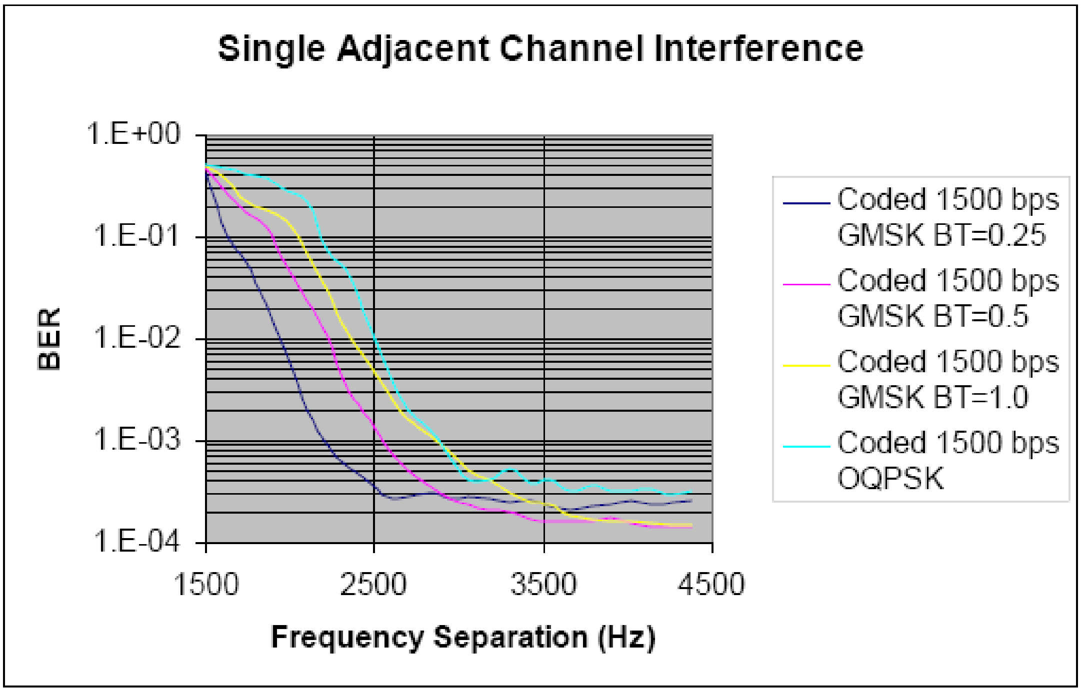

Figure 1 – BER degradation as a function of adjacent channel separation for coded data at 1500 bps for different modulation schemes.

2 PROTOTYPE IMPLEMENTATION AND VALIDATION

Upon selecting the most suitable coding scheme, preliminary specifications for the High Rate DCP system were derived (as summarised in Table 4). Based on these specifications prototype modulator and demodulators were developed. The modulator was based on a COTS FPGA implementation whereas the demodulator was based around a COTS DSP board installed in a commercial desktop PC.

The performance of the prototype implementations were validated in the laboratory and later on using MSG-2, by measuring the BER vs Eb/No performance at different bit rate and coding configurations. The results are summarised in Table 5. The measurements agree with previous simulations and therefore, confirm the use of SRRC-OQPSK as the modulation scheme to use for EUMETSAT's future high-rate DCPs. The degradation in the simulations is always smaller than the observed in the laboratory or over the satellite. The difference can be explained by the fact that simulation models did not include degradation due to imperfect phase tracking and that calibrations in the test bed are not optimal and a residual error of, at least ± 0.5 dB is always expected. These differences are more evident where the BER curves are steeper (i.e. with lower BER).

Modulation	SRRC pre-filtered (α = 0.5) OQPSK		
Modulating waveform	NRZ-L		
Modulation specifications	As defined by ECSS-E-50-05 Radio Frequency and Modulation Standards		
Bit Rate	300 bps	1200 bps	1500 bps
Coding	None	Convolutional, R = ½, K = 7	Convolutional, R = ½, K = 7
Channel Symbol Rate	150 sps	1200 sps	1500 sps
Transmission Slots	1.5 KHz channel	3.0 KHz channel	3.0 KHz channel

Table 4 – *Summary specifications for the prototype High Rate DCP.*

BER	**Uncoded**					**Coded**				
	Matlab Sim.	**Laboratory**		**MSG-2**		**Matlab Sim.**	**Laboratory**		**MSG-2**	
		300 bps	**1200 bps**	**300 bps**	**1200 bps**		**300 bps**	**1200 bps**	**300 bps**	**1200 bps**
1E-4	0.73 dB	~ 2.0 dB	~ 3.0 dB	~2.0 dB	~4,5 dB	1.25 dB	~ 2.0 dB	~1.7 dB	~1.7 dB	~1.8 dB
1E-6	1.14 dB	-	-	-	-	0.81 dB	-	~ 2.0 dB	~2.2 dB	~2.3 dB

Table 5 – *Performance degradation comparison with respect to reference theoretical performance between MATLAB simulations, laboratory dry-run tests and tests over MSG-2.*

3 CURRENT ACTIVITIES

Upon validating the HRDCP concept, current activities are focused on the final tuning of the specifications of the HRDCP service by developing and testing a new prototype HRDCP modulator and demodulator that will implement the enhancements suggested at the end of the previous phase and that are listed below:

- HRDCP message format, as shown in Figure 2, is byte-based instead of bit-based. The header's length has been extended to 12 bytes to accommodate the following information:

  1. DCP address
  2. Platform data length
  3. Sequential counter
  4. Julian day
  5. Engineering information

  This new format offers several advantages as it is possible to accommodate up to 64 Kbytes of environmental data per HRDCP message, it is easier to keep track of any lost messages and it provides HRDCP transmitter status information.

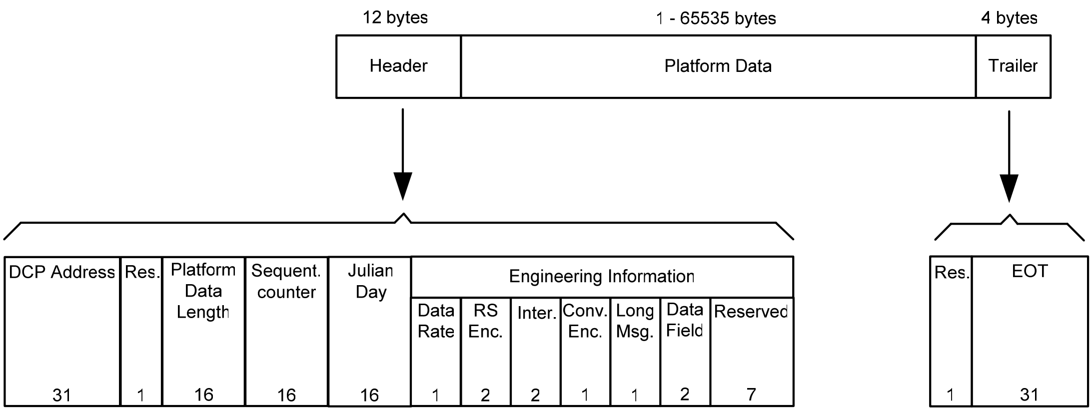

Figure 2 *– HRDCP Message format*

- Test results of the previous HRDCP prototypes over MSG-2 confirmed that the unit's performance benefit, in all possible configurations, if FEC techniques are used. Therefore, the new prototypes will implement more robust FEC techniques, i.e.: concatenated Reed-Solomon and convolutional encoding, interleaving and scrambling. During the pre-operational pilot phase the performance of the following coding schemes will be tested: RS(126, 112), RS(204, 188) and RS(28,24), interleaving depths $I = 1$, 3 and 5, with convolutional encoding ($R = ½$, $K = 7$) and scrambling.

- The communication channel is especially sensitive to the amplitude and phase ripple introduced by the spinning of the satellite, and therefore the new system specification is designed to counteract the ripple negative effects by coherently tracking a transmitted beacon signal and deriving ripple related information to be used in real time by the new DCP receivers.

The consolidation of the final HRDCP standard technical specifications will be done by gathering enough information on the overall system performance over several months in an operational-like scenario with the new HRDCP prototypes working with different configurations.

It is expected the development of the new HRDCP prototype units to start Q4 2006 and that testing with MSG-2 satellite will take place during second semester 2007, and having the final specifications of EUMETSAT's HRDCP service available by the end of 2007.

4 CDMA OVERLAY FEASIBILITY STUDY

Parallel to the development of the new HRDCP standard, a study was undertaken to verify the feasibility of a CDMA overlay service on top of the FDMA service provided by the DCS. A model of both CDMA and FDMA services was developed in a MATLAB/Simulink environment and simulations were run to quantify:

1. the degradation on a CDMA end-to-end link due to satellite despun antenna, non-linear amplifiers and multi-path interference, and
2. the interference between the CDMA service and the FDMA service

The results of this preliminary feasibility study concluded that a CDMA overlay service with a total capacity not exceeding 1000 bps, or 10x100 bps, could coexist with up to 150 FDMA transmissions with degradation on the FDMA service due to the CDMA service not exceeding 0.5 dB.

As these results were not totally satisfactory, but the system drivers were thought to have too high margins, a second study evaluated several means for improving the capacity of the CDMA service:

- using the full MSG DCP transponder bandwidth,
- implementing a more powerful FEC scheme, and
- applying interference cancellation techniques.

The study concluded that the CDMA overlay service could be optimised to increase its capacity to 8000 bps or 40 x 200 bps channels. The preliminary specifications are detailed below:

- Bit rate: 200 bps
- Bandwidth: Full transponder (Bands A + B + C)
- Modulation: SRRC-OQPSK
- Standard: ETSI MTM3
- FEC: concatenated RS(255, 233) with interleaving I = 1 and convolutional encoder (R = ½, K =7).

These are more promising results however, due to fact that this will be a new system that overlays on top of a new High Rate system, it has been decided to wait till having, at least, preliminary field results of the pre-operational pilot phase before further progressing in the realisation of prototypes for the overlay system.