Adaptive Coding and Modulation Techniques for Advanced Satellite Mobile Systems

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Abstract

In this paper, adaptive coding and modulation techniques are envisaged in a satellite mobile system adopting the WCDMA air interface. The physical layer performance, in terms of bit error rate, for several coding rates and modulation formats are reported. Preliminary results of the feasibility for OFDM techniques in the satellite channel are also shown.

I. Introduction

The interest in adaptive coding and modulation (ACM) techniques is increased dramatically in recent years, as testified by high speed terrestrial wireless data networks, such as High Speed Downlink Packet Access (HSDPA) and High Data Rate (HDR) [1]. At the same time, the exploitation of ACM techniques have also been envisaged for future broadband satellite communications at Ka-band and above [2]. In particular, ACM is a building block of the newly developed Digital Video Broadcasting over Satellite (DVB-S2) standard [3], to provide very significant capacity gains. The key to the capacity increase is to avoid the waste of system resources related to the adoption of a fixed physical layer, for which spectral efficiency must be sacrificed to introduce a link margins, necessary to guarantee link closure in worst-case conditions. On the other hand, the search for capacity increasing techniques has brought the 3GPP community to evaluate Orthogonal Frequency Division Multiplex (OFDM) techniques as a possible alternative to the single carrier HSDPA air interface [4]. OFDM is in fact known to have an high spectral efficiency with respect to the WCDMA approach. However, OFDM is also known to have high peak-to-average power ratio (PAR) which renders this techniques particularly sensitive to non linear distortion such as those introduced by satellite on-board high power amplifier (HPA). In this framework, the objective of this paper is twofold. Firstly, we investigate the extension from fixed single carrier broadband satellite transmission (e.g., DVB-S2) to satellite mobile links where the propagation channel is more challenging. Secondly, the OFDM scheme proposed within the 3GPP is analyzed in a satellite environment. To keep the similarity to the terrestrial WCDMA, the single carrier transmission (SCT) scenario considers the standardized 3GPP turbo code which can be punctured to several coding rates (from 1/3 to 6/7) with MPEG packet size. Regarding the modulation schemes, the standard 16-QAM format adopted by HSDPA is replaced by the 16-APSK scheme to exploit its increased robustness to the non-linear effects introduced by the on-board HPA. For the OFDM case, preliminary results are reported taking into account a subset of the previous coding rates and modulation schemes. The specific novelty of this contribution is to present OFDM performance in such challenging channel conditions using predistortion techniques to counteract the non-linear effects.

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II. System Model

In the following, the entire transmit-receive chain, whose block diagrams are depicted in Fig. 1 and Fig. 3 respectively, are described for the SCT scenario. Starting from the transmitter, an info data sequence with MPEG packet size passes through a channel coding block that follows the 3GPP standard [5], which foresees two possible configurations for error protection. In this work, the turbo coding option, using a double binary Recursive Systematic Convolutional (RSC) code, is considered. Then, the coded sequence is punctured to several coding rates spanning form 1/3 to 6/7 before entering in the modulation block. Besides standard modulation schemes, such as QPSK and 8-PSK, the hybrid phase and amplitude modulation format, identified as APSK, is also investigated [6]. Two sets of parameters are defined to characterize this modulation format: the first, ρ_i, corresponds to the i-th PSK ring radius normalized by the inner PSK ring radius; the second, ω_i, identifies the relative angular displacement between the i-th ring and the inner ring. The considered 16APSK modulation is composed by a double ring (4-12). The modulated signal enters an up-sampling block followed by a square root-raised cosine pulseshaping waveform filter.

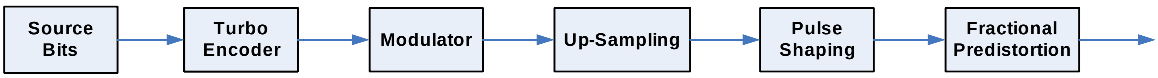

Fig. 1. Transmitter block diagram

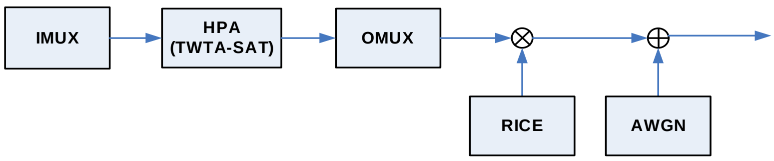

Fig. 2. Channel block diagram

Both non-linear and linear distortions, essentially due to HPA and IMUX/OMUX on-board filter, shown in Fig. 2, are taken into account. To cope with the non-linearity due to the HPA, a purposely designed predistortion technique is envisaged in the gateway architecture. In particular, we consider a fractional predistortion technique, based on a Look-Up-Table (LUT) approach, which operates after the shaping filter [7], [8]. The fractional predistorter, acting on the samples, is able both to compensate the constellation warping due to the phase distortion introduced by the AM/PM HPA characteristic and to reduce the variance of clusters on constellation points, bounding the effects of the inter-symbol interference (ISI). The considered predistorter exploits a linear-in-power indexing strategy. In linear-in-power indexing the table entries are uniformly spaced along the input signal power range, yielding denser table entries for higher amplitudes. It is characterized by a simple implementation, since it requires only a square calculation module, and it is particularly effective if the non-linearities are localized at large amplitudes, which is the case of TWT HPAs. For a transparent repeater, the linear distortion is essentially introduced by the on-board input and output multiplexing filters (IMUX and OMUX), which induce significant ISI, that adds to the residual uncompensated ISI induced by the HPA. Moreover, a time non selective correlated Ricean fading channel has been considered.

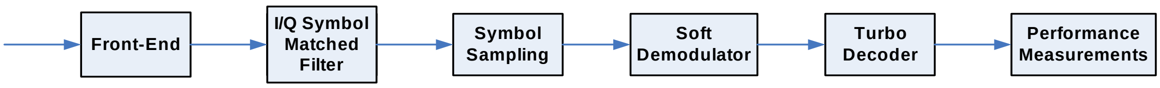

Fig. 3. Receiver block diagram

At the receiver side (Fig. 3), perfect frame synchronization is assumed as well as symbol timing recovery. The sequence enters a soft demodulator whose output is finally decoded by an iterative scheme implementing the log-MAP BCJR algorithm.

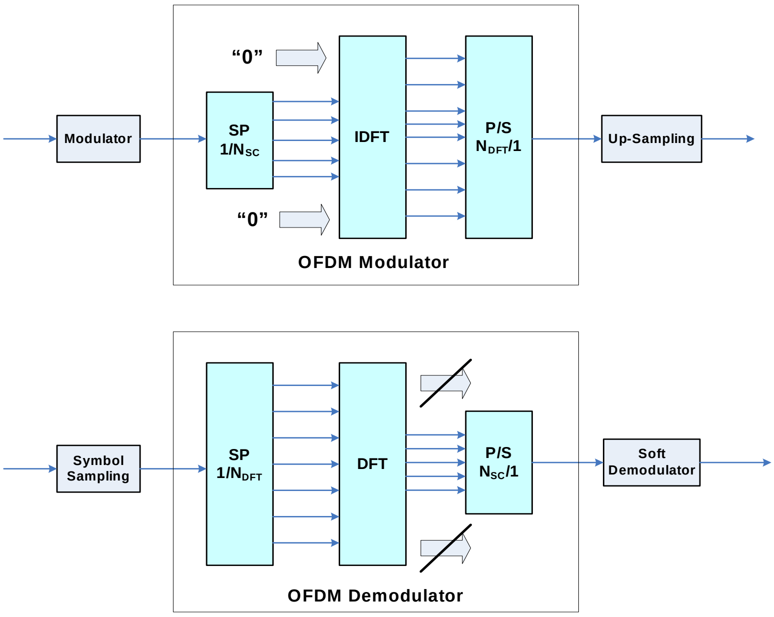

Fig. 4. OFDM block diagrams: Modulator and Demodulator

Concerning the multiple carriers transmission (MCT) scenario, the OFDM modulator and demodulator are inserted in the transmit-received chain as depicted in Fig. 4. At the transmitter side, the modulated symbols are mapped onto N_{SC} sub-carriers, and the OFDM symbol results from the inverse discrete Fourier transform (IDFT) over N_{DFT} input carriers[1]. To completely separate the OFDM symbols due to the energy dispersal induced by the multi-path channel, a cyclic prefix of N_{GS} guard symbols is inserted. In the receiver, the dual operation is performed before feeding the soft data demodulator.

III. Simulator Architecture and Numerical Results

The communication chain, described for both the SCT and the MCT cases, has been implemented using C++, building a reconfigurable physical layer simulator (PLASMA, i.e. Physical LAyer SiMulator for Adaptivity) which is described hereafter, along with the achieved numerical results.

A. Simulator Architecture

The physical layer simulator has been designed keeping in mind both reconfigurability and computational efficiency. This has been achieved by designing a modular simulator, in which the single module is a stand-alone entity, characterized by its own parameters and operating modes. In addition, each single module exchanges data with the outer environment by means of input and output connections, which are reconfigured through an external XML configuration file at launch-time. Not only it is possible to completely modify the way the modules are interconnected, but it is also possible to modify the modules run order, so as to implement nested cycles to increase flexibility. This architecture, supported by the CONDOR [9] high throughput computing platform, allows to perform simulation clusters in a

[1] Zero frequency bins are inserted to fill the OFDM bandwidth.

reasonable time. Further, since only one executable is sufficient to perform all the needed simulations, which are differentiated through the external XML file, the development and debug process is centralized and thus more efficient.

B. Numerical Results

Simulation results are synthesized in the following figures, where Packet Error Rate (PER) performance is reported against E_b/N_0. In particular, Figs. 5-9 show results for the SCT case, while Fig. 10 reports the results for the MCT case. For the 16APSK case, $\rho_1 = 2.85$ and $\omega_1 = 0$ are considered. All E_b/N_0 performance losses referred hereinafter are to be considered with respect to a PER equal to 10^{-2}.

The first result is reported in Fig. 5 is the comparison between SCT over AWGN channel (labelled as ideal channel, *IC*, curves) and SCT over a channel with both linear and non-linear distortion (labelled as distorted channel, *DC*, curves). As it can be seen, performance loss with respect to AWGN increases for increasing code rates and modulation orders. This is due to two main factors: the first lies in the reduction of the code strength for increasing coding rates, while the second is the increasing sensitivity higher order modulations. The loss is limited to 0.1 dB for all QPSK cases, 0.2 dB for the 8PSK cases, and to 2 dB for 16APSK cases. This can be regarded as a good result, as it has been obtained in the presence of strong non-linear distortion (the HPA is operating at an Input Back-Off (IBO) of 2 dB, i.e. very close to saturation, and with linearly distorting input and output multiplexers. These two contributions are quite equipollent.

Starting from the performance over the distorted channel with AWGN (*DC* curves), in Fig. 6 flat fading is introduced, with a Rice factor of 10 dB, considering ideal channel interleaving and perfect Channel State Information (CSI) recovery. Such channel is a good approximation for receivers in rural and suburban areas. In this case channel fluctuations, even if known, cause a noticeable degradation in system performance, which can be quantified in 0.4-0.5 dB for QPSK, 0.8-0.9 dB for 8PSK, 1.4-1.5 dB for 16APSK. When more densely built-up areas have to be considered, a better channel approximation can be obtained by reducing the channel Rice factor. Results for this case are reported in Fig. 7 with a Rice factor of 5 dB. The loss with respect to the *IE* curves is now much larger, and can be quantified for QPSK from 0.8 dB for the more protected code-rate, up to 2.2 dB. Similarly, the degradation is from 2.2 dB up to 3 dB for 8PSK, and at least 4.4 dB for 16APSK. This is due to the increased weight of the diffused component of the signal over the direct one.

Removing the hypothesis of ideal interleaving, and thus considering correlated channel coefficients, performance for a normalized doppler frequency equal to $f_d = 0.01$ has been computed, for a Rice factor of 10 dB. Fig. 8 reports the results for QPSK modulation, while Fig. 9 refers to 8PSK and 16APSK results. When channel correlation is introduced, channel degradation occurs in bursts, and is thus much more difficult to recover for the channel code. Performance loss starts from 1.6 dB to 3 dB for the QPSK case and at least 3.2 dB for both 8PSK and 16APSK case. For more correlated cases, where fading event length is comparable to the packet length, the adoption of channel interleaving is strongly recommended.

Considering now the MCT case, preliminary results are shown in Fig. 10, where performance over several channels is reported for QPSK modulation and code rate $\frac{1}{3}$. OFDM system parameters are $N_{DFT} = 512$, $N_{SC} = 299$, and $N_{GT} = 57$, the same identified as Set-1 in [4]. In this scenario, the Rice fading channel is supposed non time selective over the entire OFDM symbol, and ideal interleaving is considered. Taking as reference OFDM performance over the AWGN channel, the loss over the linearly and non-linearly distorted channel is of 0.5 dB. When channel fluctuations are introduced, for Rice factor 10 dB the loss is 0.7 dB while for Rice factor 5 dB the loss reaches 1.1 dB. It shall be noted that also the unknown CSI curves are reported and in this case the degradation is in the order of 0.9 dB and 2.1 dB for Rice factor 10 dB and 5 dB, respectively. This results can be considered very satisfactory taking into

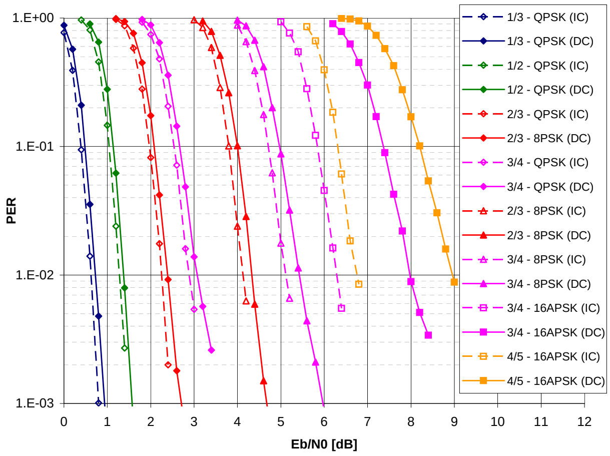

Fig. 5. WCDMA PER comparison between AWGN performance and non-linear distorted channel, IBO=2dB, with perfect CSI.

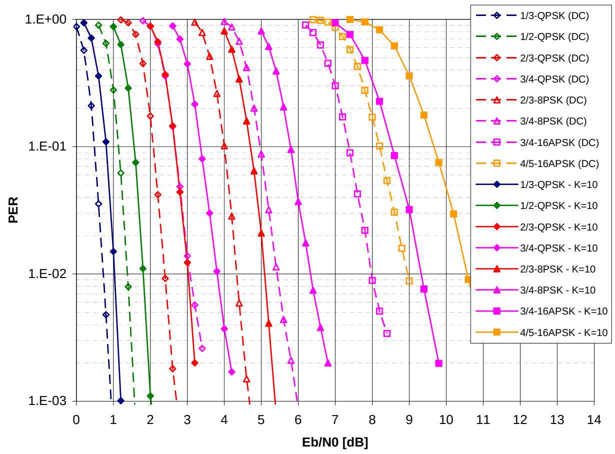

Fig. 6. WCDMA PER comparison between AWGN non-linear distorted channel, IBO=2dB, and Rice fading channel, K=10dB.

account the large sensitivity of the OFDM transformed signal to non-linear distortion.

IV. Summary and Conclusions

In this paper the WCDMA turbo code with several coding rates and modulation formats has been simulated in a satellite environment with flat and time selective Ricean fading channel and in the presence of strong non-linear distortion. Of course, increasing the coding rates or the modulation order the PER performance decreases with respect to the AWGN channel condition, but is never dramatic. Moreover, preliminary results for OFDM technique for the same previous channel condition are reported. The outcome has been very satisfactory and, in particular, it has been verified that OFDM technique is also applicable in such a mobile satellite scenario.

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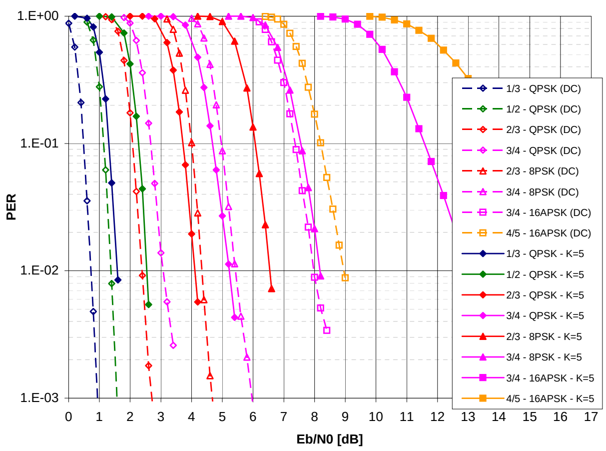

Fig. 7. WCDMA PER comparison between AWGN non-linear distorted channel, IBO=2dB, and Rice fading channel, K=5dB.

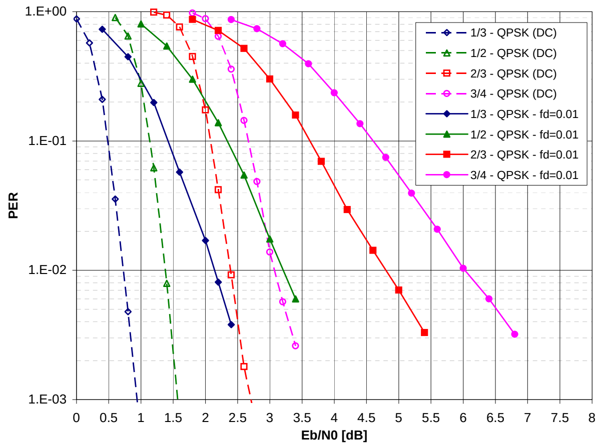

Fig. 8. WCDMA PER comparison between AWGN non-linear distorted channel, IBO=2dB, and Rice fading channel, K=10dB, with $f_d = 0.01$. QPSK modulation is considered.

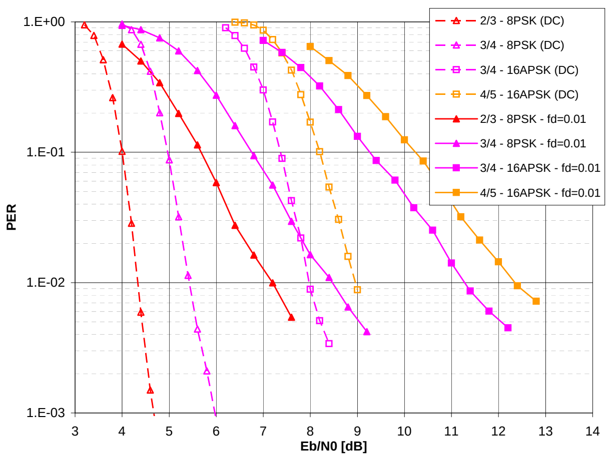

Fig. 9. WCDMA PER comparison between AWGN non-linear distorted channel, IBO=2dB, and Rice fading channel, K=10dB, with $f_d = 0.01$. 8-PSK and 16-APSK modulation are considered.

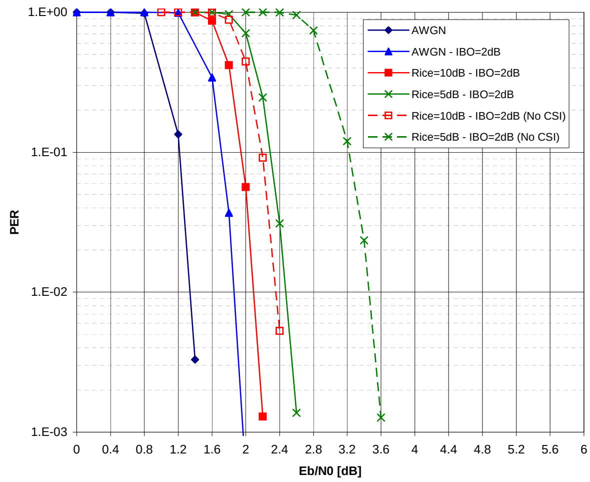

Fig. 10. OFDM results for QPSK and coding rate 1/3 in AWGN and flat Rice channel.