Resiliency of OFDM to Multipath Fading in Wireless Communications

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1 Introduction

The aim of this project is to know how OFDM performs in multipath conditions.

We have seen in class that OFDM performs better in this kind of scenarios, but is it really worth using it? why? These are two of the questions we will try to answer with this project.

This report is presented in a way that first it introduces the underlying theory, and then analyzes the simulations performed. All in order to deduce why OFDM should be better than other schemes in a multipath environment.

2 Frequency selective channels

When dealing with broadband wireless communications systems in an indoor environment, the channel the signal is transmitted through is an AWGN, Rayleigh fading and frequency selective channel. Due the scattering of the received signal on the surroundings of the receiver, the final signal is a summation of different scattered rays, which can be in phase or in contra phase. This leads to a fading of the received power, which is modeled by a Rayleigh random process. The frequency of the variations at the received power are determined by the Doppler spectrum of the signal.

Furthermore, due to the multipath characteristics of channel in an indoor environment, several rays are received. Therefore, the impulse response of the channel is not a delta function (a single path) anymore, but a set of delta functions with different delays depending on each path. The received power on each path is also different. This leads to a non flat fading frequency response of the channel that, if the transmitted signal is wide band, introduces inter symbol interference and distortion. The wide/narrow band characteristics of the signal are determined by the coherence bandwidth of the channel, which defines a maximum signal bandwidth that can be transmitted without distortion. In Figure 1 an example of an indoor channel impulse response and its frequency spectrum is shown.

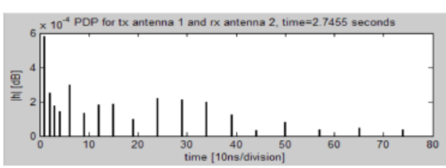

Figure 1.a.: Power Delay Profile (PDP) on an indoor mobile channel

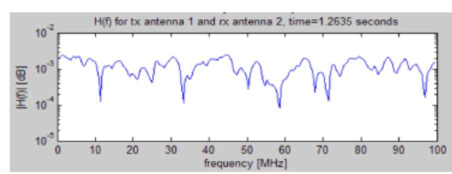

Figure 1.b.: Frequency selective indoor wireless channel

2.1 Indoor WLAN Channel Models

For this study the simulations will be based on the IEEE models for 802.11n Wireless LANs. This channel models are defined to model the MIMO indoor wireless channel for the new IEEE standard 802.11n, which is described in [3]. This is a WLAN standard improving the Physical Layer and MAC Layer for indoor MIMO/OFDM WLANs that aims to achieve a maximum bit rate of 600Mbps with a 3x3 configuration.

These channel models described in [2] are based on a statistical model for indoor multipath propagation introduced by Valenzuela and Saleh in [1]. Basically these models consider the clustering of the multiple rays arriving to the receiver. This results on a double decaying exponential distribution on the Power Delay Profile of the channel. These channel models also define the indoor environment characteristics. More specific details about the models used in the simulations and the system and environment parameters are listed in section 4.

3 Orthogonal Frequency Division Multiplexing (OFDM)

Orthogonal frequency division multiplexing is a scheme that divides a communications channel into a number of equally spaced frequency bands. A subcarrier carrying a portion of the desired information is transmitted in each band.

Also, a key feature of OFDM is that each subcarrier is orthogonal with every other subcarrier, something which differentiates OFDM from the common FDM. Each of this subcarriers is modulated with a conventional modulation scheme.

It is worth noting that in OFDM the duration of each symbol is long, thus, it is feasible to insert a guard interval between OFDM symbols, eliminating ISI.

For further information about OFDM, an interested reader should consult [4], as it is out of the scope of this document to detail all the underlying OFDM theory.

4 Implementation issues

To test the performance of OFDM systems on frequency selective channels, a system model has been designed to run the simulations. Basically, the performance and resiliency of OFDM modulation schemes in multipath fading channels is going to be analyzed in terms of the quality of the transmission, which would be related to the bit error rate (BER) at the receiver.

The results are be obtained from both a traditional modulation scheme (DPSK) and an OFDM modulation scheme, modulating each sub carrier with the same modulation as the non-OFDM scheme. Three cases for the wireless channel are analyzed: AWGN, flat fading and frequency selective channel (having the last two also AWGN included).

More specific details about modulation schemes, OFDM parameters and wireless channel characteristics used in the simulations are described in the following sub sections.

4.1 Modulation and OFDM parameters

For the non-OFDM case a 16-DPSK modulation is chosen. Initially it was planned to work with a 16-QAM modulation scheme. However, since the equalization algorithm used is very basic (it will be discussed below), a differential modulation is selected. This choice is done because of the necessity of consistent results in order to compare both techniques fairly.

The Rayleigh distributed received power of the channel adds a random phase to the signal, so without a strong equalization, all the information is lost. On a differential scheme, the important phase is the difference between two symbols, which will be mainly just due to the information modulated and not due the fading, since the random phase will remain almost constant during every coherence time. Therefore a DPSK modulation performs better in a fading channel (Figure 3.a). So finally, even though a QAM scheme performs better in an AWGN channel (Figure 3.b) because the symbols are more distributed on the constellation than in a PSK scheme, a 16-DPSK modulation is used.

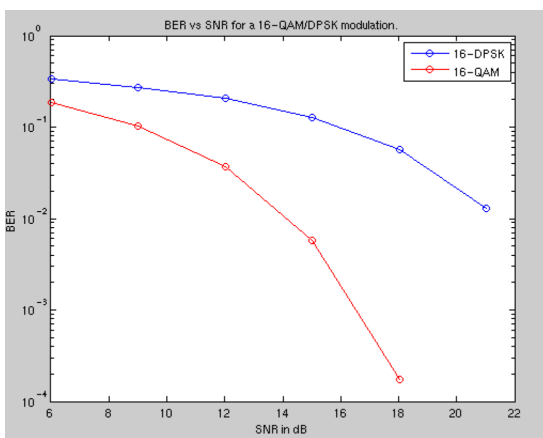

Figure 3.a.: BER vs SNR in an AWGN channel for 16-QAM/DPSK

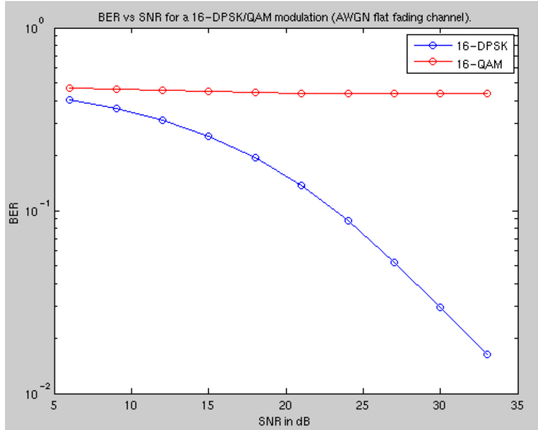

Figure 3.b.: BER vs SNR for an AWGN channel for 16-QAM/DPSK

The data is generated as random bits, pumped to the system at a rate of 100 Kbps. These bits are used to generate the 16-DPSK symbols. Therefore one symbol is transmitted every 40 microseconds.

For the OFDM scheme, each sub carrier is also modulated with a 16-DPSK constellation. The size of the IFFT/FFT engines is 64. A higher value is not necessary since most of the simulations will be with a value of the coherence bandwidth large enough to consider every sub channel flat with 64 sub channels. Finally, the length of the cyclic prefix is fixed to 10. This value is more than enough for the delay spreads considered.

For both cases, the carrier frequency is set to 5.25GHz according to what is described in [2].

4.2 Equalization scheme

Equalization techniques for OFDM-based systems is a topic out of the scope of this project. Therefore, a simple equalization technique is implemented. The aim of the algorithm is simply allow the system model to perform with consistent results that allow a fair comparison between plain DPSK modulation and an OFDM-based scheme.

For the non-OFDM system, the transmitted symbols are divided into what can be called frames. Every frame contains the number of symbols that are transmitted within one coherence time. This number (N) can be easily calculated as follows (being M=16 the size of the modulation):

$$N = \frac{R_b}{log_2(M)} \frac{1}{f_D} = \frac{R_b}{log_2(M)} \tau_c$$

The equalization algorithm transmits a set of pilot symbols (p(i), being usually i={1...100}) at the beginning and at the middle of every frame. This pilot symbols are known at the receiver, so the channel state can be calculated by computing the operation hi=pr(i)/p(i), being pr(i) the received pilot. To minimize the noise of the channel estimation, the channel values calculated with the i pilot symbols are averaged. Finally, half of the frame is equalized with the first set of pilot symbols and the other half of the frame is equalized with the second set of pilot symbols. A scheme of this equalization algorithm is shown in Figure 4.

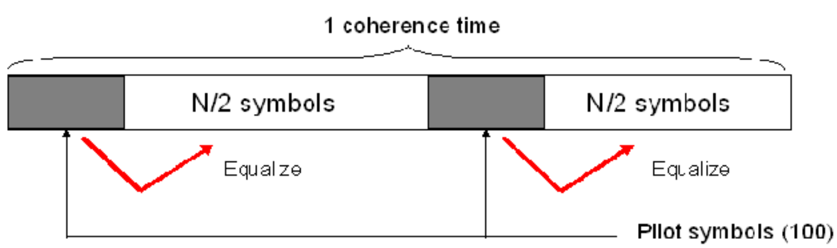

Figure 4: Equalization scheme

4.3 Radio channel model

As already mentioned, both OFDM and plain modulation systems are simulated in three different channels. All of them include AWGN, and its power is adjusted to reach the desired SNR at the reception side.

For both flat fading and frequency selective cases, the transmission is modeled as a Rayleigh channel. However, in the multipath propagation, also a LOS (Line Of Sight) path is considered and, by means of a K Ricean factor, the channel is modeled as a Ricean fading channel. These channel models an indoor environment with mobile users moving at a speed of 1.2km/h, which leads to a Doppler frequency of 5.83Hz and a coherence time of 171ms.

For the multipath case, two different models are considered (B and E as defined in [2]), being the main difference between them the delay spread of the channel (15ns for model B and 150ns for model E).

5 Results

Applying both transmission schemes on a plain AWGN channel the results obtained are the same and the BER/SNR graphs are one on top of the other. Basically, in the absence of frequency selectivity, just noise is degrading the received signal. Therefore, since the noise spectrum is flat, the same amount of noise affect the signal, even when the bandwidth is divided into several sub channels when using an OFDM scheme. As already mentioned in section 4.1, it is also shown how a 16-QAM modulation performs better that a 16-DPSK due to the fact that the symbols are more spread on a QAM constellation.

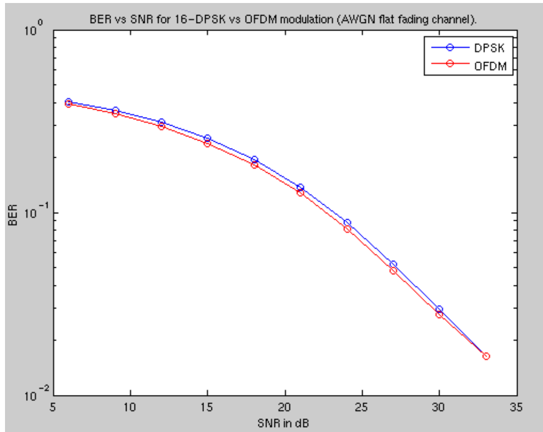

Figure 5: BER vs SNR for a flat fading channel (16-DPSK/OFDM)

Figure 5 shows the results for a flat fading channel. As expected, both a plain modulation scheme and the OFDM system perform almost equally. However, it can also be observed how the quality of the transmission gets strongly worse due the fading channel and the simple equalization scheme, leading to BERs of 10^{-2}.

Even the results are almost the same, OFDM performs slightly better due to the fact that the same equalization algorithm is applied to each sub channel. Therefore, since more pilot symbols are being used, the equalization is less noisy.

Finally, Figure 6 shows the results for a frequency selective channel. Figure 6.b plots the BER against the SNR at the receiver for the channel model B. It can be seen how OFDM performs better in terms of the quality of the received signal, achieving lower probability of error probability of error. However, model B simulates an indoor channel in a relatively small environment, such as an office area. Therefore the delay spread of the channel impulse response (which has one path or sample every 10ns) is relatively small (15ns).

Since we are dealing with a 100Kbps signal transmitted on a 16-DPSK modulation, the channel presents a multipath characteristic but it is not a very frequency selective channel (the transmitted signal is still narrow band). In order to change this, both schemes are simulated on a model E channel, which presents a delay spread of 150ns. In this case, being the signal sideband and the channel frequency selective, the performance of the plain modulation gets much worse, while OFDM presents a strong resiliency against the negative effects of the multipath and keeps performing with the same BER.

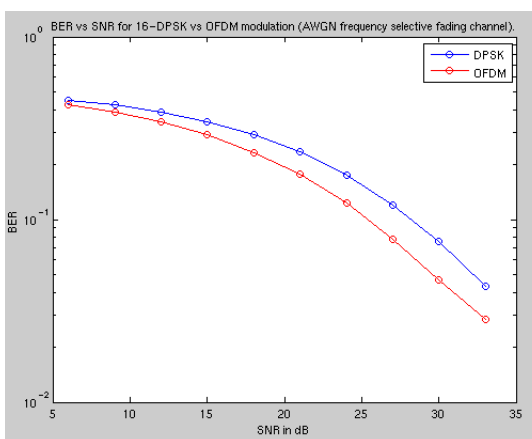

Figure 6.a.: Figure 3.a.: BER vs SNR in a frequency selective channel for 16-DPSK/OFDM **(delay spread=15ns)**.

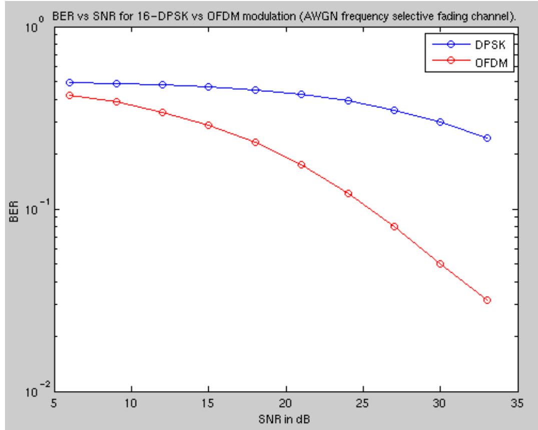

Figure 6.a.: Figure 3.a.: BER vs SNR in a frequency selective channel for 16-DPSK/OFDM **(delay spread=150ns)**.

6 Conclusion

A simulation-based study of the performance of OFDM transmission schemes has been done in order to prove and assess its performance on multipath frequency selective channels. By simulating three different kinds of channel (AWGN, flat fading and frequency selective channel), an OFDM modulation carrying a 16-DPSK modulation in each sub carrier has been compared with a plain 16-DPSK modulation scheme. The presented results are in terms of the BER against the received SNR.

It has been seen how OFDM presents a strong resiliency against frequency selective channels and how it keeps performing with the same quality even when the delay spread of the channel is enlarged, becoming the signal a wide band transmission, while plain modulation schemes perform poorly in this kind of environments with the absence of a sophisticated equalization system.

7 References

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[2] Indoor MIMO WLAN Channel Models, IEEE 802.11-03/161r2
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