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Investigation of Deep Fade Analysis in 4G OFDM Systems

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ABSTRACT

The 3G to 4G transformation improves the data rate and spectral efficiency as per the guidelines by International Telecommunication Union Radio Communication Sector (ITU-R). 4th generation cellular system has to support 100Mbps data rate for a mobile user and 1Gbps for a stationary user. The wireless multipath channels are time varying and random in nature with different attenuations and delays. Poor performance of such system depends on various factors like delay spread, Doppler Shift, feedback delay, coherent or non-coherent detection and channel estimation errors. The paper leads to a better understanding of practical aspects of these induced effects on the performance and mitigation techniques of 4G OFDM wireless systems.

Keywords

Bit Error Rate (BER), Signal to Noise Ratio (SNR), Channel State Information (CSI), Diversity.

INTRODUCTION

Increasing market expectations for 4G mobile radio systems show a great demand for wider range of services spanning from voice to high rate data services required for supporting mobile multimedia communications [1]. Multipath propagation leads to rapid fluctuations of the phase and amplitude of the signal. The presence of scatterers between a transmitter and receiver create multiple independent paths that the transmitted signal can traverse [2]. At the receiver, the superposition of these multiple copies of the transmitted signal, each traversing in the independent path has different attenuation and delay. In such multipath channels, extreme signal amplitude fading and Inter Symbol Interference (ISI) due to the frequency selectivity of the channel appears at the receiver side [3-4]. This leads to a high probability of errors and the system‘s overall performance becomes very poor. The performance of such system depends on the Diversity Order, employed Detection and Estimation Scheme and the required SNR.

An efficient approach to mitigating the detrimental multipath effects is multicarrier space time block fading (STBC) based OFDM wireless systems, used to combat hostile frequency-selective fading encountered in mobile communications [5]. The robustness against frequency selective fading is very attractive, especially for high-speed data transmission. On the other hand, Multi Input Multi Output (MIMO) systems fulfill the demands appeared in the long-term evolution (LTE) and the future fourth-generation (4G) communication systems [6–9].

Channel estimations are necessary for coherent detection in MIMO-OFDM systems [10]. The accuracy of channel estimation directly affects the performance of MIMO-OFDM systems. The combination of multiple-output (MIMO) and Orthogonal frequency division multiplexing (OFDM) system with adaptive modulation and coding (AMC) to improve system capacity with maintaining good error performance.

The paper is organized as wireless system model, performance analysis and mitigation techniques, simulation results and concluded the paper in last section.

SYSTEM MODEL

Due to the fading nature of the multipath wireless channel, the wireless system can be modeled as

$$y = hx + n \tag{1}$$

Where,

h= fading coefficient with magnitude, 'a'

x= Transmitted symbol

y= Received symbol

n= white Gaussian noise with mean zero and variance σ^2.

In nonline of sight (NLOS) environment, the fading amplitude is characterized by Rayleigh distribution and in LOS environment, modeled as Rician channels. The fading channel (h) depends on changes in channel attenuation (a_i) and changes in delays (τ_i). If the input and output signals are independent i.i.d. Gaussian random variables, and if the amplitude is Rayleigh distributed and a phase is uniformly distributed then the received fading SNR is given below.

The fading SNR is,

$$SNR_F = \frac{a^2 P}{\pm^2} = a^2\left(\frac{P}{\pm^2}\right) = a^2 SNR$$
$$\therefore\ BER = Q\left(\sqrt{SNR_F}\right) \tag{2}$$
$$\Rightarrow\ BER = Q\left(\sqrt{a^2 SNR}\right)$$

The fading channel (h) is random in nature, so the bit error rate (BER) is also random in nature. To find the average BER with respect to Rayleigh fading distribution,

$$Avg.BER = \int_0^\infty Q\left(\sqrt{a^2.SNR}\right).2ae^{-a^2}.da$$
$$= \frac{1}{2}\left(1-\sqrt{\frac{SNR}{2+SNR}}\right) \approx \frac{1}{2SNR}\,\text{underhighS NR} \tag{3}$$

Under Rayleigh fading channel, BER is just inversely proportional to the SNR. Poor performance depends upon the random quantity i.e., channel gain (a). The probability of error depends on the magnitude of channel coefficient with amplitude 'a' and the Rayleigh distribution of channel.

POOR PERFORMANCE ANALYSIS AND ITS MITIGATION TECHNIQUES

The undesirable fluctuations in the received signal power are termed as, 'fading'. There are various factors like destructive interference due to multipath propagation, user mobility, imperfect channel estimation and its errors and so on.

A) DEEP FADE ANALYSIS

The received instantaneous SNR from equation (2) is given by,

$$SNR_r = \frac{a^2 P}{\pm^2} = |h|^2 SNR \tag{4}$$

If the received signal power < Noise power, then the system is in deep fade. i.e.,

$$a^2 P \langle \pm^2$$
$$\Rightarrow \; a^2 \langle \frac{\pm^2}{P} \langle \frac{1}{SNR}$$
$$\Rightarrow \; a^2 \langle \frac{1}{SNR} \qquad (5)$$
$$\Rightarrow \; |h|^2 < \frac{1}{SNR}$$

i.e., the distance between the constellation points is less than the standard deviation of noise.

Probability of deep fade, $P_{DF} \sim \frac{1}{SNR}$ (6)

The poor performance of a reliable communication depends on the received signal strength. To combat the fading and to improve the performance of the system, employ the technique called "*diversity*".

Diversity:

When the path is in a deep fade, communication receiver will suffer from errors. A natural solution to improve the performance is to introduce, 'diversity'. Diversity is a process of sending the same information symbols over multiple independent fading paths, the maximum diversity gain can be achieved. Also, maximize the output SNR by combining each branch SNR using diversity combiner. The information symbols are coded and dispersed over time/frequency in different coherence periods so that the code words are uncorrelated. Consider a single input multiple output (SIMO) system with h_1, h_2, ……h_L, independent random variables and identically distributed Rayleigh channel coefficients.

Let, $g = \|\bar{h}\|^2 = |h_1|^2 + |h_2|^2 + \cdots |h_L|^2$, 'g' is called chi-squared random variable. At the receiver, after optimal receive combining by using maximal ratio combining (MRC) technique, the resultant SNR is,

$$SNR_m = \frac{P}{\pm^2}\left\{\|\bar{h}\|^2\right\} = g.SNR$$

where (7)

$$\|h\|^2 = \sum |h|^2$$

The probability of Chi-square function is given as,

$$f(g) = \frac{1}{(L-1)|} g^{L-1}.e^{-g} \qquad (8)$$

$$P_e = Q\left(\sqrt{SNR_m}\right) = Q\left(\sqrt{g.SNR}\right)$$

$$\therefore AverageBER = \left(\frac{1-a}{2}\right)^L \sum_{l=0}^{L-1} {}^{L+l-1}C_l \left(\frac{1+a}{2}\right)^l$$

$$\approx {}^{2L-1}C_L \cdot \left(\frac{1}{2SNR}\right)^L \qquad (9)$$

where

$$a = \sqrt{\frac{SNR}{1+SNR}}$$

Also, the probability of deep fade P_{DF} will be,

$$P\left\{\|h\|^2 < \frac{1}{SNR}\right\} \approx \frac{1}{L!} \cdot \frac{1}{SNR^{L}} \quad (10)$$

For, an IID faded channel with "L" antennas,

$$P_{DF} \sim \frac{1}{SNR^{L}} \quad (11)$$

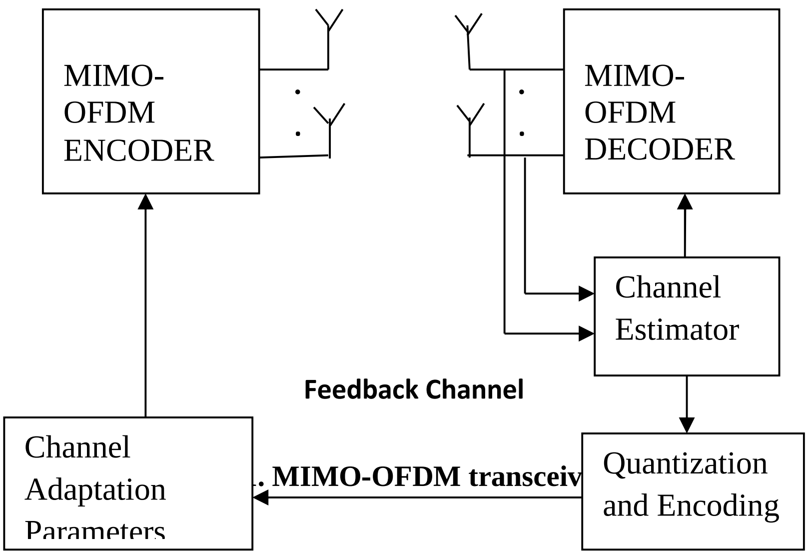
i.e., the P_{DF} decreases as ($1/SNR^{L}$) due to multiple independent fading channels employing diversity. By increasing number of independent fading paths (L), the error probability and thus the deep fade events can be decreased.

B) IMPERFECT CHANNEL ESTIMATION

The conventional channel estimation is often called the data-aided (DA) type [11], i.e., it is carried out with the help of pilot known symbols, results in a waste of bandwidth and power. The iterative adaptive modulation and coding (AMC) with the use of modest number of pilot sequences can accomplish near optimal estimates after a few iterations. The feedback delay is defined as a delay between the time that the mobile station measures the channel and the time that the base station applies that information to send the signal in downlink.

Under no feedback delay, if the channel conditions are good enough choose higher modulation scheme (256 QAM) and if the channel conditions are poor choose lower modulation scheme (QPSK). The transmitter selects the appropriate modulation level to modulate data, and maps the symbols to the available antennas in the MIMO encoder. Assume the perfect channel estimation at the receiver. Then the terminal communicates the SNR in the CSI format via the feedback channel to the transmitter. Based on the CSI, the system selects the rate and the constellation size of the modulation to be transmitted.

Feedback introduces delay as well as errors when passing information from the receiver to the transmitter. Usually, the feedback delay is of more interest as the errors can be avoided by using low modulation order and powerful coding techniques. The feedback delay influences the accuracy of the modulation order. Adaptation depends on channel estimation errors, quantization errors, and feedback delays. More specifically, in high mobility scenarios, the rapid channel variation causes the channel information contained in the feedback to become outdated. The effect of outdated estimates in channel statistics affects adaptive techniques. One way to mitigate the channel estimation errors is to use the quantized data at the receiver.



At the receiver channel state information (CSI) is fed into a quantizer that returns a small number of feedback bits to be sent as overhead on the reverse link. The transmitter can use the received feedback bits to adapt the transmitted signal to the forward channel.

Under no delay, SNR thresholds can be calculated as,

$$\gamma_i = \frac{M_i - 1}{-1.6} \ln\left(\frac{B \quad t}{0.2}\right) \qquad (12)$$

If the time correlation factor ρ is J0[2] (2πfdτ), then the updated thresholds are obtained by

$$\gamma_i = \frac{1 + \frac{1.6}{M_i - 1}\frac{\bar{\gamma}(1-\rho)}{N_t}}{\rho\frac{1.6}{M_i - 1}} \ln\left[5B \quad t\left(1 + \frac{1.6}{M_i - 1}\frac{\bar{\gamma}(1-\rho)}{N_t}\right)^{N_t N_r}\right] \qquad (13)$$

The receiver has to continuously track the post processing SNR to avoid the outdated CSI.

C) DOPPLER EFFECT ANALYSIS

Consider the mobile station/receiver is moving towards or away from the base station. Then there is a change in the received signal frequency due to motion between BS and MS, known as Doppler shift.

Let velocity of the mobile is ‘v’ and angle of the mobile w.r.t. base station is ‘θ’.

Then, Doppler shift is defined as,

$$f_d = \frac{v.c}{c} . f_c \qquad (14)$$

and the received frequency depends on travel direction w.r.t. BS is given as,

$$f_r = f_c \pm f_d \qquad (15)$$

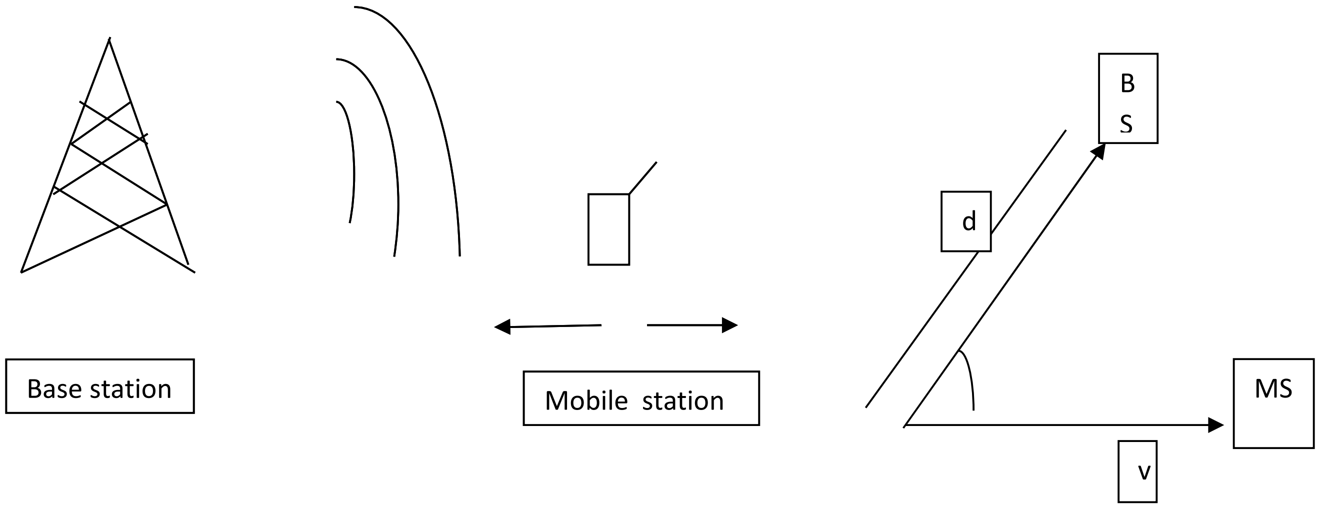


Fig. 2. Mobile receiver with velocity, v [4]

Impact of Doppler Effect on wireless channel

Let fading coefficient, $h = \sum_{i=0}^{L-1} a_i e^{-j2\pi F_c \tau_i}$

If the distance between mobile and BS is decreasing by $\frac{v.c}{c} . t$, then

$$d \quad = \tau_i(t) = \tau_i - \frac{v.c}{c}.t \qquad (16)$$

Then,

$$h = \sum_{i=0}^{L-1} a_i e^{-j2\pi F_c\{\tau_i - \frac{v.c}{c}.t\}}$$

$$= \sum_{i=0}^{L-1} a_i e^{-j2\pi F_c\{\tau_i\}}.e^{-j2\pi F_c\{\frac{v.c}{c}.t\}}$$

$$s \ , h = \sum_{i=0}^{L-1} a_i e^{-j2\pi F_c\{\tau_i\}}.e^{-j2\pi F_d t} \qquad (17)$$

Thus, MOBILITY leads to Doppler Shift which results in the channel coefficient ‘h’ is time varying, termed as time selective channel. In high mobility scenarios, the performance of channel information transmission adaptation is highly dependent on the feedback delay.

Proposed work is feasible in a slowly varying channel with minimum mobility where the coherence time is larger than the feedback delay.

SIMULATION PARAMETERS

Considering the above said problems, the MATLAB simulation of adaptive OSTBC MIMO OFDM is performed with the following parameters.

Table 1. Simulation parameters

Parameter	**Value**
Carrier frequency *fc*	2.5 GHz
Channel bandwidth *B*	8 MHz
Number of carriers *K*	128
FFT frame duration *Ts*	16 μs
OFDM symbol duration *T*	20 μs
cyclic prefix	4 μs
Modulation scheme	64 QAM
Max. delay spread *τmax*	4 μs
Max. terminal speed υ	130km/h
Norm. Max. Doppler spread *fD*	0.006 =T. 300Hz
Feedback delay ρ	1ms
Number of channel estimator iterations	1, 2, 3, 4
Number of ZF detector iterations	2, 4 with N_t =2 and N_r =2

FDD systems require feedback to obtain the channel knowledge at the transmitter, and the MS mobility determines how frequent the update of the weights should be with the low mobility, presents STBC as the best technique. In a mobile environment, several objects reflect or diffract radio signals.

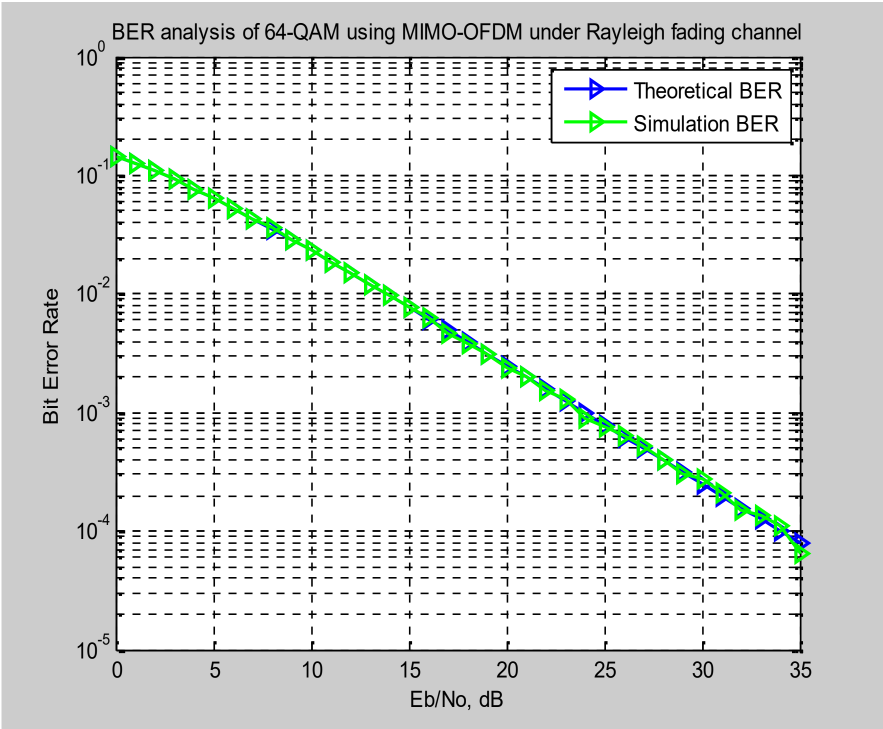
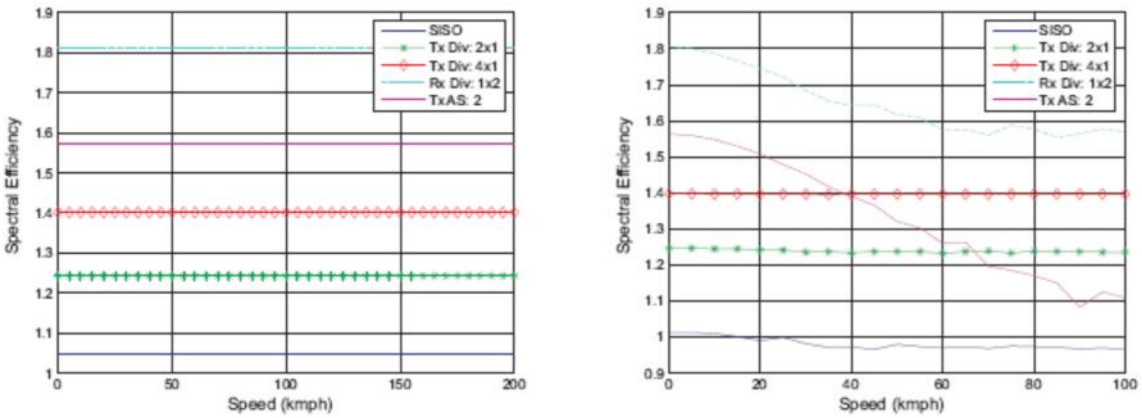


Fig.3: BER performance of STBC MIMO OFDM

From figure 3 the BER of M-QAM in Rayleigh fading using analytical techniques is shown. All modulation schemes use Gray coding which gives a few dB of margin in the BER performance.



(a) no delay feedback (ideal) (b) fast feedback: 0.5 ms, regular feedback: 1 ms

Fig.4: Performance analysis of adaptive MIMO OFDM with or without feedback delay

From figure 4(a), it is clear that the spectral efficiency versus user mobility under ideal/no CSI no feedback delay. The user speed does not affect performance, since the delay is assumed instantaneous. From 4(b), under fast feedback channel the degradation in performance due to an increase in speed for the same multi-antenna techniques. In fact, at higher speed, the channel becomes more time-variant, and the probability of choosing a modulation not appropriate for the channel quality increases.

CONCLUSIONS

The performance of channel-aware transmission adaptation is highly dependent on the feedback delay. AMC schemes provide performance gains under low mobility scenarios, but suffer degradation due to feedback delay as the speed of the terminal increases. Adaptive MIMO OFDM techniques in systems on the basis of CSI obtained via quantized feedback improves the performance in the variable channel.

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