Uncoded OFDM system performance under Rayleigh fading condition

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Abstract:
*More and more wireless communication systems are adopting orthogonal frequency division multiplexing (**OFDM**) in order to help achieving higher data rates with less error probability. In the last **3GPP2** conference **COFDM** been proposed to be the leading modulation technique in **4G**. The main problem facing such systems is multipath fading; which is mitigated by channel equalization and channel estimation. In this paper the analysis of the multipath fading channel effect on the performance of uncoded **OFDM** systems is shown, where user's mobility and channel time spread in an indoor environment have been taken into account. Although research studied such performance however none studied the effect of frequency selectivity and the user mobility at the same time.*

Introduction:

Orthogonal Frequency Division Multiplexing **(OFDM)** has lately been applied broadly in wireless communication systems due to its high data rate transmission capability with high bandwidth efficiency and its robustness to multi-path delay. It has been used in wireless **LAN** standards such as American **IEEE802.11a** and the European equivalent **HIPERLAN/2** and in multimedia wireless services such as Japanese Multimedia Mobile Access Communications.
Although a considerable amount of research has addressed the design implementation of **COFDM** systems for multipath fading channels, eg.,[1]-[3], comparatively only few of them provide satisfactory performance analysis over variable conditions of such systems because of the complex nature of this problem. In [4], a simplified channel estimation method was studied where channel variation has been taken in consideration but neglecting channel spreading effect.
This paper is focused on the analysis of **QoS** in terms of **BER** offered by **OFDM** systems based on pilot channel estimation over a flat and frequency selective Rayleich channel.
This paper is organized as follows: Section **II** describes an overview of the physical layer description for an uncoded **OFDM** wireless system. Section **III** describes the channel block pilot estimation. Section **VI** describes the simulation results.

II. System Description:

In an **OFDM** system, data is carried on narrow-band sub-carriers in frequency domain. Data is loaded on the sub-carriers through the **IDFT** (Inverse Discrete Fourier Transform) in the transmitter and transformed back into the receiver through **DFT** (Discrete Fourier Transform). The number of subcarriers is translated to the number **IDFT/DFT.**

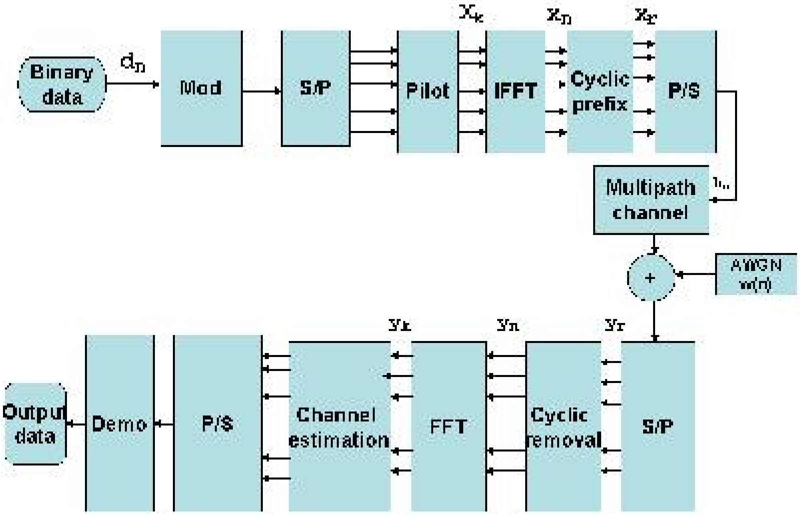

FIGURE (1)

The **OFDM** system based on block pilot channel estimation is given in Figure 1. The binary information is first grouped and mapped according to the modulation in "Mod". After inserting pilots to all sub-carriers with a specific period between the information data sequence, **IDFT** block is used to transform the data sequence of length ***N*** ***{X(k)}*** into time domain signal ***{x(n)}***.
A guard interval is added to ***{x(n)}*** which is chosen to be larger than delay spread so we can mitigate the **ISI** (Inter Symbol Interference) induced by the channel.
The guarded signal is passed through a frequency selective fading channel with additive Gaussian noise.
At the receiver the guard interval is removed from the received signal and then passed through **DFT** mapping the signal to the frequency domain and after that the channel estimation is performed. Subsequently the binary data is estimated through the demodulator.

III. Channel block pilot estimation:

A. Signal representation:

Suppose the data set to be transmitted is

$$X(-N/2), X(-N/2+1), K, X(N/2-1)$$

Where ***N*** is the total number of sub-carriers. The discrete-time representation of the signal after **IDFT** is :

$$x(n) = \frac{1}{\sqrt{N}} . \sum_{K=-N/2}^{N/2-1} X(K). \quad e^{i2\Pi Kn/N}$$

Where **n ε [-N/2, N/2].**

At the receiver the signal is represented as follows:

$$X(K) = \frac{1}{\sqrt{N}} . \sum_{K=-N/2}^{N/2-1} x(n). \quad e^{-i2\Pi . Kn/N}$$

Where **k ε [-N/2, N/2].**

Mobile radio channels are characterized by a multipath fading environment. In other words, the signal offered at the receiver side is a composition of the direct path and a large number of reflected waves that arrive at the receiver side at different times.
For burst communication systems, training symbols are used at the beginning of each burst. Since the burst is short, the channel is assumed static over a whole burst so that once the channel is estimated, the inverse of the estimated channel response will be used to compensate the signal for the whole burst. Such technique is called block pilot estimation. In block-type pilot based channel estimation, **OFDM** channel estimation symbols are transmitted periodically, in which all sub-carriers are used as pilots. The estimation can be performed by using either **LS** or **MMSE** [2], [3].

Assuming the received signal after **DFT** is:

$$Y(k) = C(k).X(k) + Z(k)$$

Where ***k*** is sub-carrier index, ***C*** is the channel, ***X*** is the pilot data, and ***Z*** is the noise. The **LS** estimate of the channel is then computed by:

$$\hat{C}(K) = \frac{Y(K)}{X(K)}$$

i.e. dividing the received signal by the known pilot. Without noise, this gives the correct estimation.

VI. SIMULATION:

A. Description Of Simulation Parameters:

Parameters	**Values**
System Bandwidth(*MHz*)	10
Sampling frequency(*Fs*,*MHz*)	11.429
Sample time(*1/Fs*,*nsec*)	88
FFT size(N_{FFT})	1024
Guard interval length	256
Number of pilot bits	1024
Channel model	Rician Fading

TABLE 1

SIMULATION PARAMETERS

1 – *System Parameters:*

OFDM system parameters are indicated in table 1, in which we assumed a perfect synchronization since the aim of our simulation is to study the performance under different channel conditions. Simulation is carried out by varying channel delay spread **Tm** and **Fd** (Doppler frequency),where we consider 2 indoor environments.

2- *Channel model:*

Jakes fading simulator applied in **MATLAB** is used to represent the Rayleigh fading channel which is characterized by Doppler shift, Sample period and PDP (Power Delay Profile). The PDP values is taken from measurements performed by [8]. Channel parameters values are described in table (2):

	Doppler frequency	Channel spread	Sample period
Environment (1)	0 HZ	0 sec	0.1 μsec
Environment (2)	10 HZ , 50 HZ	20 nsec	0.1 μsec

Table (2)

Two testing environments are considered:

A-Quasistatic Rayleigh flat fading indoor environment:

This environment is characterized by low channel variation due to immobility of users. Indoor environments are rich by scatterers producing too many multipath signals.

B-Frequency selective indoor environment:

The channel is called frequency selective if a number of multipath signals are resolvable in the receive side.

3- *Channel estimation based on block-type arrangement:*

We transmit pilot tones over all the subcarriers and we used them at the receiver to compute the LS estimation of the channel and used after that to equalize the channel effect.

B. Simulation Results:

Environment (1):

OFDM performance under a quasistatic rayleigh channel:
a quasistatic rayleigh channel describes an indoor office environment where **OFDM** is used as a modulation technique for a **WLAN** , this environment contains a number of working stations that uses a wireless router to get through Internet , users are static most of the time which means there is no mobility that sets the Doppler frequency (fd = 0), such environments are rich by scatterers and the mutlipath signals that results from such scatterer are not resolvable in the receive side. It is assumed that there is no LOS between the receiver and the transmitter (K= 0), this is modelled by a rayleigh multipath flat fading channel.
The BER of this environment is given by figure(1):

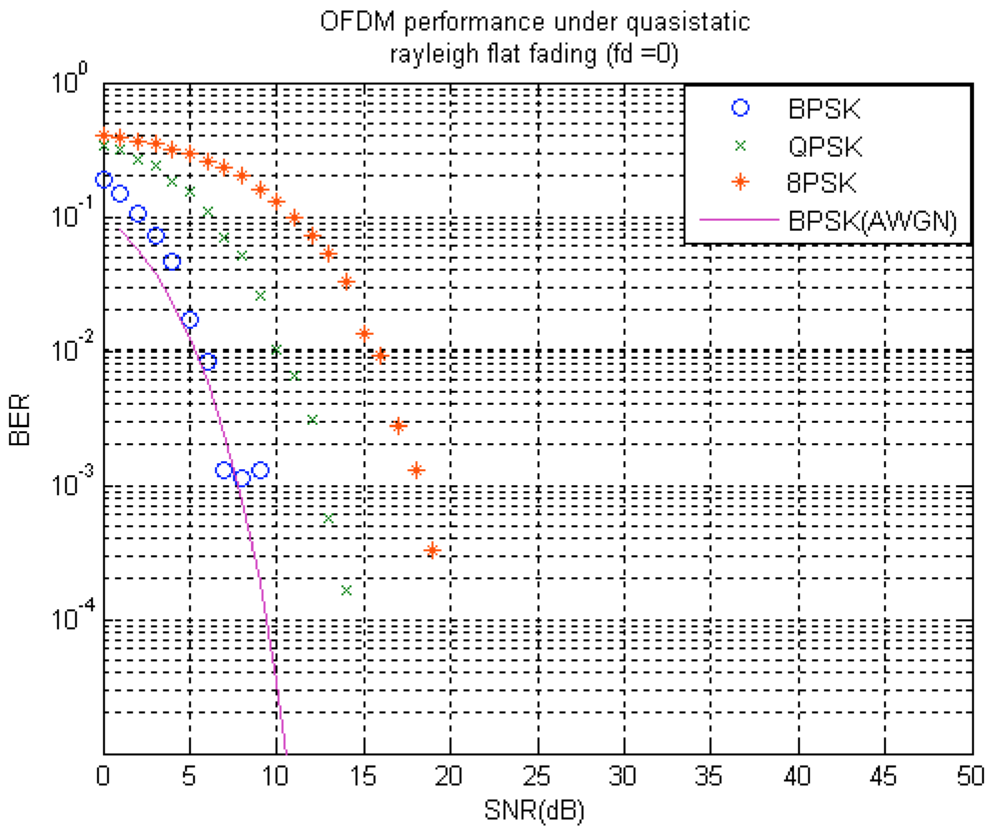

FIGURE (1)

FIGURE(1) shows the performance of **OFDM** system in the environment described above. It shows that the system perfomed as if it was subjected only to interference condition where the multipath effect was completely mitigated through pilot estimation. However the results are bit far from the theoretical ones under **AWGN** condition, that is because the removal of the cyclic prefix and the pilot symbols will cause an overall reduction of the transmitted power. From this we can conclude that there is a compromise between the number of pilot tones and the robustness against multipath which means that increasing the pilot tones can lead the system to a worse performance because the subtracted amount of signal power will decrease the SNR to a level where the improvement is negligible.
The capacity of the transmission rate can be increased by changing the modulation scheme from BPSK to 8PSK. This will be on the expense of increasing the SNR to achieve low BER with increased transmission capacity.
Enviroment (2):
OFDM performance over a frequency selective rayleigh channel:
The frequency selectivity of the channel is due to resolvable multipath signals which are imposed on each other in the receive side. We assume two mobility conditions 0.6 m/s at carrier frequency 5 GHZ (fd = 10 HZ) and 3 m/s at carrier frequency 5 GHZ (fd = 50 HZ), the channel is characterized

by a delay spread Tm = 20 ns, where this delay spread describes an indoor environment taking delay spreads between (20ns-200ns). This assumption was taken from the measurements performed by [8]. The BER of this environment is given by figures (2 ,3):

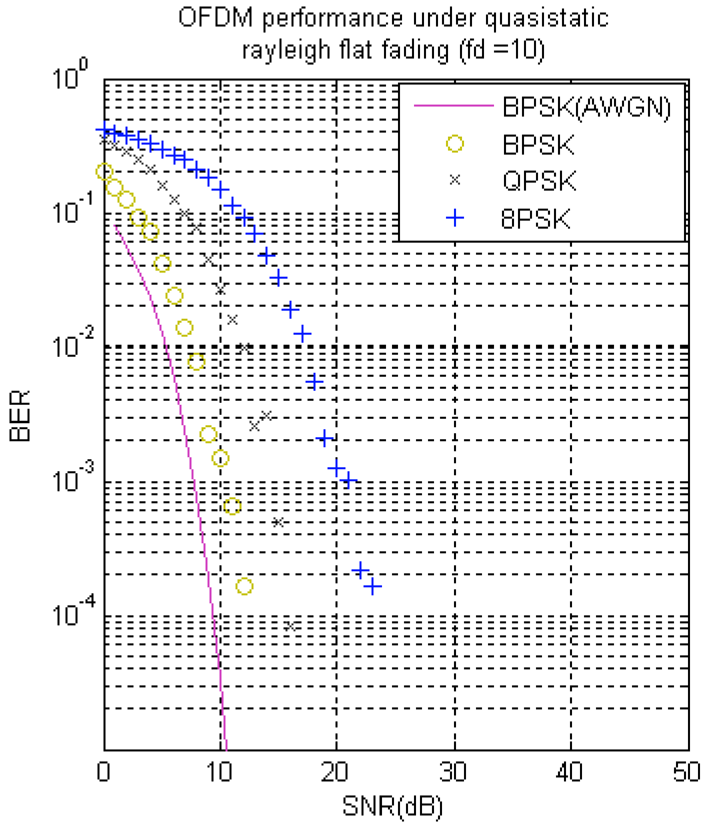

FIGURE (2)

Figure (2) shows that the resolvability of paths made the performance of the system much better than the flat fading condition. Comparing figures (1,2) we can see that at BPSK (Binary Phase Shift Keying) where SNR = 8dB will result in BER = 7.727×10^{-4} in the case of flat fading (delay spread = 0). However in the case of frequency selective fading for the same SNR = 8 and BPSK will result in BER = 7.813×10^{-3}. The reason of this difference in BER is because at flat fading case the channel estimation will result in an estimation of one complex amplitude fading coefficient. However the fading was a result of a number of multipath scenarios with different fading coefficients, Delay spread Tm is less than the symbol period Ts taking $Tm << Ts$. Therefore the pilot tones have been only able to give information about a single coefficient which is not a perfect estimate of the different irresolvable coefficients giving less improvement in the system compared to the resolvable coefficients.

The improvement of the system is only seen in the BPSK case and QPSK however at 8PSK the system performance is the same as flat fading case.

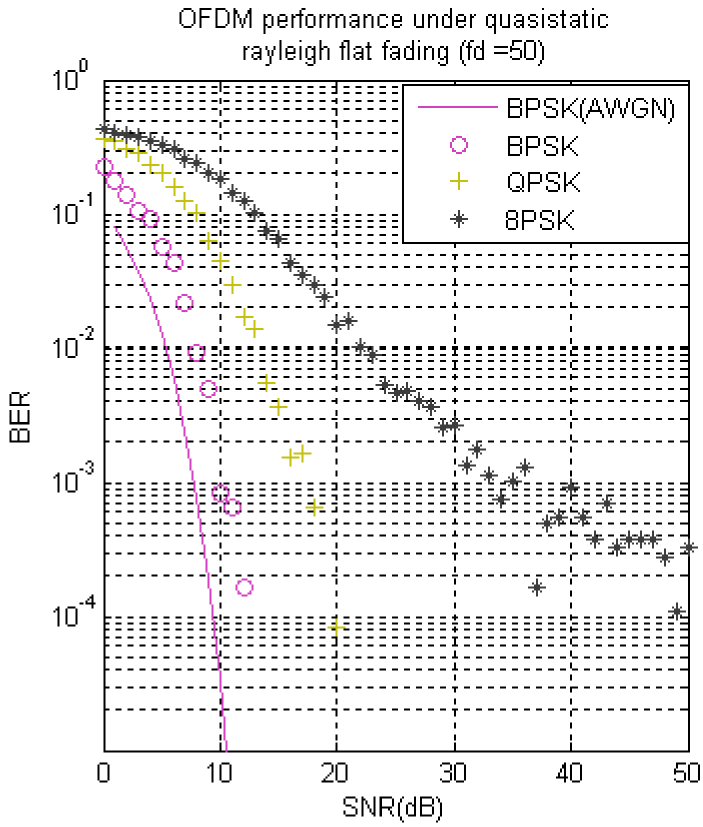

FIGURE (3)

Figure (3) shows that the mobility effect represented by the change in the Doppler frequency made the system performance to degrade notably in the case of high transmission capacity (8PSK) compared to the case where (fd =10). This failure in improving the system is due to the channel variation rate which is increased by mobility. In this case the pilot estimation fail in reproducing the channel information in the receive side since it represents only a portion of the channel information. However this does not mean that OFDM fails to deal with channel variation, but actually OFDM can resolve this problem by sending pilot tones throughout the symbol period rather than sending them only in one portion. This technique is called comb pilot tones. Another reason is that the estimation technique that is performed in this simulation is LS estimation which compared to MMSE estimation, gives less improvement compared to the later technique.
However LS is simpler to implement in the simulation compared to MMSE.

Conclusion:
OFDM systems with block pilot tones are very tolerant to slow multipath fading environments where the channel estimation improves the system to a case where system is only subjected to **AWGN** interference but with a 2dB difference from the ideal case and this was due to the power subtraction in the receive side, the system transmission capacity can be varied according to the **BER** values required by the system. This makes **OFDM** the preferable modulation technique in fixed wireless environments where the channel variation is slow but when the channel variation of the channel is increased due to the mobility of users or scatterers, the system performs poorly. In high transmission capacity **(8PSK),** the system can be improved only at low transmission **(BPSK)** capacities. Comb pilot estimation can improve the system performance in frequency selective fading environments. To present **OFDM** systems in high mobility environments, it is recommended to develop new channel estimation techniques. A number of solutions have been proposed such as adaptive modulation and smart antennas to be applied with **OFDM** systems. However there is still need for new techniques to improve the system performance.

Computer Code:

```
clear
%nloop = 100
%for f = 1:nloop
for M = [2 4 8]
%M = 2
IFFTLength = 1024
NumCa = 1024
NumSym = 6
GaIn = 256
FFTLength = IFFTLength + GaIn
Ts =1/(10e+6)
fd = 120
%for k = 1:20
 k = 0
serialdata = randint(1,NumCa*NumSym,M);
ModData = pskmod(serialdata,M);
ParallelData = reshape(ModData,NumCa,NumSym);

Ipilot = 2*randint(NumCa,1)-1;

Qpilot = zeros(NumCa,1);

ITx = [Ipilot real(ParallelData)];
QTx = [Qpilot imag(ParallelData)];

%IFFT

Tx = ITx + j*QTx;

TTx = ifft(Tx);

%GaIn

ITTx = real(TTx);
QTTx = imag(TTx);

ITTx = [ITTx((end-GaIn+1:end),:);ITTx];
QTTx = [QTTx((end-GaIn+1:end),:);QTTx];

%Txdata = ITTx + j*QTTx ;

Txdata1 = reshape(ITTx,1,FFTLength*(NumSym+1));
Txdata2 = reshape(QTTx,1,FFTLength*(NumSym+1));
Tx = Txdata1+ j*Txdata2;
%sigpow = mean((abs(Txdata1)).^2);
%Txdata1=Txdata1./sqrt(sigpow);

SNR = 0:1:50;
for n = 1:length(SNR);
```

```
c = ricianchan(Ts,fd,k)%,[0 20e-9]);% 200e-9 300e-9 400e-9 500e-9],...
    %[0 -4 -8 -12 -16 -20]);%5e-6 6e-6 7e-6 8e-6 9e-6..
    %10e-6]);
c.ResetBeforeFiltering = 0;
c.NormalizePathGains = 0;
Rx = filter(c,Tx);
RN = awgn(Rx,SNR(n),'measured');
RN1 = RN;
Rx1 = reshape(RN1,FFTLength,NumSym+1);

IRx1 = real(Rx1);
QRx1 = imag(Rx1);

IRx2 = IRx1(GaIn+1:end,:);

QRx2 = QRx1(GaIn+1:end,:);
 Rx2 = IRx2 + j*QRx2 ;

 Rx3 = fft(Rx2);

 IRx3 = real(Rx3);
 QRx3 = imag(Rx3);

 Io = ITx(:,1);
 Qo = QTx(:,1);

 I1 = IRx3(:,1);
 Q1 = QRx3(:,1);
 %(1./I1.^2+Q1.^2).*
 iv = real((Io+j.*Qo)...
     .*(I1 + j.*Q1));
 qv =  imag((Io+j.*Qo)...
     .*(I1 + j.*Q1));
%(1./I1.^2+Q1.^2).*
     for l = 1:NumSym+1
     ieqv(:,l) =iv;
     qeqv(:,l) =qv;
     end
     Icomp = real((IRx3+j.*QRx3).*conj(ieqv+j.*qeqv));

     Qcomp = imag((IRx3+j.*QRx3).*conj(ieqv+j.*qeqv));

     I5 = Icomp;
     Q5 = Qcomp;

     I6 = I5(:,end-NumSym+1:NumSym+1);
     Q6 = Q5(:,end-NumSym+1:NumSym+1);




     re = I6 + j.*Q6;
```

```
    re2 = reshape(re,1,NumCa*NumSym);
    re3 = pskdemod(re2,M);
    %[num rt] = symerr(serialdata,re3);

  [nErrors(M), BER(n,M)] = biterr(serialdata,re3);
ebno(n) = SNR(n)%-10*log10(log2(M));
end
end
% Compute theoretical performance results, for comparison.
BERtheory = berfading(ebno,'psk',M,1,'nondiff');
BERtheoryn = berawgn(ebno,'psk',M,'nondiff');
info = [BER(:,2) BER(:,4) BER(:,8)]
plot(ebno,info(:,1),ebno,info(:,2),ebno,info(:,3))


% Plot BER results.
%semilogy(ebno,BERtheory,'b-',ebno,BERtheoryn,ebno,BER,'r*');
%legend('Theoretical BER','Empirical BER');
%xlabel('ebno (dB)'); ylabel('BER');
%title( 'PSK over Rayleigh Fading Channel');
```

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