Satellite Profile in DVB-NGH

Physical layer technical choices and motivations

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Abstract—**Digital Video Broadcasting - Next Generation Handheld (DVB-NGH) is a hybrid terrestrial-satellite standard conceived to facilitate rich media content consumption using a variety of mobile, handheld devices. Still under drafting, the DVB-NGH specifications are to be released current 2012 with the target of offering superior performance, robustness and coverage with respect to existing solutions. The purpose of this paper is to give an overview of the physical layer of the satellite component of DVB-NGH and to give some insight on the motivation and technical choices that were made during the specification phase, with a focus on the waveform choice and on the pilot grid design.**

Keywords-DVB-NGH, satellite, SC-FDMA, SC-OFDM, hybrid pilot, PAPR.

I. Introduction

In the history of broadcast networks, the 1990s remain one of the most important milestones, since they mark the technology leap from analogue to digital. In the process of digitizing the traditional analogue broadcast systems, the family of Digital Video Broadcasting (DVB) standards has become the reference not only for digital television but also for data, sound and multimedia broadcasting world-wide.

DVB is a family of standardized technologies designed to facilitate broadcasting over terrestrial, cable, satellite and mobile communication systems, and to permit a large degree of user interaction. DVB standard development is at the charge of the DVB Project, an international industry-led consortium of around 250 broadcasters, manufacturers, network operators, software developers, regulatory bodies and others in over 35 countries. Specifications agreed by the DVB Project are then approved and published by a Joint Technical Committee (JTC) of European Telecommunications Standards Institute (ETSI), European Committee for Electrotechnical Standardization (CENELEC) and European Broadcasting Union (EBU).

DVB specifications cover a large variety of applications, but the most representative are satellite, cable and terrestrial transmissions. The DVB-S [1] system for digital satellite broadcasting (1993), based on Quaternary Phase Shift Keying (QPSK), is still used by most satellite broadcasters around the world for direct-to-home television services. The DVB-C [2] system for digital cable networks (1994) is centered on the use of 64 Quadrature Amplitude Modulation (QAM), and can, if needed, convey a complete satellite channel multiplex on a cable channel. Intended to cope with different noise and bandwidth environments, including multi-path, the digital terrestrial television system DVB-T [3] (1997) is so far one of the most widely adopted and deployed digital terrestrial transmission standards [4].

Due to the European analogue switch-off and increasing scarcity of spectrum, DVB drew up Commercial Requirements for more spectrum-efficient and updated standards, leading to a second generation of standards with increased capacity. DVB-S2 [5] (2005) provides higher modulation orders (16 and 32 Amplitude Phase Shift Keying (APSK)), adaptive modulation and coding and a very powerful forward error correction (FEC). DVB-T2 [6] includes increased capacity, robustness and the ability to reuse existing reception antennas. The first version was published in 2009, and the latest update (2011) included the T2-Lite subset for mobile and portable reception. Already deployed since 2010 (UK) DVB-T2 is promised to meet a big market success. So far 47 countries worldwide are considering DVB-T2 services.

Following the users request for mobility, technical specifications directed to handheld receivers also emerged. DVB-H (2004) is an enhancement of DVB-T designed to enable the efficient delivery of IP-encapsulated data over terrestrial networks using multi-protocol encapsulation and time slicing. DVB-SH (2010) is a satellite system with an optional terrestrial component allowing the use of a hybrid satellite/terrestrial mode. DVB-SH is designed to use frequencies below 3GHz (typically around 2.2GHz) in order to deliver video, audio and data services to vehicles and handheld devices.

As part of the evolution of the DVB family of standards, the newest emerging member is DVB-NGH, a terrestrial system with an optional satellite component allowing the use of a hybrid terrestrial-satellite mode. DVB-NGH is targeted for the new generation handheld (NGH) terminals. From a standardization point of view, the main technical choices were frozen at the end of 2011. Currently under drafting, the DVB-NGH specifications are to be released current 2012 (current target is September) and are expected to complement 3rd generation (3G) and beyond 3G telecom networks and offer superior performance with respect to existing DVB-H [7].

The purpose of this paper is to give an overview of the physical layer of the satellite component of DVB-NGH and to give some insight on the motivation and on the choices that were made during the specification phase. The paper is structured as follows: Section II situates the DVB-NGH technology within the DVB family and clarifies the design constraints. Section III describes some of the technical choices made during the physical layer design of DVB-NGH, such as waveforms, pilot grid structure, multiple antenna technologies. After further simulation evaluations in Section IV, Section V finally gives the conclusions of this paper.

II. DVB-NGH MARKET CONTEXT AND DESIGN CONSTRAINTS

The multimedia content market is going through a profound change, evolving from traditional linear content towards the consumption of a range of rich media content. The purpose of NGH is to ensure the delivery of this rich content, all in keeping pace with the user's demand and user's behavior, which have significantly evolved since the launch of DVB-H. NGH aims at having better performance and robustness, better indoor coverage, lower power consumption and shorter service interruption than DVB-H. NGH is targeting a wide range of devices, from wearable devices (earphones, mobile phones, MP3 players) to laptops and vehicle mounted receivers [7].

DVB-NGH emerges in a context marked, on one hand, by the success of the DVB family of standards, and on the other hand by the tremendous development of mobile cellular networks, delivering multimedia broadcast and multicast services. DVB-NGH is not a competitor of mobile cellular networks such as Third Generation Partnership Project (3GPP) / Long Term Evolution (LTE), in the sense that it may serve as a complementary overlay network, particularly in areas and at times where the broadcast capabilities of mobile cellular networks have limited capacity or coverage.

To avoid market segmentation among DVB standards, NGH needs to deliver a significant improvement over existing systems. DVB-T2, representing an important improvement with respect to DVB-T, is not optimized in mobility scenarios. DVB-H and DVB-SH, designed to support mobility, re-used most of the DVB-T physical layer, adding significant improvements in physical / transport layer coding and interleaving. NGH inherits the major improvements of DVB-T2, DVB-H and DVB-SH such as the concepts of extension frames (DVB-T2), time slicing (DVB-T2, DVB-H), flexible time interleaving and hybrid satellite/terrestrial coverage provision (DVB-SH). But DVB-NGH also exploits some new promising technologies: improved air interface (new waveform for the satellite component, optimized coding and interleaving), better Doppler performance with low pilot symbol overhead, and multiple-input multiple-output (MIMO) techniques. Each of the here-above cited technologies will be further described in the following section.

DVB-NGH standard specifies a sheer terrestrial profile and an optional hybrid terrestrial-satellite profile in the aim of improving the coverage of the terrestrial networks. Satellite transmissions require specific system parameters compatible with the propagation channel but also with the technological constraints of the satellites themselves. On top of those lies the high power amplifier (HPA) that is due to bring the signal to be transmitted at a level compatible with the receiver sensibility over large areas. In order to guarantee the durability of the satellite, it is critical to keep a low power consumption of the system, and thus to optimize the amplifier power efficiency, i.e. to drive the amplifier close to saturation. This is the reason why Single Carrier (SC) modulations, sometimes called Time Division Multiplexing (TDM) modulations, (where the multiplexing aspect should be seen as multiplexing between services and not between users) have been the reference scheme for satellite transmissions for a long time.

The evolution of the DVB specifications family was also accompanied by technology changes, especially at the level of the radio interface. While DVB-S and DVB-S2 rely on single-carrier (SC) sequential transmission, DVB-T marked the step towards Multi-Carrier (MC) transmission, embodied by the use of coded orthogonal frequency division multiplexing (OFDM). DVB-T2, DVB-H, DVB-T2 lite and one profile of DVB-SH also rely on OFDM.

Lately, OFDM became very popular in the world of wireless terrestrial communications for its well-known advantages: good spectral efficiency, good coverage, flexible resource allocation, simple equalization at tone level [8], etc. Almost all of the recent wireless communication standards (*e.g.*, IEEE 802.11n for wireless local area networks - WLAN, IEEE 802.16e-2005 for mobile WiMAX, etc.) rely on orthogonal frequency division multiple access (OFDMA) or one of its derivatives. But OFDM/OFDMA has the drawback of high peak-to-average power ratio (PAPR), which is a common characteristic of all MC modulations [9]. Significant efforts are being made to efficiently reduce the PAPR [10] in order to avoid nonlinear effects when passing through a HPA.

For the uplink of 3GPP/LTE, an OFDMA-based air interface, called Single-Carrier Frequency Division Multiple Access (SC-FDMA) was chosen. The precoder is a Direct Fourier Transform (DFT), which restores the low envelope fluctuations of SC systems [11], resulting in a waveform that combines the advantages and robustness of OFDMA with the low PAPR of SC transmission. These properties are very promising for satellite applications, where the HPA nonlinearities are a stringent issue.

Largely investigated in the wireless cellular communications world, SC-FDMA is now a mature technology that starts to gain popularity in the DVB world. As detailed in the following section, SC-FDMA has already been adopted as one of the waveforms for the satellite profile of DVB-NGH since 2011. SC-FDMA was recently investigated and recognized as a promising technique for the mesh profile of the second generation standard for return channel satellite (DVB-RCS2) [12]. SC-FDMA was not incorporated in the normative part of the DVB-RCS2 standard, but an informative annex on the performance of SC-FDMA is included in the DVB-RCS2 guidelines, released in June 2012.

III. SATELLITE PROFILE IN DVB-NGH

Two profiles are defined in DVB-NGH, for a transmission in the L and S bands: a sheer terrestrial profile (also called core profile) based on OFDM and a hybrid satellite-terrestrial profile relying on two reference waveforms: SC-FDMA and

OFDM. Since there is no user specific multiple access in NGH, SC-FDMA with full spectral allocation was called SC-OFDM in order to stress out the broadcasting aspect. When employing the hybrid profile, the NGH terminal will simultaneously receive two waveforms and combine their outputs to a single stream. The hybrid profile can be transparent to the receiver, when an identical signal is transmitted by the terrestrial and satellite transmitters (Single Frequency Network (SFN) mode). However, two different waveforms (Multiple Frequency Network (MFN) mode) can be used, one transmitted from terrestrial stations, one from the satellite. In this paper we will concentrate on the SC-OFDM satellite component of the hybrid profile, which can thus be used either in an MFN configuration with SC-OFDM on the satellite component in the L or S band and OFDM on the terrestrial component in the VUHF band, or in SFN configurations where the terrestrial emitter is a gap filler. The parameters of the SC-OFDM satellite component are described in Table I.

TABLE I. SC-OFDM IN DVB-NGH: SYSTEM PARAMETERS

Bandwidth	2.5 MHz	5 MHz
Sampling Freq.	20/7 MHz	40/7 MHz
FFT Size (*N*)	0.5K, 1K and 2K (512, 1024 and resp. 2048)	
Guard Interval	1/16 and 1/32 (with respect to *N*)	
Constellation	QPSK and 16QAM	

As far as the channel code is concerned, the satellite component is using the same scheme as the terrestrial OFDM component, i.e. a 16K Low Density Parity Check (LDPC) code followed by an outer BCH code. In the simulation section and for simplicity, only the LDPC code was simulated. As for the higher layers, they were inherited from DVB-T2 without any satellite specific modification.

A. *Waveform selection*

Figure 1. presents the baseband structure of a general MC transmitter, which applies to all types of SC or MC modulation signals transmitted in blocks. Data blocks of size M are precoded with the [M×M] matrix **P**. The M-sized output vector is then mapped on M out of N inputs of the inverse DFT according to the subcarrier mapping [N×M] matrix **Q**. In a broadcasting context, only M-N guard subcarriers are inserted at band edges and matrix Q can be expressed as:

$$\mathbf{Q}_{N\times M} = \begin{pmatrix} \mathbf{0}_{q\times M} \\ \mathbf{I}_M \\ \mathbf{0}_{(N-q-M)\times M} \end{pmatrix}, \quad (1)$$

where $\mathbf{0}_{M\times N}$ is the all-zero matrix of size [M×N] and $\mathbf{I}_M$ is the [M×M] identity matrix. To combat the effect of the frequency selective channel, a cyclic prefix of length CP (also called guard interval in DVB) is inserted in front of each N-sized block delivered by the inverse DFT.

The trivial case when **P** is the identity matrix, $\mathbf{P} = \mathbf{I}_M$, leads to OFDM. By using the discrete Fourier matrix as precoding matrix, we obtain SC-OFDM, which is in fact a DFT-precoded OFDM waveform. DFT precoding with the precoding matrix in (2) restores the single-carrier nature of the signal and thus the low envelope fluctuations:

$$\mathbf{P} = \left[p_{k,n} \right], \quad p_{k,n} = \exp\left(-j2\pi \frac{kn}{M} \right) \quad (2)$$

SC-OFDM has strictly the same PAPR as classical SC (TDM) transmission (evaluated at the same roll-off), and this PAPR is known to be significantly lower than the PAPR of OFDM. The lower PAPR allows SC-OFDM to suffer lower degradation when passing through a nonlinear HPA and can bring up to 1.5dB of performance improvement in a satellite scenario, as it will be confirmed in the following section.

Due to the intrinsic orthogonality between its subcarriers, SC-FDMA does not require the use of a roll-off and is usually employed with zero roll-off. This brings a capacity gain with respect to SC (TDM) transmission, where a typical roll-off of 20-35% is generally employed (DVB-S, DVB-S2) and where zero roll-off is not used because of pulse shaping issues. The OFDM-based structure of SC-FDMA brings another important advantage in NGH: receiver commonality between OFDM and SC-OFDM waveform-based profiles. SC-OFDM can be implemented by NGH receivers (already able of implementing OFDM for the mandatory sheer terrestrial profile) with minimum modifications, as stressed out in Figure 2., where AFC stands for automatic frequency control and P1 represents the synchronization symbol having a common OFDM-based structure for all NGH profiles. While the receiver commonality can to some extent apply to SC transmission with frequency-

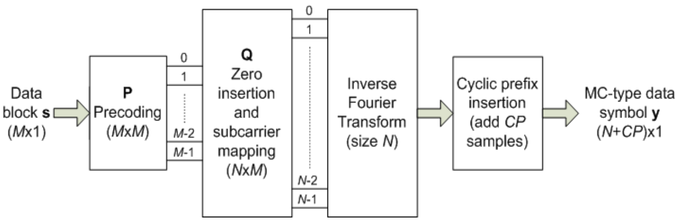

Figure 1. General MC transmitter.

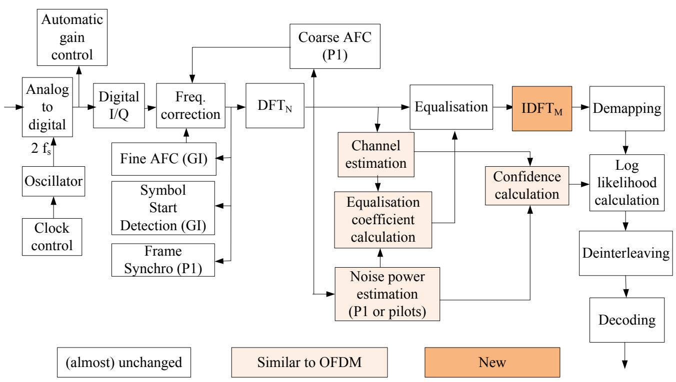

Figure 2. SC-OFDM receiver

domain equalization (SC-FDE), the main advantage of SC-OFDM is the framing flexibility. In SC-OFDM pilots can easily be inserted in the frequency domain.

In DVB-NGH, SC-OFDM was chosen in addition to OFDM because of the superior performance in the presence of nonlinearities, and was chosen over SC-FDE due to its capacity to work at zero roll-off, the OFDM-like framing flexibility and the strong commonalities with the OFDM receiver.

B. Pilot grid selection

As discussed in the previous subsection, one strong advantage of OFDM-based transmission is its flexibility and the possibility to use pilots scattered in the time and frequency domains. This flexibility opens the door to simple pilot grid design, dimensioned according to the channel characteristics such as frequency selectivity or Doppler spread. DVB-T2 specifies for example eight different pilot patterns (PP) in order to robustly cope with different channel profiles. One of the densest, PP1, is depicted in Figure 3. a).

This type of scattered pilot pattern, well suited for OFDM systems, is not compatible with the low PAPR variations of SC-OFDM. Indeed, the irregular mapping of the data-bearing remaining subcarriers strongly degrades the PAPR of the hybrid data-pilot symbol when SC-OFDM is used. In the uplink of 3GPP LTE, based on SC-FDMA, full pilot symbols are employed [11] as depicted in Figure 3. b).

One of the design constraints of NGH was to keep low overhead, as described in Section II. If full LTE-like pilot symbols were to be used, two consecutive NGH full pilot symbols would need to be separated by 11 data symbols in order to keep the same pilot overhead as PP1 of DVB-T2. But large time-domain pilot spacing (larger than the time coherence of the channel) strongly degrades the performance of the channel estimation, especially in high mobility scenarios. For these reasons, the SC-OFDM mode of the NGH hybrid profile specifies a new pilot pattern (defined as PP9 and depicted in Figure 3. c).

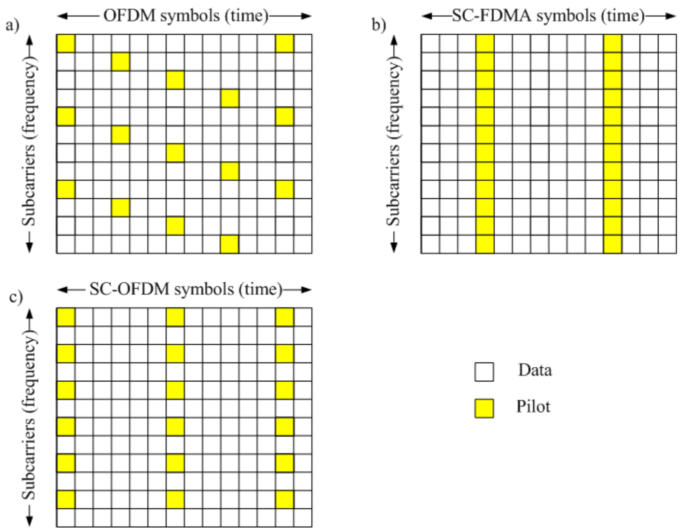

Figure 3. Pilot grid: a) DVB-T2 PP1; b) LTE SC-FDMA uplink; c) DVB-NGH for SC-OFDM

Typically, Zadoff-Chu (ZC) sequences [16] are used as pilot patterns, due to their low PAPR and their good orthogonality and correlation properties. ZC sequences are constant amplitude zero autocorrelation (CAZAC) sequences, both in the time and in the frequency domain. If we denote by L the ZC sequence length, then the complex value at each position k of each p-root ZC sequence with integer shift l is:

$$x_k = e^{-2j\frac{\pi}{L}\left(p\frac{k^2}{2}+lk\right)} \tag{3}$$

Here, we consider a ZC sequence with an even length. Constant amplitude should be understood as evaluated on a non-oversampled ZC sequence. After oversampling of digital to analog conversion, the ZC sequence is not constant amplitude, but has very low envelope fluctuations, lower than the fluctuations of a typical TDM QPSK sequence. As only one sequence is needed, we selected p=1 and l=0.

In order to have robust channel estimation in mobility scenarios and keep low pilot overhead, we need to mix pilots and data into a hybrid SC-OFDM symbol, which can be mathematically described as the sum between the data and the pilot part of the symbol. In order to limit the PAPR increase of the resulting symbol, in NGH a ZC sequence shifted by a half sample period is used:

$$x_k = e^{-2j\frac{\pi}{L}\left(k^2+0.5k\right)} \tag{4}$$

The introduction of the fractional time shift is justified as follows: the global signal, in frequency or time dimensions, corresponds to the sum of two multiplexed signals, data and pilots. As the interpolation is a linear process, the global interpolated signal corresponds also to the sum of two signals: the interpolated data signals and the interpolated pilot signals. For the data in the time domain, if no interpolation is performed and if a x-PSK constellation is used, a constant amplitude is obtained every sample period, and the maximum peaks after interpolation are placed just in-between these time instants. The same phenomenon occurs with the classical ZC sequence. Therefore, in this case, we add two signals, the peaks of which are placed at the same positions. By time shifting the ZC sequence of half a sampling period, the peaks of each signal are now interleaved. This implies that the peaks of the global signal, sum of both, are reduced. If a non constant constellation is used, e.g. 16QAM, the amplitude is no longer constant every sample period. However, the peaks will still be placed at the same positions, i.e. just in-between these time instants, and the peaks of the global signal will still be reduced by modifying the original ZC pilot sequence.

Therefore, DVB-NGH uses for the SC-OFDM satellite component a hybrid symbol with controlled PAPR, containing half data and half pilots placed on interleaved positions, where the pilot sequence is a ZC sequence shifted by a half sample period.

C. MIMO techniques

With an increasing pressure on both the frequencies (analog switch off and digital dividend) and the bandwidth requirements, it is critical to take the most of the available spectrum. Just like almost all the recent wireless systems, the DVB-NGH system relies on multi-antenna schemes to either improve the robustness (spatial diversity) or to increase the capacity (spatial multiplexing) of the broadcasting transmissions. Several options exist for the sheer terrestrial transmission, including rate-1 transmit diversity (Alamouti) and rate-2 spatial multiplexing.

For the hybrid satellite-terrestrial profile, two schemes have been devised: hybrid MIMO SFN and hybrid MIMO MFN. SC-OFDM is not an option for hybrid MIMO SFN, where a synchronized effective SFN transmission can only exist in OFDM mode (terrestrial emitters other than gap fillers only implement OFDM). The hybrid MIMO MFN describes the case where the satellite and terrestrial parts of the transmission are on different carrier frequencies and do not necessarily share any common frame or symbol timing at the physical layer. At least one of the transmission elements (i.e. terrestrial or satellite) must be made using multiple antennas; otherwise the use case lies within the hybrid profile, not the hybrid MIMO profile. Dealing with the single MFN mode implying SC-OFDM (terrestrial component set according to the core profile and a satellite component in SC-OFDM mode), three MIMO configurations can be considered:

- MIMO terrestrial component drawn from the terrestrial MIMO profile and single input single output (SISO) SC-OFDM satellite transmission;
- SISO terrestrial transmission (base profile) and SC-OFDM satellite MIMO transmission using basic Spatial Multiplexing (SM);
- Both links operate in MIMO, where the terrestrial component operates in MIMO according to any scheme from the MIMO profile while the satellite link operates in SM mode.

It may be noted that the SM mode for SC-OFDM can be used for a stand-alone sheer satellite transmission. Moreover, the frequency domain implementation of SC-OFDM makes the SM decoding very simple.

IV. Simulation Results

Let us further investigate the performance of SC-FDMA in the satellite profile of DVB-NGH and support through numerical simulation the reasoning developed in Section III.

In order to evaluate the PAPR of different signals, the Complementary Cumulative Distribution Function (CCDF) of PAPR is often used. Nevertheless, CCDF of PAPR has one important drawback: it only gives information of one sample in each analyzed sample block. At a certain clipping probability, the CCDF of PAPR ensures that at least one peak per block has an important amplitude and is susceptible to suffer severe distortion when passing through a HPA, but gives no information on how many samples in that block are distorted. Yet, in practical scenarios it is of great interest to know how many samples have a certain level and are thus susceptible to be distorted, as all of these samples cause degradation. Severely clipping one single peak in a large block has a negligible effect but distortion (even mild) of a large number of samples might have unacceptable consequences. Lately, the CCDF of the instantaneous normalized power (INP) [13], [14], is more and more often considered instead of the CCDF of PAPR. The CCDF of INP indicates the probability that the INP at a sample level exceeds a certain threshold γ^2. In order to have a good approximation of the signal after digital to analog conversion, the signal must be oversampled at least 4 times before any evaluation of the envelope fluctuations.

Figure 4. plots the CCDF of INP of SC-OFDM, OFDM, and respectively hybrid data and pilot SC-OFDM symbols. Simulation parameters considered an FFT size of 0.5K (N=512) and QPSK signal mapping. An oversampling factor of 4 was considered. Results in Figure 4. confirm the overall low envelope fluctuations of the hybrid data and pilot SC-OFDM symbol. At a clipping probability per sample of $2 \cdot 10^{-2}$ SC-OFDM outperforms OFDM by 2dB and the hybrid symbol has close performance to SC-OFDM, with a slight degradation of 0.4dB. Since the hybrid symbol appears in a frame once every 6 SC-OFDM symbols, this slight degradation has overall no impact on the performance. At higher clipping probabilities the performance difference between SC-OFDM and OFDM is even higher, and the hybrid symbol has lower envelope variations than the SC-OFDM data symbol. We can also see that the shift of a half sample period brings some performance improvement (up to 0.3dB at a clipping probability per sample of 10^{-5}), for reasons detailed in section III.B. As expected, the proposed pilot pattern (one symbol out of two is a pilot symbol) outperforms pilot patterns with different insertion ratios. Performance of pilot insertion patterns of ratios 4 (like in Figure 3.a, one symbol out of four is a pilot) and 8 are also depicted. As expected, the irregular mapping of the data-bearing subcarriers degrades the CCDF of INP of the data part (and thus of the resulting hybrid symbol). The degradation is of 0.7dB and 0.8dB respectively at a clipping probability per sample of 10^{-2}.

CCDF of INP gives a good representation of the signal statistics but in order to have a more realistic evaluation of the system performance, the behavior of the signal in the presence of a nonlinear HPA needs to be analyzed. In order to limit the nonlinear effects such as spectral re-growth, out of band emission and in-band distortions, the nonlinear HPA needs to be backed-off with respect to its saturation level. Let us define the input/output back-off (IBO/OBO) as the difference, in dB, between the average signal power passing through a HPA and the input/output power saturation levels of that HPA.

For practical system design, the main relevant evaluation criterion is the necessary amount of OBO that is needed to reach some performance, e.g., a given bit error rate (BER) while complying with the spectrum mask requirements and the out-of-band radiation limits. For a system, the OBO is perceived as a power efficiency loss and needs to be minimized. But insufficient OBO results in high nonlinear distortions, and thus a performance loss that can be evaluated as a signal to noise (SNR) loss, ΔSNR with respect to the linear case. The loss ΔSNR increases with the decrease of OBO, and

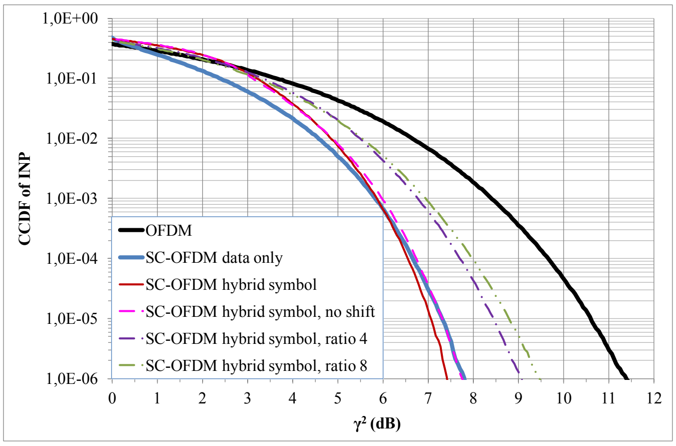

Figure 4. CCDF of INP of OFDM, SC-OFDM and SC-OFDM hybrid pilot and data symbol

tends towards zero at very high OBOs that push the signal into the HPA's linear zone. A trade-off ΔSNR vs. OBO needs to be found. This trade-off is generally represented by the total degradation (TD) curves which estimate the total degradation suffered by a system (ΔSNR + OBO) at a given IBO or OBO and at a given target performance.

In satellite applications, the linearized Travelling Wave Tube Amplifier (TWTA) is considered to be a realistic HPA model [15]. In the evaluations performed in DVB-NGH, we use a linearized TWTA introducing both amplitude distortions (AM/AM conversion) and phase distortions (AM/PM conversion) with parameters as described here-below. The AM/AM conversion is given by:

$$\left|v_{\mathrm{OUT}}(t)\right|_{\mathrm{dB}} = \sqrt{U} - \sqrt{U + V * \left|v_{\mathrm{IN}}(t)\right|^2_{\mathrm{dB}}}\ , \qquad (5)$$

with U = 24.29, V =1.28, v_{IN} and v_{OUT} are the signals at the input and respectively output of the TWTA HPA. The AM/PM conversion is piecewise linear curve having a slope K_p given by:

$$K_p = \begin{cases} 0 \text{ degrees/dB}, & \left|v_{\mathrm{IN}}(t)\right|_{\mathrm{dB}} = -\infty \ldots -15\mathrm{dB} \\ 0.2 \text{ degrees/dB}, & \left|v_{\mathrm{IN}}(t)\right|_{\mathrm{dB}} = -15\mathrm{dB} \ldots -9\mathrm{dB}\ . \\ 2.0 \text{ degrees/dB}, & \left|v_{\mathrm{IN}}(t)\right|_{\mathrm{dB}} = -9\mathrm{dB} \ldots 0\mathrm{dB} \end{cases} \qquad (6)$$

Figure 5. plots the total degradation (full line curves) and OBO (dotted curves) in function of IBO for SC-OFDM and OFDM for a target BER=10^{-5}. We used an FFT size of 0.5k (N=512) in the 5MHz bandwidth, QPSK signal mapping with a low density parity check code of rate 4/9. Since the satellite channel is usually not frequency selective we used an additive white Gaussian channel (AWGN) in order to investigate the nonlinear behavior of the two waveforms. When important IBO is performed, the TD is mainly given by the OBO value since there is virtually no non-linear ΔSNR loss. The OBO in function of IBO response obviously depends on the employed waveform. When low IBO is employed, forward error coding is no longer able to compensate the signal degradation introduced by the HPA. ΔSNR is higher for OFDM than for SC-OFDM because OFDM, having more important envelope fluctuations, suffers higher distortion. Overall, the TD of SC-OFDM is 1.5dB lower than the TD of OFDM, which validates the interest of using SC-OFDM rather than OFDM for satellite transmission.

As mentioned in the commercial requirements, DVB-NGH networks are expected to support moving terminals for speeds up to 350 km/h. The requirement applies to the satellite segment and thus to the SC-OFDM modulation. To illustrate the robustness the SC-OFDM modulation against Doppler degradation, let us further investigate the performance of channel estimation relying on the hybrid pilot symbol described in Section III.B. BER performance has been evaluated by simulation in the case of a Rice fading (K=5) under the following assumptions: 2.2 GHz carrier frequency, 5 MHz bandwidth, FFT size N=512 with GI=1/32, QPSK signal mapping, LDPC 4/9 error correcting code, time interleaving of 100ms and basic frequency tracking at the receiver.

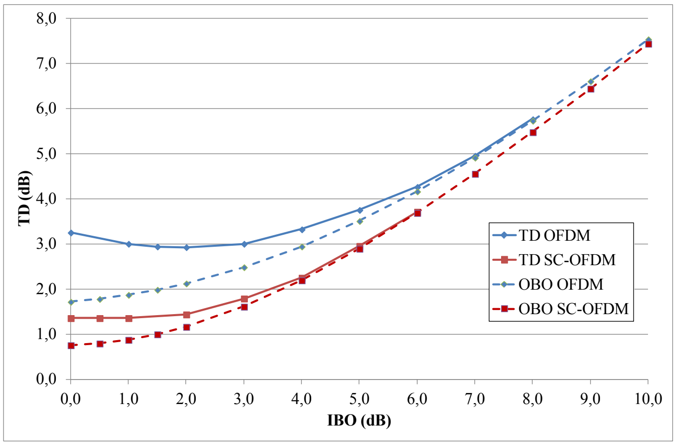

Figure 5. Total degradation and OBO against IBO for SC-OFDM and OFDM

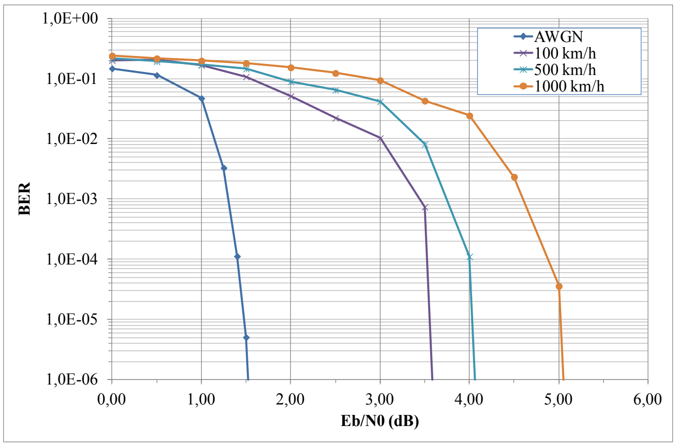

Figure 6. Doppler performance of SC-OFDM with hybrid pilot

Figure 6. depicts the result of the BER evaluation for 3 different speeds: 100, 500 and 1000 km/h. The results in Figure 6. confirms the robustness of the SC-OFDM modulation to Doppler degradations with a degradation of ~2 dB for a speed of 100 km/h and 3.5dB for 1000 km/h. These good results are also explained by the rather large subcarrier spacing due to the small FFT size used in the simulations (N=512).

Since the only MIMO scheme used in the NGH SC-OFDM profile is classical spatial multiplexing with classical performance, we will not further investigate this aspect in the current paper.

V. CONCLUSION

The newest member of the DVB family of standards, DVB-NGH, directed towards new generation handheld terminals, will be released current 2012. Besides a core terrestrial component, DVB-NGH encompasses a hybrid terrestrial-satellite profile. The current paper gives an overview of the physical layer of the satellite component of DVB-NGH, concentrating on the SC-OFDM waveform. The paper shows theoretical reasoning and simulation results that motivated the technical choices made during the standardization phase of DVB-NGH. The interest of using SC-OFDM in satellite applications is assessed by means of performance evaluation. A hybrid pilot symbol compatible with the low envelope variations of SC-OFDM and with the robustness to high mobility scenarios is presented and its good performance is proven by numerical simulations.

ACKNOWLEDGMENT

We would like to thank our DVB-NGH colleagues for constructive debates during NGH meetings. Moreover, this work has been performed in the framework of the CELTIC Engines project.

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