PERFORMANCES OF LOW SNR DVB-RCS MODEM USING TEST FREQUENCY ALGORITHM

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ABSTRACT

Burst demodulation at low Signal to Noise Ratio represents a key issue, especially for satellite return link MF-TDMA access. Besides inherent coding performances, modem implementation losses and reference symbol overhead have to be minimized for a system efficiency objective. This paper presents a new demodulation algorithm, called Test Frequency, and its implementation in a modem prototype called "TurboCode Mock-Up". The measured performances of this modem applied to a DVB-RCS (Digital Video Broadcasting – Return Channel by Satellite) transmission scheme are presented for realistic channel conditions. The reference symbol dimensioning and positioning are discussed, and recommendations for DVB-RCS standard evolutions are proposed.

1. INTRODUCTION

Turbo-Code Mock-Up is a generic modem prototype addressing various modulation and coding schemes for both burst and continuous transmissions. Based on a FPGA-DSP platform, Turbo-Code Mock-Up (TMU) has been developed by CNES and Thales Communications as a very open tool to evaluate and compare different transmission schemes and different modem parameters settings. In this paper, we focus on low SNR burst transmissions, and present the specific phase and frequency recovery algorithm implemented in TMU called Test Frequency algorithm. At first, TMU and Test Frequency algorithm are detailed. Then, DVB-RCS main features are recalled and transmission channel characteristics are introduced. In a third part, the test environment and methodology is provided. Finally, modem low implementation losses for DVB-RCS transmission are assessed in realistic transmission channel conditions, especially for short bursts, with low coding rates, and low symbol rates. The reference symbols dimensioning is discussed and the use of distributed symbols inside the burst is compared with today DVB-RCS approach based on reference symbols grouped into one single preamble.

2. MODEM DESCRIPTION

2.1. Hardware platform

The hardware receiver is a COTS PCI platform integrated in a host PC. The signal is sampled in a daughter board (IF=140MHz +/- 10MHz) at 80MHz with a true 9 bits ADC. An AGC with resolution of 0.03dB allows tuning the input level at the ADC input. A first FPGA (DDC) is performing the down conversion, the fractional resampling at 3.F_{symb} with F_{symb} the symbol rate, and then the RX signal filtering with a programmable 31 taps complex filter. The filtered signal is then sent to demodulator on the mother board.

2.2. Receiver Architecture

The receiver is split in two FPGA of 3MGates. The first one is in charge of preamble detection, rhythm [1] and power recovery. Phase and frequency recovery according to the Test Frequency Algorithm are done in the second one, together with symbol demapping and up to soft input provision to the decoder.

The first FPGA detects the burst by correlating at 3F_{symb} the received signal with the preamble, and compares the power of the correlation with the received power. When a given threshold is reached, the FPGA starts to store the burst to achieve a feed forward estimation of the power (for necessary AGC on the carrier, for 16QAM, 16APSK…) and of the rhythm.

Then the FPGA interpolates the filtered signal to provide a one sample per symbol, with unitary power.

The preamble correlator is able to provide the initial phase to the phase and frequency module. The correlator is also able to provide a first rough estimate of the received frequency, by computing the correlation of the signal with several versions of the preamble shifted in frequency. The precision of this is estimation is limited by the Cramer Rao bound:

$$\sigma_{\delta F} = \frac{\sqrt{6L^{-3}(1-1/L^2)(C/N)^{-1}}}{2\pi}$$

A typical value of this standard deviation is 0.17% of the symbol rate (C/N=3dB, L=30 symbols). Therefore, the precision (at 4σ) of this indicator is worst than 0.5%

2.3. Test Frequency Algorithm

In order to mitigate this frequency incertitude, the demodulator will make several demodulations, testing different incident frequency shifts. For each tested frequency, the modem will:

- Start from the phase estimated on the preamble
- Update the phase estimate according to a first order loop: $\varphi_{n+1} = \varphi_n + \gamma\cdot\delta\vartheta_n$.
  φ_n is the phase estimate for symbol n, (φ_0 is the phase

estimated on preamble) and $\delta\vartheta_n$ is the phase error estimated on received symbol n. This phase error is programmed in a table in order to cope with any constellation. The underlying law for this table may be chosen between "probable angle", sinus law (for M-PSK), and hard decision. Reference and data symbols use different tables and different weightings.

- Accumulate the quadratic error between the decided symbols and the received symbols. The law for this quadratic error is tabulated and may be based on a "hard decision" (i.e. quadratic distance with the closest point) or on a "soft decision" (probable distance).

This operation is repeated for each tested frequency. For lower data rate (less than 80kbaud), the demodulator may test up to 1000 different frequencies.

Once the burst is completely demodulated, the demodulator selects the best frequency (i.e. the one with the least quadratic error) and demodulates the burst again and provides its output to the demapper.

This second demodulation is necessary because the demodulator is not able to store the (up to) 1000 different results of demodulation (each result may contain more than 2000 symbols). Furthermore, the second demodulation is made with a closer loop (a smaller gain γ) and with a frequency estimation given by $(\varphi_L-\varphi_0)/L$, where φ_L and φ_0 are initial and final phase estimates in the loop, and L is the burst length.

Depending on reference number and position, SNR, constellation and burst length, the statistical distribution (cost function) of the quadratic error varies and may provides poor conditioning for some frequencies.

Typically, for QPSK with preamble only, there is an obvious aliased frequency on the cost function at $F=1/4/T_{burst}= F_{symb}/4/L$, corresponding to an ambiguity of $\pi/2$ at the end of the burst. While adding a postamble, we can avoid this first alias, still having a alias at $F=F_{symb}/L$.

To reject this alias, we can add a midamble in the burst. The position of this midamble will determine the position and the depth of the alias. When midamble is set at 50%, C(F) is aliased at $F=2\cdot F_{symb}/L$. If set at 66% the cost function is aliased at $F=3\cdot F_{symb}/L$. The cost function is represented on **Fig 1**.

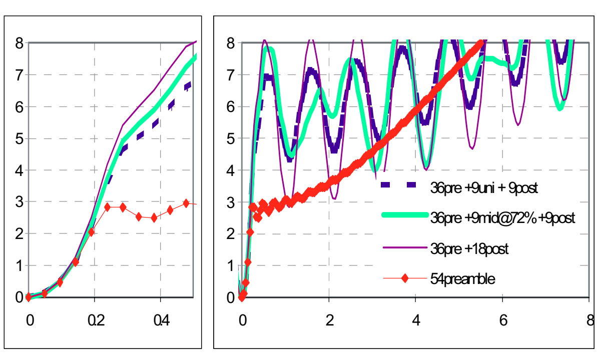

Fig 1 : Cost function for different reference distribution

Abscise of cost function is frequency normalised by burst frequency $F_{burst}=F_{symb}/L$, while y is the average cost normalised by the standard deviation of the cost function at $\delta F \tilde{=} 0$.

N.B.: These curves are obtained by simulation while following curves are measurements on a real modem. The cost function is show for C/N=2.5dB, 1 ATM cell with coding rate ½, and 54 symbols of reference.

The lower curve (preamble only) shows important aliases at Fburst/4: the modem is not able to demodulate when frequency error is bigger than ~+/-10Hz, when Fsymb=50kbaud. Adding a postamble allows accepting frequency error up to +/-50Hz. Wrong detection will occur while searching in a band wider than Fburst. A preamble set at 70% of the burst allows a frequency error up to +/-150Hz, with some penalty when using bigger frequency: The alias at 3*Fburst and 4*Fburst is not to deep, but still exists. Using uniformly distributed references instead of midamble avoids any deep alias in the cost function and minimizes the probability of false frequency error detection.

2.4. Turbo decoding

The decoder is provided by IP from TurboConcept™, including TC1000 DVB-RCS decoder, TC2000 duo-binary 16 states decoder, or TC3000 TPC decoder. Theses IP are implemented in a third FPGA, including also the output of the decoded bit to the user.

3. DVB-RCS CONTEXT

3.1. DVB-RCS main features

DVB-RCS [2] physical layer is based on QPSK modulation and on parallel convolutional turbocoding, with coding rates 1/3, 1/2, 2/3, 4/5, 6/7.

Today, burst formatting only includes the insertion of a preamble, contrary to other standards like DVB-S2, where pilot symbols are distributed. In this article, compared performances evaluation is proposed between the DVB-RCS case with preamble only, and an alternative approach with reference symbols split into preamble, midamble and postamble.

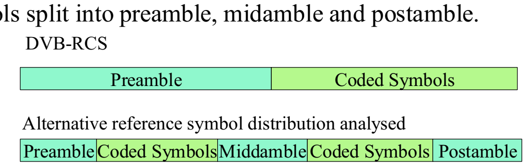

Fig 2: Different distribution for reference

3.2. Transmission scheme selection

Ka band future DVB-RCS systems based on several transmission schemes have a need for both spectral efficient bursts and more robust ones with higher access granularity (short bursts). For demodulation issues, this later case of short bursts, with low date rate, and low SNR is the most challenging [3][4][5]. The selected schemes for further performances evaluation are given in Table 1.

The selection of 1/2 as lowest coding rate is motivated by the poor decoding gain for an identical size in bits of 1/3 which provides only a gain of 0.3 dB compared to 1/2 for a spectral occupation increase of 50%. Nowadays DVB-RCS receivers typically provide coding rates beyond 2/3 for traffic bursts.

Table 1 : Selected transmission schemes

	coding rate	burst size	symbol rate
Case 1	4/5	2ATM	304 ksps
Case 2	2/3	2ATM	152 ksps
Case 3	1/2	1ATM	76 ksps

3.3. Transmission channel hypothesis

The frequency and timing synchronization DVB-RCS process combines the reception of on the one hand Network Clock Reference and on the other hand time and frequency correction messages from the Gateway. We consider here that these two synchronization mechanisms at system level result in residual frequency ant rhythm errors of ±5kHz and 10ppm (worst case).

4. TEST ENVIRONMENT AND METHODOLOGY

4.1. Test configuration

The following test environment is used for performances evaluations. Different channel perturbations are emulated. We consider typically a sinusoidal frequency error in ±5kHz with a maximal slope of 10Hz/s and a timing error of 10 ppm. The frequency error is introduced by a CNES-patented equipment called Propagation Channel Emulator and provided by SMP, a satellite equipment supplier.

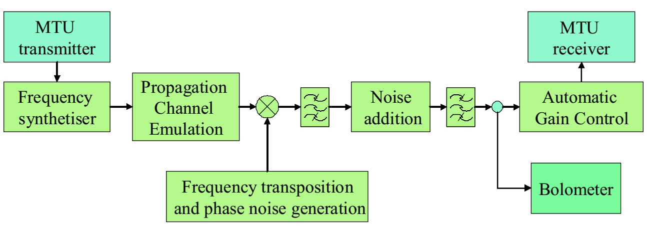

Figure 3 : Test configuration

Besides, a typical phase noise profile is introduced in the transmission chain. This phase noise is compared to the phase noise mask provided in DVB-RCS guidelines [6] on Fig 4.

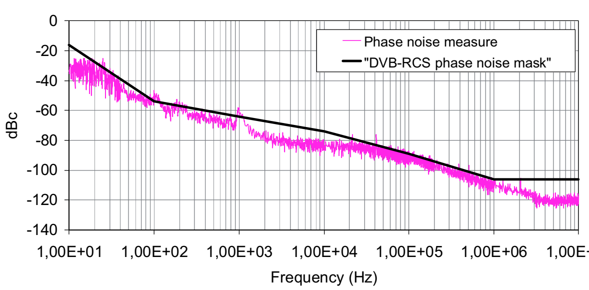

Fig 4: Applied phase noise and mask

4.2. Signal to Noise Ratio measurement methodology

The precision for SNR estimation is fundamental in the performances evaluation for turbocode transmissions, since a 0.2dB can cause a significant BER change. A dedicated calibration procedure allows accurate measurement of Eb/No ratio. Noise level is measured with a bolometer behind a finely calibrated noise bandwidth filter and the signal is measured by the same equipment in a continuous flow configuration.

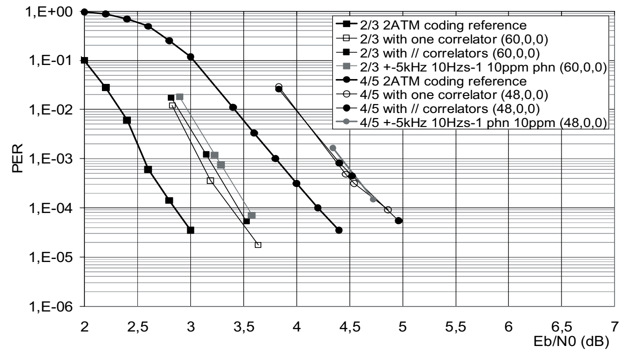

Fig 5: Performances of R=2/3 and R=4/5 in Gaussian and in realistic channel conditions

5. PERFORMANCES

For all the following results, Eb/N0 x-axis integrates the reference symbol overhead.

5.1. DVB-RCS reference schemes and first results

Fig 5 shows PER performances of TMU for 2/3 and 4/5 cases for respectively 60 and 48 symbols preamble in an additive white Gaussian noise channel and in the more realistic transmission channel with phase noise mask presented in Fig 4 and frequency and timing error as described in 3.3. We can see that TMU modem losses compared with coding reference curves are under 0.6dB (including 0.35dB preamble overhead), for these two classically used DVB-RCS schemes.

5.2. Impact of symbol repartition and sensitivity analysis to number of reference symbols

Case 3 in Table 1 is more critical from demodulation point. In that case, the dimensioning of reference symbols and of their position inside the burst is all the more important. As illustrated on Fig 6, in that case, the use of all reference symbols grouped inside a preamble significantly degrades performances. On the opposite, we can see that for an equivalent number of reference symbols, their distribution inside the burst presents a very significant performance enhancement.

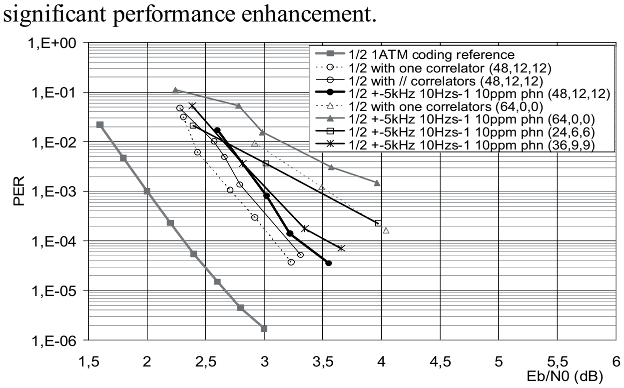

Fig 6: R=½, sensitivity to reference symbol position and number

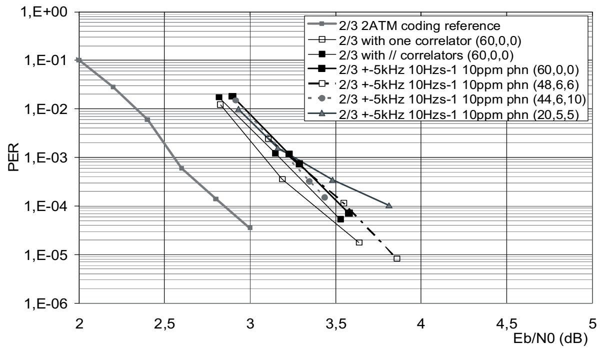

Fig 7: R=2/3, sensitivity to references position & number

Besides, based on results of Fig 6, a sensitivity analysis on the number of reference symbols is possible. We can see in this case that an increase of symbol reference to (48,12,12), in spite of the overhead increase, provides an enhancement of final performances. N.B. for ATM 1/2, the frequency error is as big as 10% of F_{symb}

Coming back to cases 1 and 2, the same type of sensitivity analysis can be proposed for symbol repartition and number of reference symbols. For 2/3 coding rate (case 2), as shown on Fig 7, the benefit of symbol distribution compared with preamble only is not significant. When the coding rate and the burst size increase, the importance of reference symbol position becomes less significant. Fig 7 shows also a sensitivity analysis on the number of reference symbols.

Finally for 4/5 coding rate (case 1), Fig 8 shows a typical trade-off analysis on the preamble size to find the optimal number of reference symbols. From 48 to 18 reference symbols, the performances are enhanced. Then, for shorter preambles, the gain in preamble overhead is compensated by demodulation performances degradations.

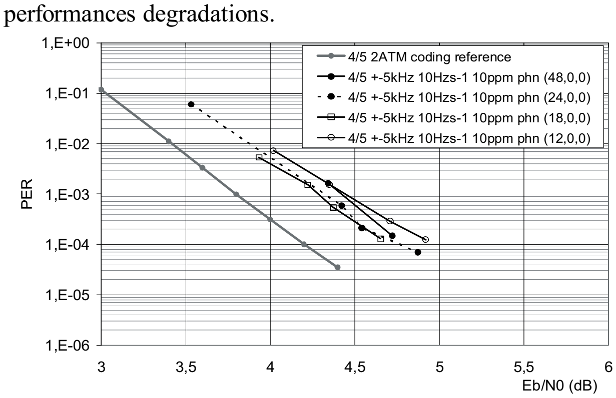

Fig 8: R= 4/5, sensitivity to reference symbol number

5.3. Sensitivity analysis to timing error and frequency error

This type of sensitivity analysis can be used to find the best trade-off in the DVB-RCS frequency and timing synchronisation loop dimensioning, and can be all the more important that DVB-RCS adaptation to mobile is an up-to-date issue.

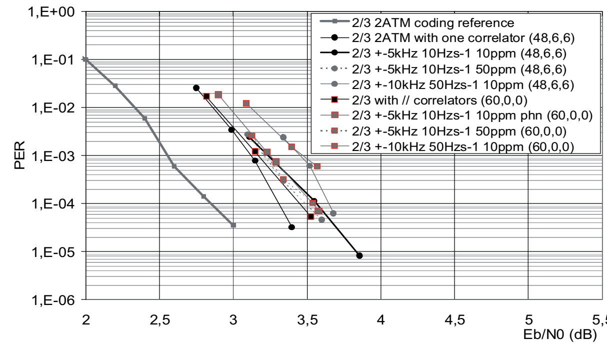

Fig 9: R=2/3, sensitivity to channel perturbations

6. CONCLUSION

Test Frequency algorithm and its implementation inside TurboCode Mock-Up represents a very efficient and performing demodulation solution for low SNR burst transmissions. This paper highlights the very low implementation losses and good performances in realistic transmission channel conditions in presence of phase noise, and with timing and frequency errors.

A sensitivity analysis is proposed to reference symbols dimensioning. The paper highlights the impact of reference symbol positions inside the burst. For short bursts with low SNR, the paper indeed shows the very significant gain that can be obtained through a symbol distribution into preamble, midamble and postamble. These results can be used to argue in favour of DVB-RCS standard evolution on this point. These results will be completed by further work on other distributions of reference symbols and on smaller signalisation packets.

11. ACKNOWLEDGEMENTS

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12. REFERENCES

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