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OFDMA in 4G Systems- LTE, LTE-A, Wi-MAX

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Abstract—*This paper studies Orthogonal Frequency Division Multiple Access system which is used in the latest Wireless MANs such as LTE, LTE-A and WiMAX release2. We begin by discussing the transmission and reception of OFDMA system and understand the advantage of using it in a frequency selective channel. We discuss few limitations of OFDM modulation scheme like high sensitivity to RF-impairments and high Peak-to-Power Ratio (PAPR). Then we perform a simulation of OFDMA system in MATLAB and analyze in detail how its performance degrades in the presence of phase noise by comparing the bit error rates in different conditions such as varying SINR, changing the carrier spacing and changing the 3db bandwidth of phase noise.*

Keywords*: multi-carrier transmissions, orthogonal carriers, PAPR, phase noise, RF-impairments, delay spread.*

1. INTRODUCTION

OFDM stands for Orthogonal Frequency Division Multiple Access. It is a unique form of multicarrier transmission method where all the sub-carriers are orthogonal to each other. Multi carrier transmission is useful for robust transmission at high data rates in a hostile wireless transmission channel. When data rates are high, then signal can be distorted due to time dispersion and spreading of symbols. This is called delay spread which leads to Inter Symbol Interference (ISI).

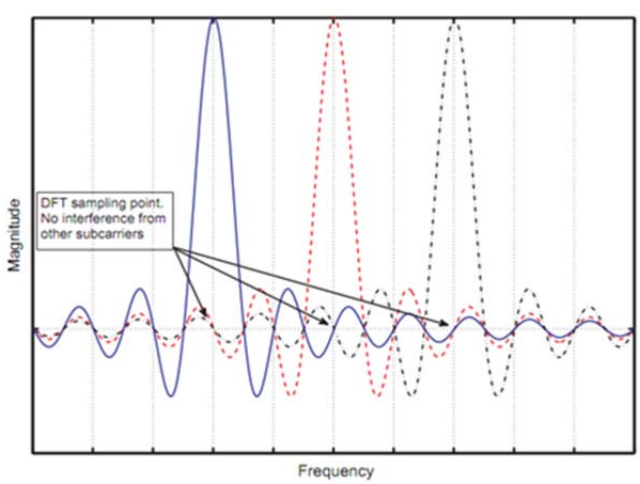

Fig. 1: OFDM signal

This time domain phenomenon has its effects in frequency domain as well i.e. with the increase in delay spread the coherence bandwidth reduces. This further increases the frequency selective fading in the channel, which is very random and makes it almost impossible for the simple receiver to predict the transmitted data [2]. OFDM simplifies this problem by turning the frequency selective channel into a flat channel. Due to multi carrier transmission, the symbol time duration increases such that delay spread no longer effects the transmission. Thus, in this way OFDM reduces the effects of ISI. OFDM is currently been used in 4G technology and is expected to be a base for all future communication technologies.

2. OFDM TRANSCEIVER

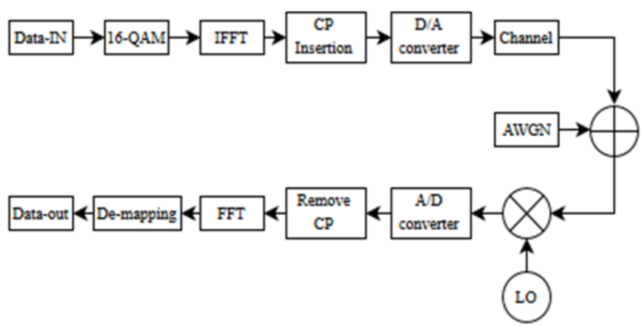

Fig. 2: OFDM system model

In digital domain, input data is collected and mapped to corresponding constellation points using 16-QAM. At this point, data are represented as complex numbers. The IFFT operation is performed on these complex data numbers. The transformed data are grouped and cyclic prefix is inserted in every block of data according to the system specification to keep the OFDM symbols orthogonal. A digital-to-analog converter is used to convert the data from time-domain digital data to time-domain analog data, after which the signal is up-converted with the help of RF modulation. The signal then passes through the channel where it goes through all anomalies and hostility of wireless channel. This effect of channel is shown in the system model by addition of AWGN (Additive White Gaussian Noise) to the signal. The receiver performs opposite of the transmitter and we get back the digital data. It should be noted that phase noise and AWGN channel effects are all assumed at the receiver during the system modeling.

3. OFDM ADVANTAGES

OFDM is form of multi carrier transmission maintaining orthogonally between subcarriers. In a single carrier system each user data is assigned full bandwidth, so the symbol duration is very low.

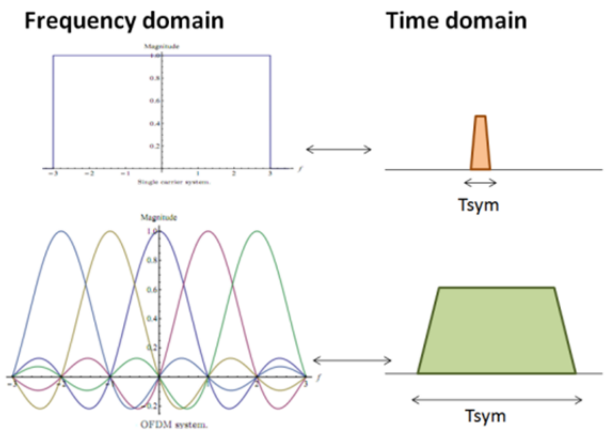

Fig. 3: Comparing symbol duration

In multi carrier transmission, the bandwidth is divided into sub bands and user data is transmitted on those sub bands or sub carriers. Since the user data is transmitted on sub-bands, the symbol duration is increased. In multi path transmissions, there is time difference between the LOS component and other components. This time difference leads to 'delay spread'. It is inversely related to coherence bandwidth i.e. bandwidth over which channel response is considered to be flat. When symbol duration is more, as in the case of OFDM system, the effect of delay spread is very low. This reduces the frequency selectivity of the channel and now it is more or less similar to just an AWGN channel.

4. OFDM LIMITATIONS

The OFDM system assigns the subcarrier frequencies very close to each other, to efficiently utilize the bandwidth. But this makes the system very sensitive to receiver frequency synchronization. OFDM is dependent on the receiver synchronization or what is called RF-impairments [5].

The types of RF impairments include IQ imbalance, carrier frequency offset, phase noise, power amplifier non linearity and jitter. IQ imbalance occurs when there is a mismatch in the amplitude and phase of oscillator signals that are used for mixing the In-phase and Quadrature components. This can happen due to inaccuracy in the generation of these signals because of hardware constraints. Frequency offset is the mismatch in carrier frequencies of the incoming RF signal and local oscillator used at the receiver.

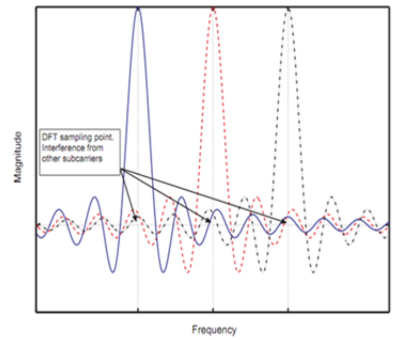

Fig. 4: OFDM signal with phase noise

Phase noise is random disturbance in the phase of the carrier signal that the local oscillator generates. The distinguishing point between the frequency offset and phase noise is that frequency offset is predictable whereas phase noise is random. The two main causes of emergence of frequency offset can be mismatch of frequency between transmitter and receiver oscillator, and variation of transmitted RF frequency in time due to channel effects, commonly called Doppler Effect. Jitter is caused when analog signal is converted to digital due to erratic fluctuations in the sampling instants. It causes the ADC to sample at wrong instants. OFDM signals are known to have large peak-to-average-power ratio (PAPR) and they are clipped when they are passed through a amplifier. This causes in band and out of band spectral re growth.

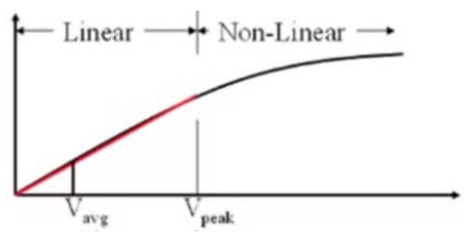

Fig. 5: Amplifier response

The high PAPR is observed because of addition of different signals due to multi carrier transmission. The amplifier linear region is very small as shown in Fig. 5, and when OFDM signal passes through non-linear region then it gets clipped and there is loss of signal. Amplifiers with better response are very expensive and complex. Therefore it cannot be used at mobile stations. Due to this reason only OFDMA is replaced by SC-FDMA in uplink transmissions in LTE. Wi-MAX still uses OFDMA in both uplink and downlink transmissions.

5. OFDM SIMULATION

To examine the effects of phase noise to an OFDM system, we performed a MATLAB simulation to study the performance of the system with and without phase noise. We studied the Bit Error Rate (BER) in three different scenarios: (1) variable SNR, (2) variable sub-carrier spacing and (3) variable 3dB bandwidth. To start, we generated an OFDM signal with 512 subcarriers and a 512 long cyclic prefix using 16-QAM modulation. The signal was passed through a channel with a coherence bandwidth of 800 KHz, 4 channel taps. At the receiver side, phase noise and Average White Gaussian Noise (AWGN) were added to the signal.

Step 1: keep the carrier spacing constant to 15 KHz and vary the SNR value between 0 to 30dB with 5dB intervals, and change the 3dB bandwidth from 0 to 200Hz. Observe the BER for each value and plot the curves.

Step 2: keep SNR=30dB & 3dB bandwidth=50 Hz. Vary the subcarrier spacing between 15-60 KHz with 15 KHz intervals. Observe BER for each value and plot the curve.

Step 3: keep SNR=30dB & subcarrier spacing =15 KHz. Vary the 3dB bandwidth between 50-200 Hz.

6. OFDM SIMULATION RESULTS

We plot the results in form of two graphs, first showing the effect of phase noise addition to system on its performance and second showing how subcarrier spacing can improve the performance. We have taken the BER (Bit Error Rate) as the parameter to measure the performance. The lower the BER, the better is the performance. In Fig. 6, it is shown that as the SNR is increased, the BER value keeps reducing.

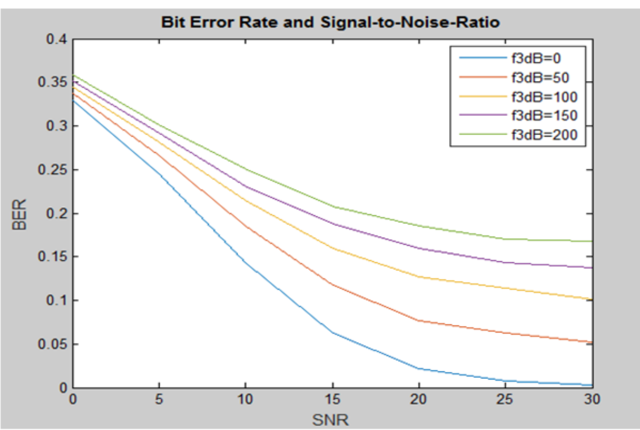

Fig. 6: BER vs SNR curve

Also in Fig. 6, the curve for f3dB = 0 refers to the curve of system without phase noise (ideal system). f3dB value specifies the 3dB bandwidth of the phase noise. We can clearly see that for same SNR value, if the phase noise increases then the BER value also increases. This means phase noise addition degrades the performance of the OFDM system drastically.

Fig. 7 shows how increasing sub carrier spacing improves the performance. As from the curve, it is clear that with the increase in sub carrier spacing, BER value reduces significantly even for systems affected by phase noise.

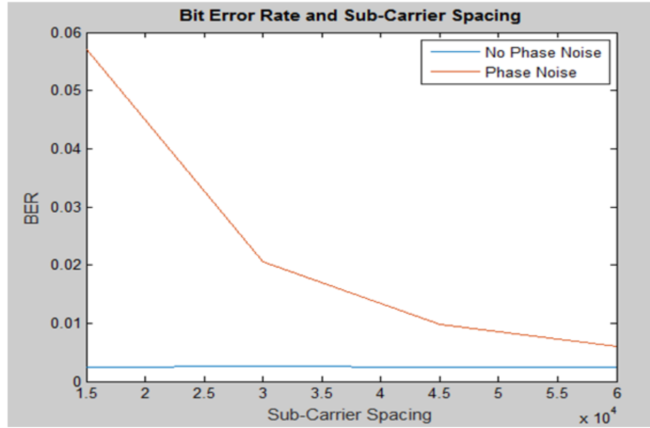

Fig. 7: BER vs carrier spacing

7. CONCLUSIONS

We can say that OFDM system offers advantages in the practical scenario where we need high speed data transmissions in multi path transmissions. That's why it is believed to be used in all latest wireless communication technologies. It is also observed that phase noise affects the OFDM signal in two ways:

First, by increasing the Inter Carrier Interference (ICI) which is caused due to loss of orthogonality between subcarriers, second it reduces the signal value because by shifting the subcarriers there is no peak value at sampling instants. With reference to the results we obtained, there is clear observation of degradation in the performance of the OFDM system which is evident from the increase in the Bit Error Rate (BER) for systems having phase noise as compared with systems not affected by phase noise at the same SNR level. The degradation of BER caused by random phase noise makes the multi-carrier OFDM system much more sensitive than single carrier systems. The phase noise effect reduces with the increase in the subcarrier spacing, Δf. However, as the subcarrier space is increased, the number of sub carriers are reduced, which shortens the symbol duration and can cause problems of delay spread.

Therefore, there is a trade off between frequency and timing synchronization and the optimal value for Δf should be selected. For LTE systems, 15 KHz is selected as the best suited Δf value [4]. In practice frequency synchronization estimators are used to reduce the effects of phase noise. In OFDM systems, some of the subcarriers are used for transmission of reference or pilot signals. These reference signals are known by both the transmitter and receiver, based on these known symbols the frequency offset caused by the phase noise can be estimated [1]. Also if the frequency errors caused due to phase noise is relatively slow in comparison with the OFDM symbol rate, then a Phase Locked Loop (PLL) can be used to further reduce the bit error rate [3].

8. FUTURE WORK

The same experiment can be conducted using coded OFDM signals and check whether there is any improvement in the performance of the system. Also we can use channel estimator scheme in the MATLAB simulation to check for further improvements in the performance.

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