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An Evaluation Mechanism for OFDM Modulation of the Channel in Mobile Radio Systems

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Abstract— **The goal of this article is to evaluate the transmission channel in mobile radio systems to OFDM (Orthogonal Frequency Division Multiplexing). In an OFDM system, the frequency band is divided into multiple orthogonal subcarriers. The speed and mobility fluctuation of the channel causes the loss of orthogonality of an OFDM system. Therefore, they introduce the ICI (Inter-Carrier Interference) type of interference at the receiver. This article proposes a mechanism that will allow not only to exploit channel estimation techniques, but also techniques to eliminate interference between carriers in the use of phase separation method for assessing the channel gains and that of the Doppler effect. The simulations are made under Matlab to measure the performance of our mechanism.**

Keywords-component; OFDM; Doppler; mobile radio; ICI; channel estimation

I. INTRODUCTION

In the past few years, wireless communication systems have made a revolution. Because of their relatively low cost, and the requirements due to the propagation medium (in places where the use of cables appears to be difficult), the wireless connection has been established and wireless communication systems have gained great popularity [5]. However, it is more difficult for an engineering system to maintain reliable communication in wireless channels on the cable channels. OFDM has been put forward as a better solution against multipath propagation. OFDM is one of the most powerful communication technologies which are implemented in current wireless communications systems. In OFDM, the transmitted high-speed data is converted into parallel data of N subchannels. Then, the transmitted data of each parallel subchannel is modulated by an adequate modulation scheme like quadrature phase shift keying (QPSK). These modulated data are fed into an inverse fast Fourier transform (IFFT) to generate the multicarrier OFDM signal. OFDM is a multicarrier modulation technology which has efficient spectrum utilization to support the transmission of high data rates [13]. Despite these advantages, the performance of OFDM is much less satisfactory in a scenario with high mobility communications where the Doppler effect plays an important role [6]. Thus in a frequency selective channel, certain frequencies are transmitted faster than others, or are attenuated more than others. The signal will be distorted during transmission so the data will be in time, and can lead to intersymbol interference [4]. This phenomenon of frequency selectivity is compounded by the presence of multiple paths for the same transmitted signal. Since the transmitted signal is reflected by many obstacles before arriving at the receiver, the receiver will then receive a series of echo amplitude and variable delays [6]. This issue of the multipath channel is critical in the case of a mobile radio channel [4].

The purpose of a multi-carrier modulation is to perform frequency division multiplexing based on the notion of orthogonal subcarriers. The change in gain of the channel during the period of a symbol results in the loss of orthogonality between the subcarriers, which makes the recovery of transmitted data at the receiver difficult. This phenomenon is known as inter-carrier interference. Our study stands within this context by proposing a mechanism to reduce significantly the effect of inter-carrier interference at a mobile radio communication in high-mobility OFDM.

The goal of this study is to propose a mechanism for elimination of ICI by distinguishing the assessment phase of the Doppler effect of the channel gains.

II. LITERATURE REVIEW

Studies on OFDM are a hot topic of interest in the area of wireless communication. Kowal et al. [8] present a simulation model of the MIMO (Multiple Input, Multiple Output)-OFDM system compliant with IEEE 802.11n. During the work on the simulation model the transmitter, the receiver and the model of telecommunication channel were developed. Signals generated at the transmitter output are fully compatible with signals described in IEEE 802.11n. Simulations are conducted on a radiofrequency, so they can be compared with results of measurements of real systems. Sanchez-Sanchez et al. [10] study the statistical distribution of the enhanced noise after zero forcing frequency domain equalization in an OFDM system transmitting over a Nakagami-m fading channel. With this purpose, they obtain the expression of the density function of the ratio between the modulus of a complex Gaussian random variable and that of an n-dimensional Gaussian random variable. From this expression, they derive the density and the distribution of the resulting noise term after zero forcing equalization. Lastly, they present an analytical expression for BER in the scenario under study which is validated through simulations. Sanchez-Martinez et al. paper [9] analyses the performance of an OFDM system on in-vehicle power line channels. The achievable bit-rate as function of the cyclic prefix length and the number of subcarriers is obtained over a set of measured channels. Statistical results are drawn and the system parameters design is undertaken determining the values that maximize the system performance. Bujalance et al. work [2] is about a performance evaluation for six scheduling algorithms over a MIMO-OFDM based cellular system. Performance evaluation is focused on average delay under different cell load conditions, which indirectly provides information on the capacity gain associated to each algorithm. S. M. Riazul Islam and Kyung Sup Kwak [15], study Estimation in MB-OFDM UWB Systems with Time Varying Dispersive Fading Channel. The estimation technique in this study can be efficiently used to estimate the channel in MB-OFDM UWB systems. Interpolation of higher order derivatives provides a pre-stage tracking of dispersive fading channel. And then the joint work of channel estimation and ICI suppression filter can successfully estimate the channel along with ICI elimination. Since this estimator can track the time varying nature of multipath channel, it can support mobility of high rate UWB nodes.

The Designing of a channel estimator is based on two fundamental issues: the amount of pilot symbols to be transmitted and the performance of the estimator with respect to various constraints of the transmission channel. However, there are some methods that use no driver information. These methods are called "blind" [12]. The channel estimation can be performed using the pilot symbol insertion on all the subcarriers of an OFDM symbol with a specific period, known as a "pilot by channel estimation of block ". This approach was developed under the assumption of a slow fading channel [7]. Using the pilot block, Peng et al. [11] propose an iterative channel estimation and ICI elimination leading to satisfactory results. Despite the performance obtained, this algorithm is still limited by the coherence time, which reveals that it is very sensitive to the Doppler effect [6]. Cao et al. [3] provide a mechanism for estimating that uses a polynomial expansion in the time-frequency domain to the frequency response of the channel. Hijazi [6] propose a mechanism by using the interpolation in the time domain.

III. METHODOLOGICAL APPROACH

The ICI interference is mainly due to the variation of the complex gain of the channel during transmission of a symbol. Usually, when it comes to the disposal problem of the ICI, it is considered that the rate of change of the gain depends on the type of channel [6], in this case, channel fading fast or slow. It is established that the variation of the gain depends on the ratio between the effective time of an OFDM symbol T_u and the channel coherence time [1], thus, this variation is directly related to the Doppler frequency. In this sense we can say that the absence of the Doppler effect (low mobility) implies that the complex gain of the channel varies slowly at the point where it can be considered constant during one OFDM symbol. The idea introduced in the proposed mechanism significantly simplifies the study of a high-mobility channel.

A. *Modeling of the Doppler effect and channel assessment*

In the case of transmission of an OFDM signal via a non-mobile channel, the complex gain of the channel is considered invariant for several OFDM symbols. In the presence of mobility, the complex gain of the channel varies sinusoidally and depends on the speed between the transmitter and receiver.

Referent by the formula channel by establishing M. A. Ahmed, S. A. Jimaa, and I. Y. Abualhaol [14], the signal at the input of the OFDM modulator becomes:

$$r_{(n)}(q) = \sum_{l=1}^{L} \frac{1}{N} \sum_{k=-\frac{N}{2}}^{\frac{N}{2}-1} x_{(n)}(k) W_N^{(k+\Delta_l)((q+nV)-\tau_l)} \tag{1}$$

where n is the index of the OFDM symbol being transmitted, N is the number of subcarriers, V is the number of samples in one OFDM symbol and τ_l is the propagation delay associated with the l^{th} path. After OFDM demodulation, we have:

$$y_{(n)}(m) = \frac{1}{N} \sum_{l=1}^{L} \sum_{k=-\frac{N}{2}}^{\frac{N}{2}-1} x_{(n)}(k)\, W_N^{k\tau_l} h_l / \sum_{q=0}^{N-1} W_N^{-\Delta_l(nV)} W_N^{-\Delta_l(q)} W_N^{(m-k}$$

where $W_N^s = e^{-j2\pi\frac{s}{N}}$, $x_{(n)}$, $y_{(n)}$ and L respectively represent the n^{th} OFDM symbol transmitted, the n^{th} OFDM symbol received and the number of paths in the channel. The simulations performed to model this type of channel showed that the amplitudes of harmonics located between the two ends of the spectrum of Jakes are relatively low compared to the amplitudes of the two extreme components. This allows us to neglect the flat spectrum and represent the complex gain of l^{th} path by:

$$h_l(t) = g_l(e^{j2\pi f_d t} + e^{-j2\pi f_d t}) \tag{3}$$

By making $t = (q + q_0)T_s$, where T_s and q_0 respectively represent the sampling period and the initial time, g_l is the complex gain of channel without Doppler effect, we obtain from (3):

$$h_l(q) = g_l W_N^{\Delta_l q_0} W_N^{\Delta_l q} + g_l W_N^{-\Delta_l q_0} W_N^{-\Delta_l q} \quad (4)$$

By making $g1_l = g_l W_N^{\Delta_l q_0}$ and $g2_l = g_l W_N^{-\Delta_l q_0}$, equation (4) becomes:

$$h_l(q) = g1_l W_N^{\Delta_l q} + g2_l W_N^{-\Delta_l q} \quad (5)$$

Taking into account equation (5), equation (2) of the nth received symbol becomes:

$$y_{(n)}(m) = \sum_{l=1}^{L} \sum_{k=-\frac{N}{2}}^{\frac{N}{2}-1} x_{(n)}(k)\, W_N^{k\tau_l} \left\{ g1_l \sum_{q=0}^{N-1} W_N^{\Delta_l mV} W_N^{\Delta_l(q)} W_N^{(m-k)q} + g2_l \sum_{q=0}^{N-1} W_N^{-\Delta_l nV} W_N^{-\Delta_l(q)} W_N^{(m-k)q} \right\} \quad (6)$$

B. Evaluation of the Doppler effect Evaluation of the Doppler effect

In this step, we estimate the parameter c that characterizes the maximum Doppler spectrum at Jakes. To this end, we assume that the maximum Doppler is the same for all routes of the channel. To evaluate this parameter, we have provided the transmission of a training sequence containing three identical pilot symbols:

$x_{(1)}(k) = x_{(2)}(k) = x_{(3)}(k)$, which allows to estimate the three unknown parameters, namely: $g1, g2$ and c.

The equation of nth received symbol can be written in the form $I_{(n)} = Q * y_{(n)}$ where Q is a matrix of dimension *(2L,N)* which the generic element is of the form $Q(\psi, m) = W_N^{m\psi}$. We have:

$$I_{(n)}(\psi) = \sum_{m=-\frac{N}{2}}^{\frac{N}{2}-1} Q(\psi, m) \sum_{l=1}^{L} \sum_{k=-\frac{N}{2}}^{\frac{N}{2}-1} x_{(n)}(k)\, W_N^{k\tau_l} / \left\{ g1_l \sum_{q=0}^{N-1} W_N^{\Delta_l mV} W_N^{\Delta_l(q)} W_N^{(m-k)q} + g2_l \sum_{q=0}^{N-1} W_N^{-\Delta_l nV} W_N^{-\Delta_l(q)} W_N^{(m-k)q} \right\} \quad (7)$$

We noted that $I_{(n)}(\psi)$, $I_{(n-1)}(\psi)$ and $I_{(n-2)}(\psi)$ can be reformulated as a function of the parameter c.

From these three relationships, a second degree equation giving the parameter c is extracted :

$$c^2 - \frac{\left(I_{(n)}(\psi) + I_{(n-2)}(\psi)\right)}{I_{(n-1)}(\psi)} c + 1 = 0$$

(8)

Solving this equation leads to two solutions, one relating to the term $W_N^{\Delta V}$ and the other representing the term $W_N^{-\Delta V}$. The desired Doppler spread can then be calculated from $\Delta = \frac{\arg(c)}{V}$.

C. Evaluation of profile

Once the Doppler effect is known, one can calculate the complex gains of the paths by using the vector $I_{(n)}$. To simplify the matrix representation, we introduce the following two variables to condense the notation

$$g_{\lambda,n} = \begin{cases} g1_\lambda c^n & , \quad \lambda = 1, \dots, L \\ g2_{\lambda-L} c^{-n} & , \quad \lambda = L+1, \dots, 2L \end{cases} \quad (9)$$

$$\Delta_\lambda = \begin{cases} \Delta_\lambda & , \lambda = 1, \dots, L \\ -\Delta_{\lambda-L}, & \lambda = L+1, \dots, 2L \end{cases} \quad (10)$$

$$\tau_\lambda = \begin{cases} \tau_\lambda & , \lambda = 1, \dots, L \\ -\tau_{\lambda-L}, & \lambda = L+1, \dots, 2L \end{cases} \quad (11)$$

We have :

$$I_{(n)}(\psi) = \sum_{\lambda=1}^{2L} g_{\lambda,(n)} M_{(n)}(\psi, \lambda) \quad (12)$$

where

$$M_{(n)}(\psi, \lambda) = \sum_{m=-\frac{N}{2}}^{\frac{N}{2}-1} \sum_{k=-\frac{N}{2}}^{\frac{N}{2}-1} Q(m, \psi) W_N^{k\tau_\lambda} x_{(n)}(k) \sum_{q=0}^{N-1} W_N^{\Delta_\lambda(q)} W_N^{(m-k)q}$$

$\psi, \lambda = 1, \dots, 2L$

Thus in matrix notation, the vector $I_{(n)}$ can be written in the form:

$$I_{(n)} = M_{(n)} g_{(n)} \quad (14)$$

which provides:

$$g_{(n)} = M_{(n)}^{-1} I_{(n)} \quad (15)$$

D. Calculation of the channel matrix

In the first two steps, we evaluated all the parameters of the channel. In this section we calculate the channel matrix $H_{(n)}$ on the n^{th} symbol, using the complex gains obtained from the symbol of rank $(n-1)$, which leads to (16):

$$y_{(n)}(m) = \sum_{k=-\frac{N}{2}}^{\frac{N}{2}-1} x_{(n)}(k) \sum_{\lambda=1}^{2L} W_N^{k\tau_\lambda} g_{\lambda,n} \sum_{q=0}^{N-1} W_N^{\Delta_\lambda(q)} W_N^{(m-k)q} \quad (16)$$

Equation (16) in compact form is expressed by (17):

$$y_{(n)}(m) = \sum_{k=-\frac{N}{2}}^{\frac{N}{2}-1} x_{(n)}(k) H_{(n)}(m, k) \quad (17)$$

with

$$H_{(n)}(m, k) = \sum_{\lambda=1}^{2L} W_N^{k\tau_\lambda} g_{\lambda,n} \sum_{q=0}^{N-1} W_N^{\Delta_\lambda(q)} W_N^{(m-k)q} \quad (18)$$

The term $g_{\lambda,n}$ can be calculated from $g_{\lambda,n-1}$ in a recursive form as follows:

$$g_{\lambda,n} = \begin{cases} g1_\lambda c^n = c\, g1_\lambda c^{n-1} = c g_{\lambda,n-1} \\ \quad for \quad \lambda = 1, \dots, L \\ g2_{\lambda-L} c^{-n} = c g2_{\lambda-L} c^{-n-1} = c^{-1} g_{\lambda-L,n-1} \\ \quad for \ \lambda = L+1, \dots, 2L \end{cases} \quad (19)$$

IV. RESULTS AND DISCUSSION

To analyze the performance of our mechanism, we used two metrics, namely the bit error rate (BER) and the mean square error (MSE) between the transmitted data and those estimated at the reception. This mechanism was tested as a function of signal to noise ratio (SNR) of the AWGN (Additive White Gaussian Noise) component and the parameter of the Doppler effect $f_d T$ using two modulation types, namely the QPSK and the 8PSK. The OFDM system analyzed in our sample consists of 128 subcarriers with a guard interval of 16Ts.

The curves in Fig. 1 and Fig. 2 illustrate the variation of BER and MSE as a function of SNR for a set of Doppler parameters $f_d T = 0.03$, $f_d T = 0.05$ and $f_d T = 0.1$ describing a range of Doppler effects ranging from mild to medium mobility (Doppler parameter corresponds to $f_d T = 0.1$ a speed of 333km/h for 5GHz carrier).

According to Figures 3 and 4, we note that the variation of the Doppler effect has little influence on the error rate in contrast to the effect of the SNR which is considerable.

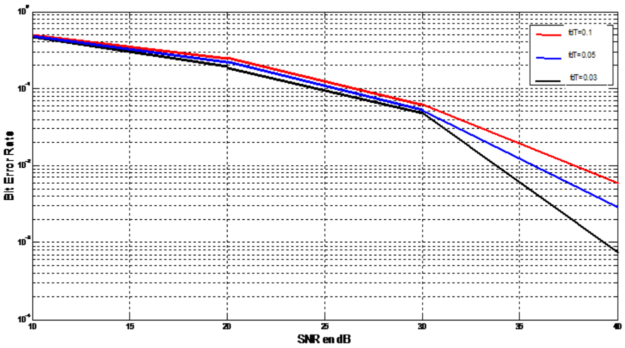

Figure 1. BER as a function of SNR

In Fig. 5, we conducted a comparison in terms of BER between the proposed method based on the distinction of the Doppler effect and that developed by Hijazi [6]. The results are obtained based on the Doppler parameter for an SNR of 40 dB. We note that the method of Hijazi provides a better error rate than ours in the presence of additive noise. This proves, once again, that our algorithm is designed to handle the pure Doppler and must associate screening procedures to reduce the effect of AWGN noise.

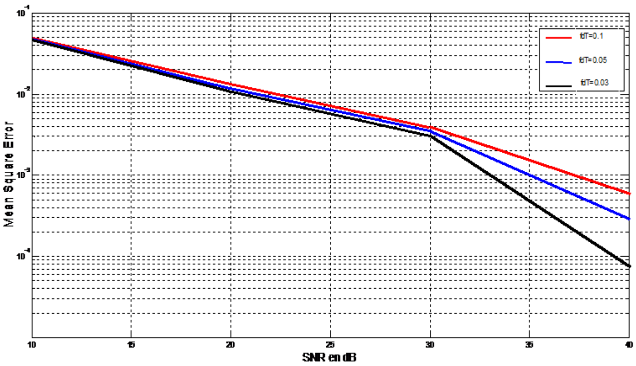

Figure 2. MSE as a function of SNR

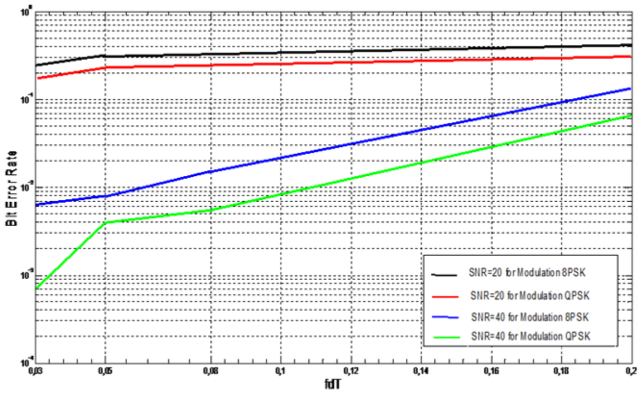

Figure 3. BER as a function of $f_d T$ for SNR=20 dB and 40 dB with a constellation QPSK, 8PSK

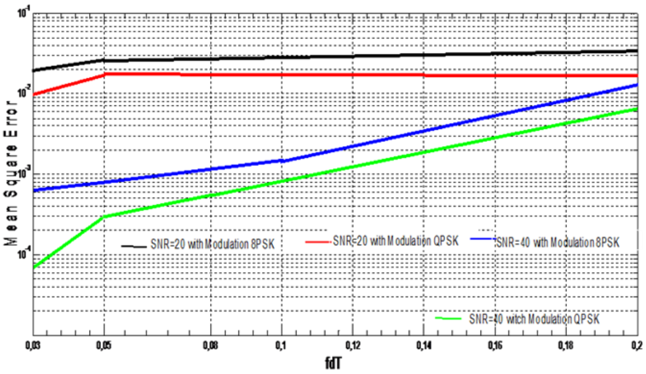

Figure 4. MSE as a function of $f_d T$ for SNR=20 dB and 40 dB with a constellation QPSK, 8PSK

The mechanism we developed provides an acceptable error rate for high values of SNR, which may seem like an unsatisfactory result. In against part, the average performance in terms of SNR is compensated in the case of large Doppler effect. Indeed, Fig. 1 and Fig. 2 show that the performance in terms of BER and MSE are satisfactory even for very high speeds. In fact, the BER is around 10% error in spite of a high Doppler parameter $f_d T = 0.2$, corresponding to a speed receiver 666 Km / h for a carrier 5GHZ.

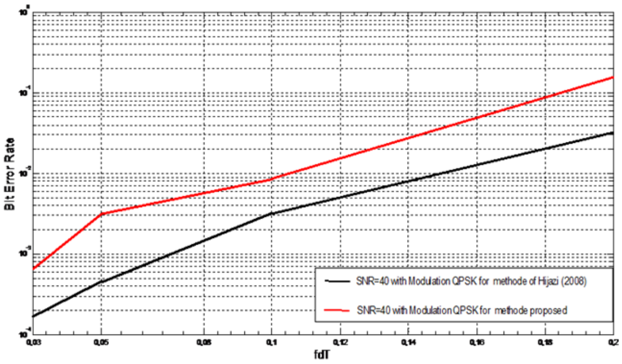

Figure 5. Comparison of BER for SNR = 40dB with the method of Hijazi

The main simulation results show that our method is robust and effective in the presence of significant Doppler effect. The proposed mechanism has better performance compared to that presented by Hijazi, in the absence of additive noise. This applies even in situations of high mobility, allowing us to earmark the treatment of pure Doppler effect. In contrast to the approach presented in this paper, the method of Hijazi requires a lot of calculations including the interpolation by treating simultaneously several OFDM symbols.

V. CONCLUSION

In this paper, we studied and analyzed the channel estimation and reduction of interference between subcarriers in an OFDM transmission. Prior to this, we described the mathematical model for both analog and digital OFDM systems. This allowed us to identify the source of ICI interference in a communication channel of mobile radio. Then, we proposed a mechanism for the successive elimination of ICI based on the distinction of the estimated channel gain from that of the Doppler effect. This method gave better results compared to the method of Hijazi.

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