IMPACT OF PHASE NOISE ON CARRIER PHASE ESTIMATION AT Ka BAND

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ABSTRACT

Demodulation on-board a satellite is a key issue for future multimedia communication systems as multi-point to multi-point transmissions are concerned due to its mandatory role before a packet switching process. At Ka-band the carrier frequency on the up-link is 30GHz approximately, thus phase noise equipment's induced by up-conversions can become critical for the coherent digital demodulator. For short burst transmissions feedforward functions have to be used instead of feedback structures. In this paper the impact of phase noise on carrier phase estimators is characterized for different algorithms and several phase modulations in term of standard deviation and resulting degradation of the Eb/N0.

1. INTRODUCTION

For multimedia systems, dealing with multi-point to multi-point communications, a satellite with numerous on-board processing's and thus offering a complete infrastructure is of great interest: a large coverage is rapidly given by the satellite even in regions with no terrestrial infrastructure and most of the processing's are realized so that the ground segment can be reduced. In order to implement intelligent on-board switching at the satellite level, headers of user packets that are transmitted need to be "readable" by the routing table; the consequence is the necessity to demodulate the signal on-board with a high accuracy.

When small user terminals are addressed the available transmitted power is reduced and powerful coded schemes have to be used to satisfy stringent budget links. Thus the operating point of the on-board digital receiver is low, typically down to Ec/N0=0dB (Ec = energy per bit on the channel). Moreover transmissions are packet-oriented which implies the use of feedforward algorithms instead of digital and phase locked loops in the demodulator architecture. Performant structures have to be used to achieve reduced degradations of the demodulator at low signal to noise ratio (SNR), considering only the thermal noise in first approximation. In a real system, propagation impairments as well as equipment's impairments introduce distortion on the received signal; this has to be taken into account by the demodulator design to keep the robustness required by the routing function.

In this paper we evaluate the impact of the phase noise introduced by local oscillators (that realize up and down-conversions of the signal) on carrier phase estimators for MPSK modulations. The coding structures used in satellite transmissions and the Ka-band characteristics are presented. Then the carrier phase estimators suited to the selected demodulator architecture are described. A typical phase noise mask has been generated by applying filtering methods and this distortion has been added on the channel transmission for simulations. Different estimators are evaluated with different MPSK modulations.

2. CODING SCHEMES

Satellites are commonly used for information broadcasting with powerful gateways; therefore "classical" coding schemes have remained sufficient for a long time. The DVB-S norm [1] recommends a coding scheme based on a concatenation of a Reed-Solomon code with a convolutional code separated by an interleaver over twelve MPEG2 frames. The RS code is a (204,188,t=8) shortened from the (255,239,t=8), the initial convolutional code is a (1/2,7) generated by polynom generators 133 and 171 (in octal form) and the interleaver is of the convolutional type. Puncturing patterns are defined to allow coding rates from 1/2 to 7/8. For broadcast applications continuous transmission is assumed. For burst transmissions with packet lengths shorter than 188 bytes the RS code can be even more shortened; for example a (69,53,t=8) can be used for encoding one ATM cell. Performances are not as good as they were previously but the same global encoding scheme is kept.

Evolution of communications by satellites has lead to define a norm for the "return channel by satellite" (RCS) [2] in order to introduce an interactive channel used by individual user terminals. This norm specifies on the return link a parallel concatenated convolutional code (PCCC) having the following characteristics: duo-binary encoded system, circularization of the trellis, elementary recursive systematic code generated by 15 (feedback), 13 and 11 (redundancy) (all in octal form), interleavers defined by formulas for various packet lengths (in particular 1, 2 and 4 ATM cells). Moreover puncturing patterns allow to define coding rates from 1/3 to 6/7 for all packet lengths. A specificity is also introduced in the mapping: the systematic bits are transmitted first and they are followed by the redundancy bits (of both codes before and after interleaving).

These two norms assume a QPSK modulation scheme filtered by a raised root cosine filter with roll-off α=0.35 which is of common use for satellite transmissions.

3. KA BAND CHARACTERISTICS

Congestion of frequency bands push towards the use of Ka-band (30GHz on the up-link/20GHz on the down-link) for fixed satellite services (FSS).

Rain is a "classical" source of attenuation on a link between a ground station and a satellite. When increasing the carrier frequency, other sources of attenuation become important: oxygen, clouds, water vapor, scintillation,… At Ka-band several tenth of dB of attenuation can appear. It is quite impossible to design a system with such a margin but fade mitigation techniques (FMT) allow to compensate the presence of 10 to 12dB of attenuation. This is realized by cumulating different techniques: power control, coding rate fluctuation, binary rate reduction in particular [3].

Other sources of attenuation and distortion of the transmitted signal are the radio frequency (RF) components of the terminal. One of these is called phase noise and is introduced by frequency local oscillators, each of their amplifier generating a self noise. As the up-link and down-link are respectively 30 and 20GHz, the frequency transposition from base-band to frequency carrier and reverse is done by steps; three successive transpositions are generally performed. An example of phase noise mask is given in Table 1 for the up-link of a system operating at Ka-band with a transmission from a fixed user terminal to a satellite.

Table 1: Phase noise mask at Ka-band

Frequency in Hz	10	10^2	10^3	10^4	10^5	10^6
Mask in dBc/Hz	-45	-66	-69	-74	-103	-103

Noting ε the residual carrier phase error at output of the carrier recovery unit we have:

$$\sigma_\varepsilon^2 = \int S_\Psi(f).\left|1 - H(f)\right|^2 df$$

with $S_\Psi(f)$ the power spectral density of the phase noise Ψ and H the transfer function in closed loop of the estimator. The phase jitter is thus depending of the high-pass component of the carrier phase algorithm while it is dependent of the low-pass component for the thermal noise.

To realize the mask of Table 1 a structure based on filters and Fourier transforms has been used; the frequency response obtained is exactly the one given. With a simpler structure like a first or second order loop, the different slopes of the mask can not be generated.

4. FEEDFORWARD DEMODULATION

4.1. Demodulator architecture

The choice of algorithms implemented in a demodulator are mainly dependent on the access scheme and the operating point. When short burst transmissions are addressed, acquisition time of the functions implemented at receiver level has to be limited to a few symbols; therefore feedback loop structures are avoided. Digital feedforward algorithms are selected for the various functions to be performed:

- timing recovery,
- carrier frequency recovery,
- carrier phase recovery.

The O&M algorithm [4] is suitable to timing recovery. The input signal is sampled at 3 or 4 times the symbol rate and the correction is performed by interpolation in the matched filter [5].

For carrier frequency recovery, algorithms presented in [6] and [7] can be used.

For carrier phase recovery we develop in the next paragraphs of this section suitable algorithms.

An entire feedforward demodulator can thus be defined to satisfy the constraint of acquisition time. An integration over several symbols is performed for each algorithm and this value is directly linked to the acquisition time and the residual jitter.

Feedforward structures are divided in mainly two classes:

- decision directed (DD): an estimation of transmitted bits is used in the estimation process
- non-data aided (NDA): no estimated bits are necessary, only an hypothesis on the modulation characteristics.

4.2. NDA carrier phase estimation

Let *p(k)* be the complex received signal at time kT_s after matched filtering and timing recovery. Application of the maximum likelihood (ML) principle for QPSK modulation leads to the minimization of:

$$\sum_k Re^4\left(p(k)e^{-j\tilde{\theta}}\right) + \mathrm{Im}^4\left(p(k)e^{-j\tilde{\theta}}\right)$$

where $\tilde{\theta}$ is the estimated carrier phase error. An equivalent method called the Viterbi and Viterbi (V&V) algorithm is established in [8]. The estimated carrier phase error for MPSK modulation is:

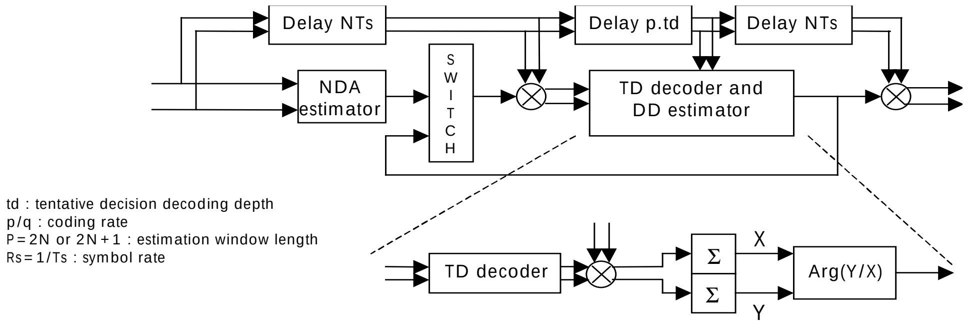

Figure 1: Synoptic of the TD estimator

$$\hat{\theta}_n = \frac{1}{M} Arg\left\{ \sum_{k=-N}^{+N} F(\rho_{k+n}) e^{-jM\theta_{k+n}} \right\}$$

where F(.) is a nonlinear function and $p(k) = \rho_k e^{-j\theta_k}$. The estimated value is in $[-\pi/M ;+\pi/M[$ and needs to be unwrapped in $[-\pi;+\pi[$. This process can be realized using the structure proposed in [9]; the final estimation $\hat{\varphi}_n$ is given by:

$$\hat{\varphi}_n = \hat{\varphi}_{n-1} + \mathrm{mod}\left(\hat{\theta}_n - \hat{\varphi}_{n-1}, 2\pi/M\right)$$

4.3. TD carrier phase estimation

The tentative decision (TD) carrier phase estimation [10][11] belongs to the DD class and is well adapted for transmissions using an error control code based on convolutional codes. A tentative decision decoder is a classical convolutional decoder with short decoding depth (typically 1 to 5 input frames). Decoded bits are called tentative decisions and replaced the hard decisions ($\hat{d}_k^*$) in the DD phase estimator: $\hat{\theta}_n = Arg\left\{ \sum_k \hat{d}_k^* p(k) \right\}$. Due to the delay introduced by the decoding process, an initialization function has been added as shown in Figure 1.

The three main steps of this estimator are:

- Evaluation with a NDA algorithm of an initialization carrier phase error θ_1.
- Pre-correction with either θ_1 or θ_2.
- Evaluation of the carrier phase error θ_2 by the DD structure.

For use with turbo-codes, the structure has to be slightly changed in order to cope with several elementary codes. To minimize delays, the only code to be considered by the TD decoder is the one before interleaving. A simple threshold is applied to other bits to determine hard decisions. Otherwise the structure of Figure 1 s unchanged.

5. PERFORMANCES

The evaluation of performances of the different estimators has been done considering the mask presented in paragraph 3 generated by a filtering method using FFT.

5.1. Impact of the modulation

The criteria used to evaluate the impact of phase noise on estimators is either the variance (or standard deviation) or the bit error rate degradation. Considering a non coded transmission the same mask (given in Table 1) has been introduced for a QPSK and a 8PSK modulation. A V&V carrier phase estimator with a second order non linearity ($F(\rho)=|\rho|^2$) and an integration window length P=33 is considered. The resulting standard deviation is given in Figure 2 and compared to the corresponding Cramer-Rao bound (CRB) and the standard deviation assuming only thermal noise.

The jitter is due to thermal noise σ_{th}^2 and phase noise σ_{ψ}^2 at output of the carrier phase recovery algorithm is $\sigma^2 = \sigma_{th}^2 + \sigma_{\psi}^2$. Results of Figure 2 confirm this equation so that the presence of phase noise introduces a degradation on the estimator variance. As the phase jitter does not depend on the SNR, σ_{ψ}^2 component impact is then highlighted at high SNR.

Sensitivity to phase noise increases with the modulation order.

Nevertheless in both cases the impact of phase noise on the estimator is limited to a few tenth of degree (<0.3°) which results in 0.1dB BER degradation for a QPSK or 8PSK modulation.

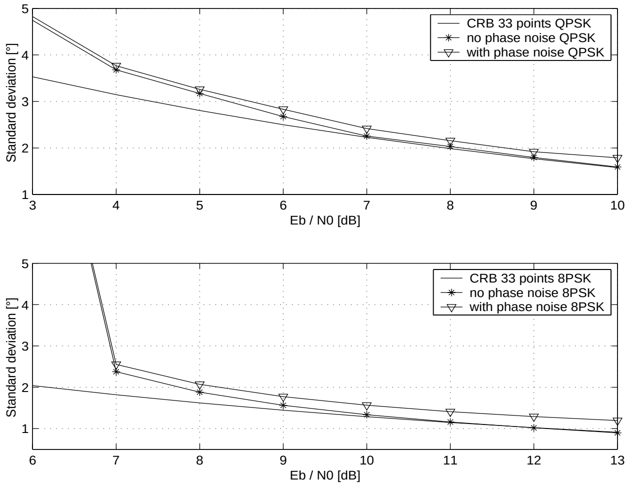

Figure 2: Standard deviation with QPSK and 8PSK modulation for a given phase noise mask at Ka-band with the V&V algorithm

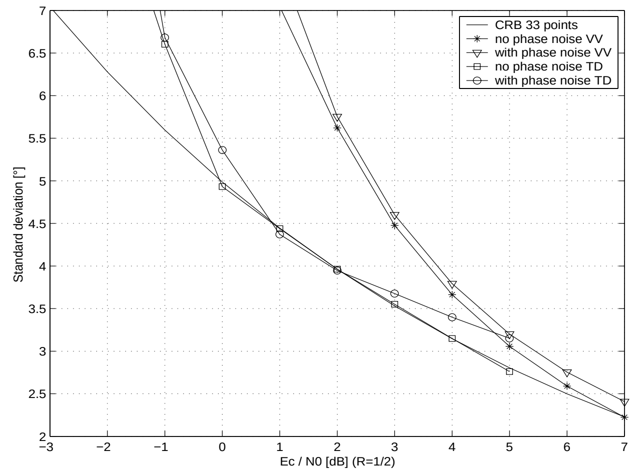

Figure 3: Standard deviation of various estimators with convolutional encoding (1/2,7) and QPSK modulation

5.2. Sensitivity of different estimators

Different estimators have been evaluated with the same generated phase noise. Some results are presented in Figure 3 for a QPSK modulation with a (1/2,7) convolutional encoding. The V&V algorithm is suited to transmissions with a Eb/N0 of 6-7dB; the TD estimator is considered for lower Eb/N0 (2-3dB). The TD algorithm is more sensitive to phase especially when considering very small decoding depth. To improve performances of this algorithm with phase noise, an increase of the decoding depth is necessary.

The value of 33 for the integration window length of estimators has been chosen for implementation complexity reasons. With smaller values the impact of phase noise would be reduced but global performances of estimators would not be sufficient. This is given by the theoretical jitter expression seen previously. For a turbo-coded transmission the impact of phase noise on the TD estimator is similar as only one tentative decision decoder is taken into account.

6. CONCLUSION

In this paper the impact of phase noise has been evaluated for the up-link of a transmission by satellite at Ka-band considering power-limited end-user terminals and burst mode digital coherent demodulation. Phase noise has been generated by filtering methods for simulation purposes. It is shown that the high frequency component is preponderant for the jitter due to phase noise and that its main impact is at medium and high SNR. Nevertheless it is limited and the residual Eb/N0 degradation is restricted to a few tenth of dB.

7. REFERENCES

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