Adapting DVB-SH system parameters to mobile environments

Sokchenda Sreng
Université de Toulouse
INP-ENSEEIHT/IRIT
Toulouse, France
sokchenda.sreng@enseeiht.fr

Benoît Escrig
Université de Toulouse
INP-ENSEEIHT/IRIT
Toulouse, France
benoit.escrig@enseeiht.fr

Marie-Laure Boucheret
Université de Toulouse
INP-ENSEEIHT/IRIT
Toulouse, France
marie-laure.boucheret@enseeiht.fr

***Abstract*—A performance analysis of the digital video broadcasting - satellite to handheld (DVB-SH) system in presence of ground mobile terminals (GMTs) is presented. The paper focuses on the Doppler spread issue. Indeed, the mobility of GMTs induces a Doppler spread in the orthogonal frequency division multiplexing (OFDM) signal that destroys the orthogonality of subcarriers. The loss of orthogonality produces inter-carrier interference (ICI) and hence a degradation of the system performance in terms of symbol error probability. The paper presents the conditions in which this degradation can be compensated for by an increase in the signal to noise ratio (SNR) at the receiver side. The result depends on both the modulation scheme and the speed of GMTs. Inversely, having a maximum allowable margin on the received SNR allows us to determine an upper bound on the mobile station velocity.**

***Keywords*-DVB-SH; Doppler spreading; degradation.**

I. INTRODUCTION

DVB-SH is a broadcast standard for the delivery of video and data stream to GMTs. In a DVB-SH system, GMTs receive signals from two network segments: the Satellite Component (SC) and the Complementary Ground Component (CGC). The SC ensures geographical global coverage while the CGC provides cellular-type coverage. On the CGC, the OFDM modulation scheme has been chosen as it is the basis of both Digital Video Broadcasting - Terrestrial (DVB-T) and Digital Video Broadcasting - Handheld (DVB-H) systems. On the SC, two transmission schemes are available: Time Division Multiplexing (TDM) or OFDM leading to two reference architectures termed SH-A and SH-B. SH-A uses OFDM both on the satellite and the terrestrial link while SH-B uses TDM on the satellite link and OFDM for the terrestrial link.

The signals received by GMTs suffer from several impairments according to the corresponding segment: delay, Doppler shift and Doppler spreading. Delay and Doppler shift issues have been addressed in the DVB-SH standard [1] [2] by the implementation of a SH frame Information Packet (SHIP). This synchronization scheme is similar to the Megaframe Initialization Packet (MIP) in DVB-T and the pre-compensation of the time delay variation at the gateway location. The principles of synchronization can be summarized as follows.

- SHIP inserter performs the insertion of a GPS-based time stamp ($\pm 0.1\ \mu$s accuracy) in the SH-Frame indicating the transmission time of the beginning of the next SH Frame.
- Single Frequency Network (SFN) adapters in the transmitters (repeaters) perform buffering of incoming MPEG-TS packets and transmission of SH Frame aligned with GPS relative time stamp.

On the other hand, the Doppler spreading on DVB-SH signals has not been addressed to the same extend. This issue needs to be investigated more precisely because the Doppler spreading has a great impact on the physical layer performance. Indeed, the Doppler spread destroys the orthogonality of subcarriers in the OFDM signal and generate power leakage among subcarriers, known as ICI. The loss of orthogonality has been characterized in [3] [4] [5] [6]. In [6], the ICI and the degradation due to Doppler spreading have been evaluated. The purpose of this paper does not consist in proposing the receiving technique in order to reduce the Doppler spread instead system parameters will be adjusted in order to cope with the constraints. More precisely, the effect of the Doppler spread can be reduced by limiting the mobile velocity. Another approach consists in adding an additional margin on the received SNR per symbol. To avoid Doppler spread impairments, the speed of GMTs should not exceeds a maximum allowable value. This maximum allowable velocity should not induce a Doppler spread higher than 13.28% of the subcarrier spacing [7]. For example, when the carrier spacing in a 2k mode is 2.79 kHz, it has been shown that the system still achieves the target performance provided that the Doppler spread does not exceed a value of 0.37 kHz. This induces a maximum velocity for the GMT of 183.9 km/h.

In this paper, we propose another method to mitigate the Doppler spreading by compensating for the degradation of the SNR per symbol at the input of the decoder. The required margin can be estimated. We compute the difference in terms of SNR per symbol using the symbol error probability curve which is affected by a Doppler spread and another one without Doppler spreading. This method can be applied only to any OFDM modulation scheme of the CGC (e.g., SH-A and SH-B).

The rest of this paper is organized as follows. In Section II, we describe the Doppler spreading induced by the two segments of the DVB-SH system. In Section III, we evaluate the relation of the ICI and the degradation of SNR per symbol. In Section IV, methods of dimensioning are provided. Finally, the conclusions are given in Section V.

II. DOPPLER SPREADING IN DVB-SH SYSTEMS

A. Doppler spread induced on the SC segment

The satellite motion and the ground terminal mobility induce a Doppler shift and a Doppler spread [8].

- The Doppler shift ν_0 is given by, $\nu_0 = \frac{V_{sr}}{\lambda}$, where V_{sr} represents the radial velocity of the satellite and λ is the signal wavelength.
- The Doppler spread σ_ν is defined such that σ_ν^2 is a sum of three terms.

$$\begin{aligned}\sigma_\nu^2 &= \sigma_{\nu,g}^2 + \sigma_{\nu,s}^2 + \sigma_{\nu,ch}^2 \\ &= (\frac{V_g}{\Lambda_c})^2 + (\frac{\Omega_s}{\alpha_c})^2 + (\frac{1}{T_{ch}})^2 \qquad (1)\end{aligned}$$

The first term $\sigma_{\nu,g}^2 = (\frac{V_g}{\Lambda_c})^2$ is due to the ground terminal motion, where V_g represents the ground terminal velocity and Λ_c is the coherence length, usually of the order of the signal wavelength.

The second term $\sigma_{\nu,s}^2 = (\frac{\Omega_s}{\alpha_c})^2$ is the Doppler spread originated by the motion of satellite. Ω_s is the angular velocity of the satellite and α_c is the coherence angle. The angular velocity of the geostationary earth orbit (GEO) satellite should theoretically be zero. In practical cases, this parameter is non zero but it is some four orders less than the same parameter for a low earth orbit (LEO) satellite.

The third term $\sigma_{\nu,ch}^2 = (\frac{1}{T_{ch}})^2$ is the channel self Doppler spread, where T_{ch} is the characteristic time constant which describes the effects of moving and changing objects in the vicinity of the ground station.

B. Doppler spread induced on the CGC segment

On the CGC segment, the Doppler spread is mainly produced by the mobility of GMTs for fixed relay stations. For mobile relay stations, the total Doppler spread is the sum of the Doppler spreads induced by both GMTs and relay stations [9]. The average Doppler shift is zero. Let V_g be the velocity of the GMT and V_r, the velocity of the relay station, then the total Doppler spread can be expressed as:

$$F_d = \frac{V_g}{c} \times f_c + \frac{V_r}{c} \times f_c \qquad (2)$$

where f_c is the carrier frequency and $c = 3.10^8 m/s$ is the speed of light.

III. ICI AND DEGRADATION

In this section, we evaluate the ICI and the degradation of the SNR per symbol due to Doppler spreading. We assume that each subcarrier is transmitted in a frequency flat Rayleigh fading channel which corresponds to the channel between relay stations and GMTs. The OFDM system uses N subcarriers. For typical modulation schemes such as phase-shift keying (PSK) and quadrature-amplitude modulation (QAM), the carrier to interference ratio (C/I) on subcarrier i is given in [6] as:

$$\frac{C}{I} = \frac{1}{\frac{(NTF_d)^2}{2} \sum_{k=1,k\neq i}^{N} \frac{1}{(k-i)^2}} \qquad (3)$$

where F_d is the maximum Doppler spread. As in typical C/I computations, we assume that the interference produced by other subchannels is an additive noise. Without interference and Doppler spreading, the signal to noise ratio per symbol is E_s/N_0, where E_s denotes the mean energy received per symbol and $2N_0$ denotes the variance of the AWGN noise in an equivalent low pass channel model. With interference and Doppler spreading, the signal to interference plus noise ratio is $E_s/(N_0 + N_I)$, where $E_s = C/R_s$, $N_I = I/R_s$ and $R_s = 1/T$ is the input symbol rate. Then we obtain:

$$\frac{E_s}{N_0 + N_I} = \frac{\frac{E_s}{N_0}}{1 + \frac{E_s}{N_0}(\frac{C}{I})^{-1}} \qquad (4)$$

So, in decibel,

$$\begin{aligned}\Delta_{dB} &= [\frac{E_s}{N_0 + N_I}]_{dB} - [\frac{E_s}{N_0}]_{dB} \\ &= -10\log[1 + \frac{E_s}{N_0}(\frac{C}{I})^{-1}] \qquad (5)\end{aligned}$$

Equation (5) gives the degradation Δ_{dB} of the signal to noise ratio at the receiver when there are interferences between subcarriers.

The C/I curves of the middle subcarrier index $k = N/2$ are plotted versus the Doppler spread F_d in Figure 1 for several DVB-SH transmission modes at a carrier frequency of 2.175 GHz and a bandwidth of 5 MHz. The 8k mode is experiencing more interference than the other modes because its subcarrier spacing is smaller than the one of other modes.

For a given C/I of 15 dB, the 1k mode can support a Doppler spread of 800 Hz and Doppler spread of 400 Hz for the 2k mode. For the same value of C/I, the 4k mode allows a maximum Doppler spread of 200 Hz while the 8k mode can support only 100 Hz. According to these Doppler spread values, we can calculate the maximum allowable velocity for the GMT. The numerical values of the maximum allowable velocity for the GMT for a 5 MHz DVB-SH bandwidth channel at 2.175 GHz and C/I of 15 dB are shown in Table I. We see that the 1k mode allows the GMT moves at a maximum speed of 397.22 km/h while the 2k mode can support up to 198.61 km/h. On the other hand, the 4k

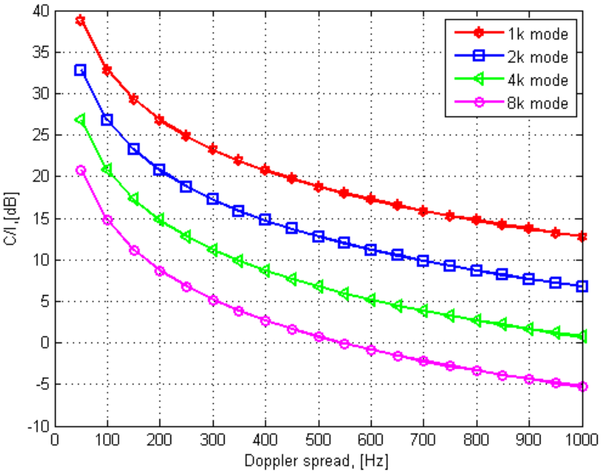

Figure 1. C/I curves as a function of Doppler spread.

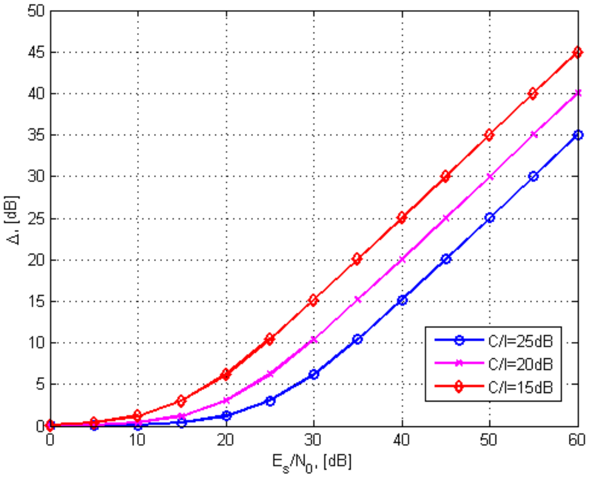

Figure 2. Degradation Δ_{dB} as a function of E_s/N_0.

mode provides a maximum allowable velocity for the GMT of 99.30 km/h. Finally, the 8k mode can only support at the maximum speed of 49.65 km/h.

Figure 2 illustrates the degradation due to Doppler spreading with respect to the E_s/N_0 ratio for several values of C/I. We observe that the degradation not only depends on the C/I ratio but also on the E_s/N_0 ratio. For small values of E_s/N_0, the degradation has less influence on the system performance. In particular, when E_s/N_0 is smaller than 10 dB the degradation is less than 2 dB.

IV. DIMENSIONING OF THE DVB-SH SYSTEM ACCORDING TO THE DOPPLER SPREADING

In this section, we express the degradation of SNR per symbol, E_s/N_0, which corresponds to the velocity of GMTs. This degradation is estimated by computing the difference in E_s/N_0 between the symbol error probability curve which is affected by the Doppler spreading and the one without Doppler spreading with respect to the same target value of symbol error probability. Figure 3 through 6 are plotted by using the expression of symbol error probability of Rayleigh OFDM QPSK and 16-QAM and replacing the expression of E_s/N_0 by $E_s/(N_0 + N_I)$ derived in (4).

Table I
MAXIMUM ALLOWABLE VELOCITY FOR THE GMT FOR A 5 MHz DVB-SH BANDWIDTH CHANNEL AT 2.175 GHz AND A C/I OF 15 dB

Mode	FFT size	Subcarrier spacing [kHz]	Doppler spread [Hz]	Maximum velocity [km/h]
1k	1024	5.580	800	397.22
2k	2048	2.790	400	198.61
4k	4096	1.395	200	99.30
8k	8192	0.698	100	49.65

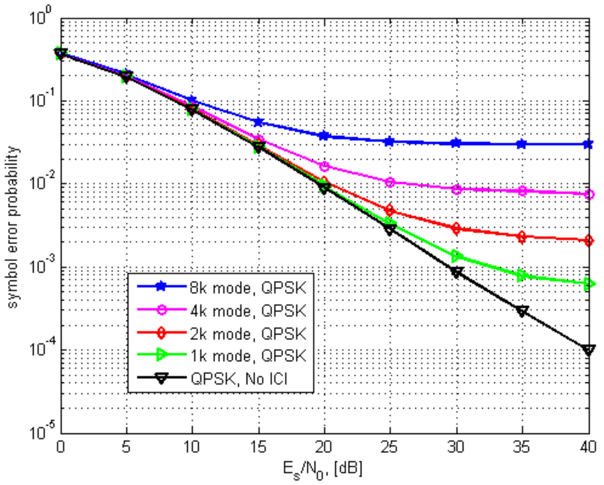

Figure 3. Performance of uncoded QPSK OFDM system in Rayleigh channel with carrier frequency f_c=2.175 GHz, and mobile speed of 50 km/h.

Figures 3 and 4 illustrate the symbol error probability of uncoded QPSK OFDM and uncoded 16-QAM OFDM for several modes of DVB-SH over a frequency-selective Rayleigh channel under the Doppler spread, F_d, of 100 Hz, corresponding to a mobile speed of 50 km/h. The carrier frequency is 2.175 GHz. When the E_s/N_0 is large, the ICI is the limiting factor in performance at any mobile speed. For example, when the target symbol error probability is in the order of 10^{-2}, the degradation of uncoded QPSK modulation are 0.5 dB for 1k mode, 1 dB for 2k modes, and around 6 dB for 4k mode while the degradation can not be computed (NC) for 8k mode. In case of uncoded 16-QAM, the degradation are 2 dB for 1k mode and NC for

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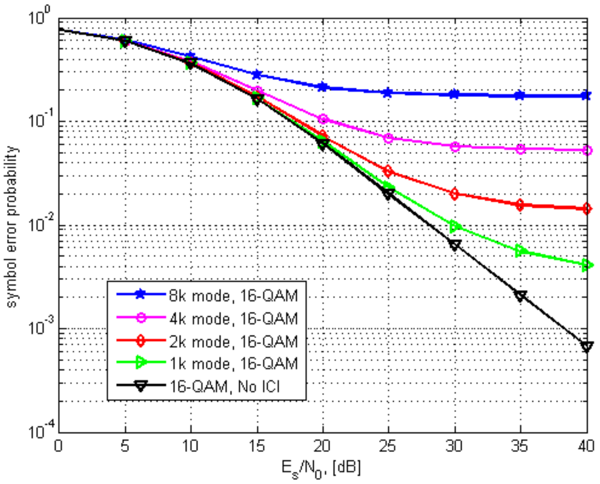

Figure 4. Performance of uncoded 16-QAM OFDM system in Rayleigh channel with carrier frequency f_c=2.175 GHz, and mobile speed of 50 km/h.

Table II
THE REQUIRED MARGIN FOR A 5 MHz DVB-SH BANDWIDTH CHANNEL AT 2.175 GHz AND MOBILE SPEED OF 50 km/h WITH TARGET SYMBOL ERROR PROBABILITY OF 10^{-2}

Mode	1k	2k	4k	8k
uncoded QPSK	0.5 dB	1 dB	6 dB	NC
uncoded 16-QAM	2 dB	NC	NC	NC

other modes. Hence, we can not compensate the degradation for uncoded QPSK 8k mode and the same for uncoded 16-QAM 2k, 4k and 8k mode.

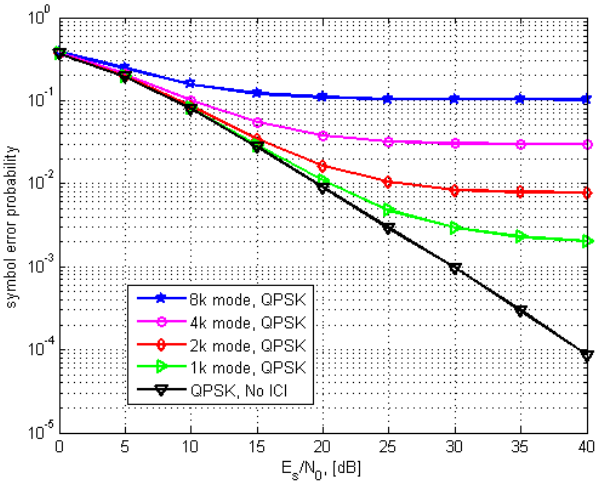

Figure 5. Performance of uncoded QPSK OFDM system in Rayleigh channel with carrier frequency f_c=2.175 GHz, and mobile speed of 100 km/h.

The other performance curves for uncoded QPSK OFDM and uncoded 16-QAM OFDM Rayleigh channel are plotted in Figures 5 and 6 with carrier frequency f_c=2.175 GHz under Doppler spread, F_d, of 200 Hz, corresponding to the mobile speed of 100 km/h. If the target symbol error probability is in the order of 10^{-2}, we see that only two modes of the uncoded QPSK modulation can be compensated for the degradation, 1 dB for 1k mode and 6 dB for 2k mode. The other modes are totally degraded and can not be compensated for because their minimum symbol error probabilities are higher then the target value.

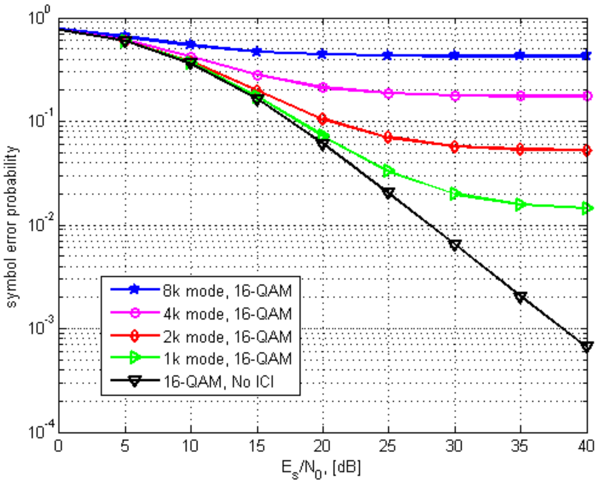

Figure 6. Performance of uncoded 16-QAM OFDM system in Rayleigh channel with carrier frequency f_c=2.175 GHz, and mobile speed of 100 km/h.

Table III
THE REQUIRED MARGIN FOR A 5 MHz DVB-SH BANDWIDTH CHANNEL AT 2.175 GHz AND MOBILE SPEED OF 100 km/h WITH TARGET SYMBOL ERROR PROBABILITY OF 10^{-2}

Mode	1k	2k	4k	8k
uncoded QPSK	1 dB	6 dB	NC	NC
uncoded 16-QAM	NC	NC	NC	NC

V. CONCLUSIONS AND FUTURE WORKS

In this paper, the maximum mobile speed of GMTs with respect to the required minimum C/I value was determined. Then the degradation was evaluated with respect to the target system performance. This degradation could be compensated for by the margin before decoding. It was also shown that the degradation does not only depend on the mobile velocity but also depend on the modulation scheme. For high Doppler spread, for example when the velocity of the GMT is 100 km/h, the DVB-SH system using 16-QAM OFDM modulation is totally degraded and the compensation is not possible. So, one way to solve this problem is to limit the velocity of the GMT to an appropriate level, which is one of the interesting subjects for future research.

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