Complex Baseband Model of Wireless OFDM Digital Communication System

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Abstract – **In this paper, a complex baseband channel model is developed for the scenarios of wireless OFDM digital communication link. The model is adapted for use in computer simulations. To compare the performance of the complex channel model with a real channel model, experiments of the performance of an OFDM link with narrowband interference (NBI) are performed**.

Keywords – **OFDM, NBI, Complex Signals**

I. Introduction

In this paper, a complex baseband channel model is developed for the scenarios of wireless OFDM digital communication links. To compare the performance of the complex channel with a real channel model, experiments of the performance of an OFDM link with NBI are performed.

The outline of this report is as following: After an introductory section, an overview of a complex baseband model of a wireless OFDM digital communication system is given. Simulation methods and results are presented in Section 3. Final conclusions can be found in Section 4.

II. The Wireless OFDM Communication System Complex Baseband Model

This section provides a description of the complex baseband model of a wireless OFDM digital communication link. The model describes the signal at the output of the OFDM transmitter, the model of the complex channel, and the signal at the input of the receiver [1,8]. In this study the complex modeling of each of above parts is adopted.

The complex baseband model of the OFDM signal at the output of digital OFDM modulator can be described as: ([1]):

$$s_k(t)=\begin{cases} w(t-t_s)\sum\limits_{i=Ns/2}^{Ns/2-1} d_{i+Ns(k+1/2)}e^{j2\pi\left(fc-\frac{i+0.5}{Ts}\right)(t-ts-Tprefix)} \\ \qquad\qquad ,t_s\le t<t_s+T_s(1+\beta) \\ 0,\quad t<t_s\cup t>t_s+T_s(1+\beta) \end{cases} \quad ,(1)$$

Where, $s_i \equiv 0$ for $i < 0$ and the complex OFDM symbol starts at time $t = t_s = kT_s$ and T_s is the symbol interval.

To make the spectrum going down more rapidly, windowing is applied to the individual complex OFDM symbols. A commonly used widow type is raised cosine window, defined as ([2], [3]):

$$w(t)=\begin{cases} 0.5+0.5\cos\left(\pi+\dfrac{t\pi}{\beta Ts}\right), & 0\le t\le\beta Ts \\ 1, \quad \beta Ts\le t\le Ts & \\ 0.5+0.5\cos\left((t-Ts)\pi+\dfrac{t\pi}{\beta Ts}\right), & Ts\le t\le(1+\beta)Ts \end{cases} \quad ,(2)$$

Both the air-to-air and the air-to-ground communication scenarios can be described by a multi-ray model with a direct and a delayed (reflected) components ([7], [9], [10].

The complex baseband model of the simulated channel is shown in Figure 1 ([5], [9]). Here, s(t) denotes the complex baseband transmitted signal, τ the delay of the fading signal complex components, y(t) is a complex fading process, z(t) is an complex interfering signal, n(t) is a complex white Gaussian noise, and r(t) is the received complex baseband OFDM signal.

The complex baseband model of a fading channel is modeled by a FIR filter, where the subscript *i* indicates that the sample was taken at time $t = iT_s$ with tap weights given by:

$$h_n=\mathrm{Re}[h_n]+j\,\mathrm{Im}[h_n]=\sum_i \mathrm{sinc}\left(\frac{\tau_k}{T}-n\right)h_i, \qquad (3)$$

The complex output signal of the fading channel FIR filter is given by:

$$y(i)=\mathrm{Re}[y_i]+j\,\mathrm{Im}[y_i]=\sum_{j=0}^{N-1}s(i-j)h(j) \qquad (4)$$

Additionally, an additive complex white Gaussian noise is added to the faded signal. A continuous time complex Gaussian process is defined as ([10]):

$$\mu(t)=\mu_1(t)+j\mu_2(t) \quad , \qquad (5)$$

With

$$\mu_1(t),\mu_2(t)\in N(0,\sigma_0^{\,2}) \ , \qquad (6)$$

where $\mu_1(t)$ and $\mu_2(t)$ are independent real Gaussian processes with variance σ_0^2. The Power Spectral Density (PSD) for the complex white Gaussian process $\mu(t)$ was originally derived by Clarke under the assumption of an idealized model for omnidirectional antennas where the wave propagation occurs in the two-dimensional plane. The angle of arrival is assumed to be uniformly distributed from 0 to 2π. The PSD of this process for *i* = 1, 2 is ([6], [9]):

$$S\mu\mu(f)=S\mu_1\mu_1(f)+S\mu_2\mu_2(f) \quad , \qquad (7)$$

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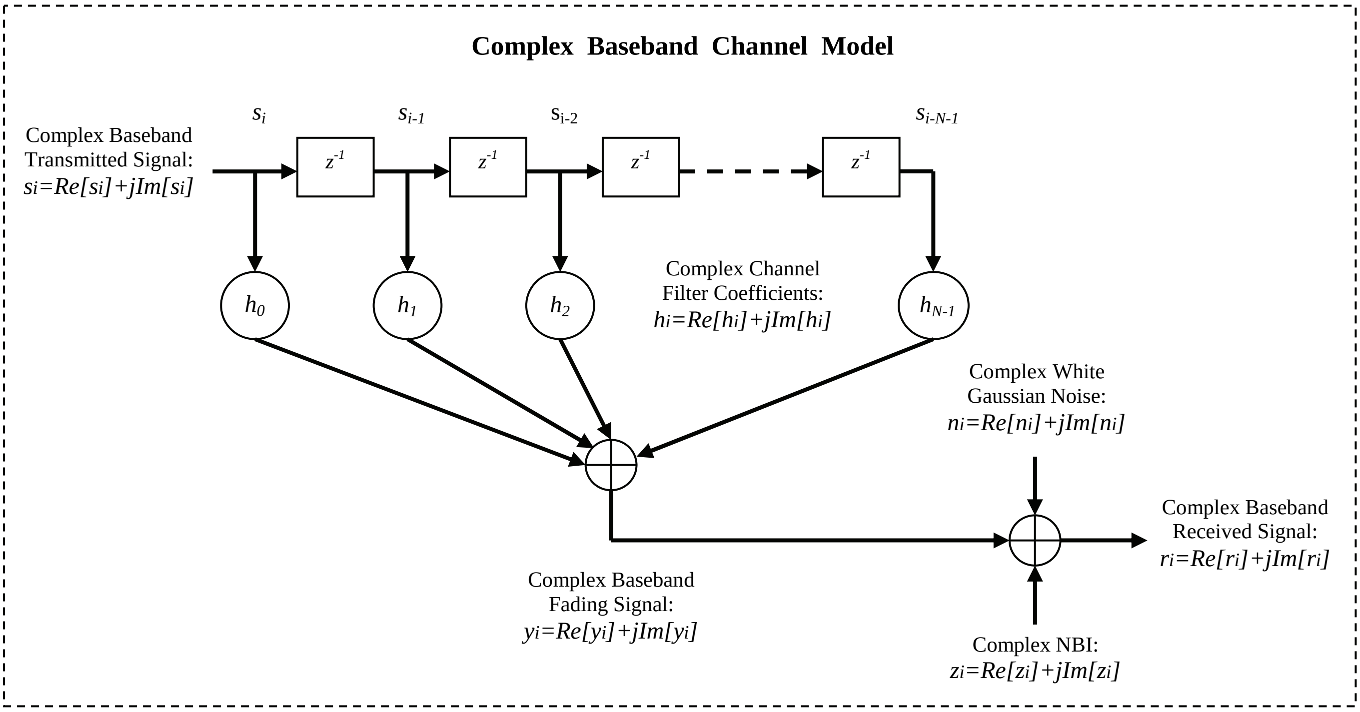

Fig. 1: Simulated Complex Baseband Channel Model.

With

$$S\mu_i\mu_i(f)=\begin{cases}\dfrac{\sigma_0^{\,2}}{\pi f_{\max}\sqrt{1-\left(\dfrac{f}{f_{\max}}\right)^2}}, & |f|\le f_{\max}\\ 0, & otherwise\end{cases}, \qquad (8)$$

Here f_{max} = ν/λ denotes the maximum Doppler frequency. The parameter ν is the velocity of the mobile receiver. The wavelength λ of the carrier is defined as $\lambda = \nu_{light} / f_c$, where ν_{light} is speed of light and f_c is the carrier frequency.

For the experiments, a complex NBI is modeled as a sum of complex sine wave functions with random, Gaussian distributed amplitudes and random uniformly distributed phases, such that the power of a complex NBI signal is higher than the power of a received faded signal in the same narrow frequency bandwidth.

Typically, the average SIR is expected to be in the interval, from – 20 dB to 0 dB.

$$\begin{aligned} z(t) &= \mathrm{Re}[\,z(t)] + j\,\mathrm{Im}[\,z(t)] = \\ &= \sum_{k=1}^{K} Z_j(t)e^{\,j(\omega_k t + \varphi_k(t))} \end{aligned}, \qquad (9)$$

Finally, the complex baseband OFDM signal at the input of the receiver can be written as ([5], [7]):

$$\begin{aligned} r_i &= \mathrm{Re}[r_i] + j\,\mathrm{Im}[r_i] = y_i + z_i + n_i = \\ &= \sum_{j=0}^{N-1} s(i-j)h(j) + z_i + n_i \end{aligned}, \qquad (10)$$

where r_i is the complex baseband signal sample at the receiver input, s_i is the complex transmitted symbol, y_i is the complex fading, n_i is the complex noise, and z_i is the complex narrowband interference signal.

III. Experimental Results

Using the proposed general complex baseband simulation model, different experiments are performed, estimating the bit error ratio (BER) as a function of the Signal to Interference Ratio (SIR) for different channel types, for a standard OFDM system including error correction and interleaving. The basic parameters of the OFDM model are: convolutional encoder with a code ratio: $Rc = 1/2$, a Viterbi hard threshold convolutional decoder, a random access permutation table matrix interleaver, 64-QAM, 256-FFT/IFFT.

In Figure 2 the real and complex channel models for AWGN channel with and without NBI are compared. The simulation results for the case of no NBI show, that the behavior of both models is quite similar. However the BER results for the case of a real model are little bit more optimistic due to the simplified channel equalization algorithm. For the case of AWGN channel with NBI, the clear difference in the behavior of both models is observed. This is due to two reasons. First, the simplified channel equalization algorithm in a real case is not as good as in the absence of NBI. The second reason is that for the case of real model, the correlation between positive and negative frequency bins is very strong as they carry the same data, thus allowing for the higher SNIR. In the case of complex model, the positive and negative frequency bins carry different data allowing for doubled bit-rate, but in presence of complex NBI, the SNIR is lower than in the real case. It can be concluded, that the complex channel model represents more precise the influence of variety of impairments existing in deployed RF channels, as NBI, Fading, AWGN, etc.

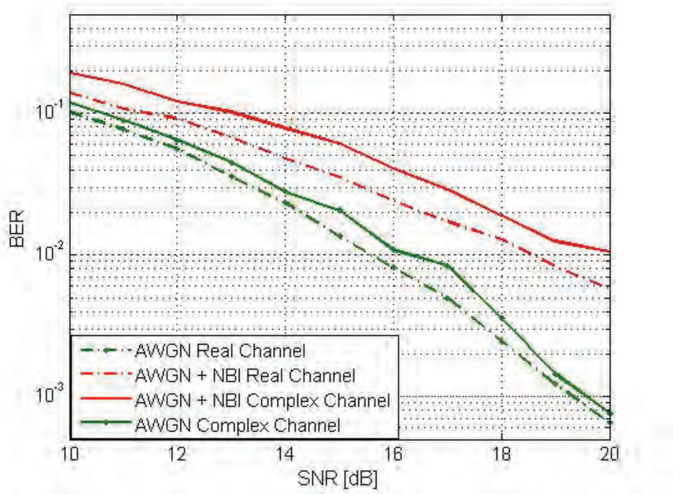

Fig. 2: BER as a function of SNR for complex and real baseband models of AWGN channel

In Figure 3, the standard CM1 G802.16 UWB channel is simulated, using the real baseband channel model. Real additive Gaussian noise with SNR=-20dB is added to the signal. Different types of NBI suppression techniques are investigated and compared, according to [11]. In Figure 4, the standard CM1 G802.16 UWB channel is simulated, but this time, using the complex baseband channel model, keeping all the model parameters the same as in the real model from Figure 3. Comparing Figure 3 to Figure 4, a BER degradation could be observed, which confirms the comments made for the results from Figure 2.

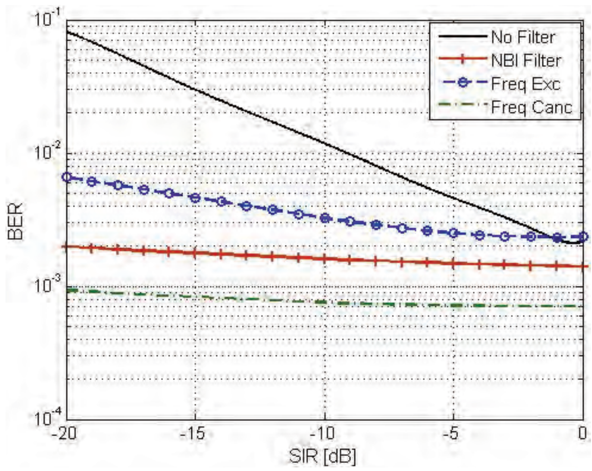

Fig. 3: BER as a function of SIR for a real baseband channel model

IV. Conclusion

In this paper, the complex baseband channel model is developed for the scenarios of wireless OFDM digital communication links. Complex additive white Gaussian noise and complex narrowband interferences (NBI) are added to the wireless channel. The bit error rate performance, in the presence and absence of complex NBI, is presented. Several NBI mitigation schemes are simulated and the results are compared using standard CM1 G802.16 UWB channel. The results show that the BER results for the case of a real model are more optimistic. For the case of AWGN channel with NBI, the clear difference in the behavior of both models could be observed. The research results might be used to optimize resource allocation in NGN considering application-specific requirements as to [12].

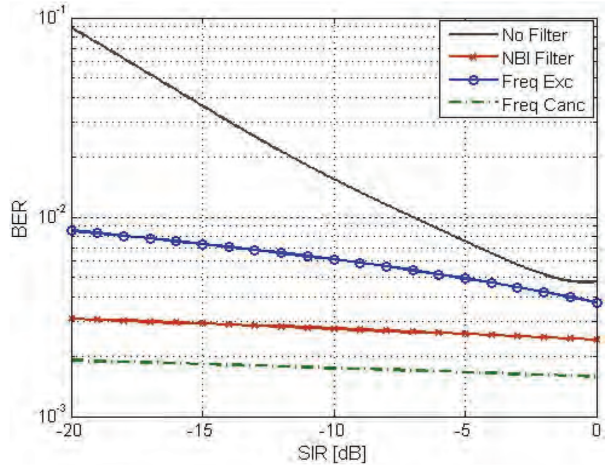

Fig. 4: BER as a function of SIR for a complex baseband channel model

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