Performance Evaluation of Preamble Detection under ITU and SUI Channel Models in Mobile WiMAX

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***Abstract*—In wireless-domain, performance evaluation of preamble detection under varying channel conditions is of compelling research interest nowadays. Most of the existing works, based on preamble detection under channel conditions are limited to ITU, AWGN etc in Mobile WiMAX. In this work, we have performed preamble detection for 1024 point FFT and 512 point FFT data under SUI channel models in addition to ITU –R Vehicular A and Pedestrian B models. The results show that the performance of 1024 FFT is better than 512 FFT under various channel models. Moreover, we analyzed the behavior of various channels for these two different bandwidths.**

Keywords: Preamble detection, index calculation, SUI channels, ITU-R Vehicular A, Pedestrian B, Mobile WiMAX

I. Introduction

IN simple terms, preamble is used to communicate to the receiver that transmitted data is on the way. In the context of WiFi (802.11) Technology, Preamble allows the receiver to acquire the wireless signal and synchronize itself with the transmitter [7].

In wireless OFDM systems like WiMAX (802.16e), preamble is first symbol of the downlink transmission which is used for initial frame timing/synchronization by mobile stations. Initially, when a MS (Mobile Station) enters a network, it has to search for the neighboring BSs (Base Station) in order to achieve synchronization. For this purpose, the process of detecting a packet/signal pertaining to WiMAX standard is present is a must. Preamble symbol for WiMAX is entirely different from wireless standard like WLAN where in symbol is formed from one of the 114 PN sequences as defined in the standard [10].

The cyclic shift due to small misalignment in FFT window can be avoided if preamble is detected accurately. As a sequel to this, it may affect the handover at cell boundaries. Solution to this, otherwise, demands for complex hardware and software burdening. So preamble detection problem is indeed of significant research topic nowadays.

In Mobile WiMAX, according to IEEE802.16e, the official standard, initial synchronization at the MS is achieved by detecting the preamble that is transmitted by the BS in the Down Link (DL). Existing techniques such as initial synchronization algorithm determines start of frame by observing autocorrelation of time domain replica to detect preamble.

Bhatt et al. [1] have done initial synchronization and cell identification in 802.16e OFDMA downlink. They have evaluated their scheme using multipath fading but limited to ITU channel models only. As stated by Hou et al. [4], DL preambles currently defined in 802.16e standard require that MSs capture preamble symbols and correlate with 114 PN sequences in frequency-domain to determine IDcell and Segment of specific sector. Jie et al. [5] have proposed a preamble detection/synchronization technique in OFDMA wireless communication systems. In their work, symbol correlation of sequence of symbols is computed in correlation window using either time-domain correlation or frequency-domain correlation. The works such as Oka et al. [6] and Segal et al. [3] proposed different preamble sequences which have low PAPR (Peak to Average Power ratio). However, we use the preamble sequence proposed in the standard IEEE 802.16e.

The general requirements for Mobile Station receiver as stated by Cho et al. [2] include:

a) Fast and accurate initial synchronization
b) Easy deployment of system
c) High system throughput and
d) Enough number of cell IDs.

Although considerable work has been done among the research community on preamble detection, no exhaustive performance testing has been done yet using varying channel models. In this paper, we provide comparative performance analysis of preamble detection under varying channel models. In particular, we have evaluated preamble detection for 1024 FFT and 512 FFT OFDMA PHY.

The organization of the paper is as follows. In first section, we have introduced preamble detection. Section 2 provides preliminaries on preamble and channel models. Section 3 provides the framework description. Results and discussions follow in Section 4. Finally, the conclusion is given in Section 5.

II. Preamble and Channel Models

A. *Preamble*

Preamble is the first symbol of downlink transmission in wireless OFDM systems. It is used for initial frame timing/ synchronization by MSs. In order to transmit and receive frames, the BS and MS should acquire mutual synchronization. For this, MS has to detect the start position of Preamble transmitted from the Base Station. A symbol is verified from CP (Cyclic Prefix) based auto correlation. The symbol can be either preamble or data. For example, in WiMAX, once this synchronization occurred, MAC layer will start obtaining channel control parameters.

TABLE I. SUI CHANNEL PARAMETER VALUES

SUI	P	K	Tau	Doppler	Ant_corr	Fnorm
1	[0 -15 -20]	[4 0 0]	[0 0.4 0.9]	[0.4 0.3 0.5]	0.7	-0.1771
2	[0 -12 -15]	[2 0 0]	[0 0.4 1.1]	[0.2 0.15 0.25]	0.5	-0.3930
3	[0 -5 -10]	[1 0 0]	[0 0.4 0.9]	[0.4 0.3 0.5]	0.4	-1.5113
4	[0 -4 -8]	[0 0 0]	[0 1.5 4]	[0.2 0.15 0.25]	0.3	-1.9218
5	[0 -5 -10]	[0 0 0]	[0 4 10]	[2.0 1.5 2.5]	0.3	-1.5113
6	[0 –10 -14]	[0 0 0]	[0 14 20]	[0.4 0.3 0.5]	0.3	-0.5683

P – Power in each tap in dB, K- Ricean K-factor in linear scale, Tau – tap delay, Doppler – Doppler maximal frequency parameter, Ant_corr - antenna correlation (envelope correlation coefficient), Fnorm-gain normalization factor in dB.

B. Channels

The wireless channels can be modeled using AWGN (Additive White Gaussian noise, SUI (Stanford University Interim) Channel models [8], ITU – Vehicular and Pedestrian models [8,9]. We have provided the channel parameter values for ITU and SUI channel models in Table 1 and Table 2 respectively.

TABLE II. ITU CHANNEL PARAMETER VALUES

ITU-R	P (dB)	Tau (ms)	Doppler (Hz)
Vehicular(A)	[0 -1 -9 -10 -15 -20]	[0 0.31 0.71 1.09 1.73 2.51]	[100 400 833] (30 Km/hr, 120 Km/hr, 250 Km/hr)
Pedestrian(B)	[0 -0.9 -4.9 -8.0 -7.8 -23.9]	[0 0.20 0.80 1.2 2.3 3.7]	10 (30 Km/hr)

P – Power in each tap in dB, K-Ricean K-factor in linear scale, Tau – tap delay, Doppler – Doppler maximal frequency parameter

Each of the SUI-Channels corresponds to particular terrain category A, B, and C. Type A terrain category include SUI-5, 6 (hilly/heavy tree density), Type B include SUI-3, 4 (moderate tree density) and Type C include SUI-1,2 (flat/light tree density).

III. FRAMEWORK DESCRIPTION

The process in which the synchronization is achieved consists of the following steps (Refer Figure 1).

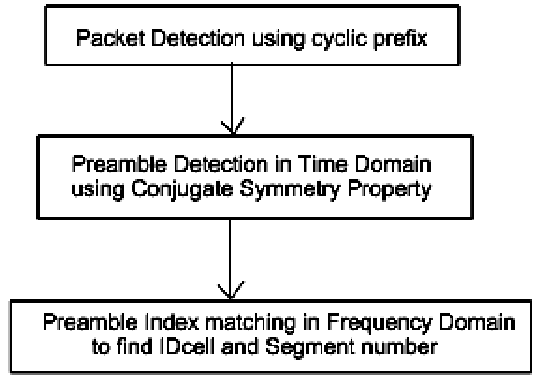


Figure 1. Steps in Preamble detection

i. Packet Detection using Cyclic Prefix,
ii. Preamble Detection in Time Domain using the conjugate symmetric property
iii. Preamble Index matching in Frequency Domain to find IDcell and Segment number

The description of the above steps for correlation and matching the sequence is given below.

A. Packet Detection using Cyclic Prefix

Generally, the detection of a packet for any OFDM based system is done by auto-correlation using Cyclic Prefix. All the OFDM symbols are transmitted by appending a copy of the last few samples of the OFDM symbol to the front, known as Cyclic Prefix. This helps us in finding the OFDM symbol in air, by making use of the high correlation between the first CP samples and last CP samples of the OFDM symbol. By performing a delayed correlation of the CP with the last CP samples of the OFDM symbol, start of a packet can be detected [1]. The peak in the Figure 5 illustrates the detected packet.

B. Preamble Detection in Time Domain

As MS can enter the network at any point of time and every OFDM symbol in a WiMAX frame is transmitted along with CP, packet detection using Cyclic Prefix alone would not suffice.

We perform preamble detection in time domain by making use of conjugate symmetry and repetition property. Though data will never have same sequence as preamble in frequency domain, sometimes it may be interpreted as preamble due to noise and other interferes. . In order to identify the intended periodic and repetition property of Preamble from that of noise and interferers, care should be taken in setting threshold values and window settings.

After the preamble symbol is detected, it has to be compared to the PN table to determine the segment number and IDcell number that the preamble symbol is from. This has to be performed by regrouping the subcarriers in the preamble symbol into preamble carrier-sets.

Since, Preamble Symbol is formed by performing inverse Fourier Transform (IFFT) on the Preamble sequence that contains non-zero values at every third subcarrier in the frequency domain; we obtain the conjugate symmetric sequence in the time-domain. If we divide the time-domain preamble sequence into roughly 3 equal parts, every part will be in near-conjugate symmetry with the nearest part. This property can be made use of in detecting the Preamble in time domain.

All the subcarriers in the OFDMA symbol are split into three groups. Furthermore in a preamble OFDMA symbol, the second group of subcarriers (index 342 – 683), is a conjugate of first and third group of subcarriers (index 0 - 341 and index 684-1024) respectively. The first peak exceeding the threshold value is from conjugate calculation between the first group and the second group. The second peak in the graph is from conjugate results between the second group and the third group. When conjugation condition is satisfied, the OFDMA symbol can be determined to be a preamble. Figure 6 can better illustrate the above understanding.

Also, because the Preamble Sequence is transmitted using higher power compared to data symbols, we can make use of this property for more robust Preamble detection.

C. Preamble Detection in Frequency Domain

Once the Preamble is detected in time domain, the Preamble Sequence in frequency domain is obtained by performing Fast Fourier Transform (FFT) on the same. As there are 114 sets of preamble sequences, the task is to find a best match of the received sequence from one of the 114 available preamble sequences. This process requires cross-correlation of each one of the 114 Preamble sequences with the received sequence. It is obvious that it may require more number of hardware resources.

To reduce the hardware, a signed correlation method can be used instead of performing multiplicative correlation. Since the preamble sequences are only real because of BPSK modulation, we can directly compare the signs of the received sequence with available preamble sequences. This would significantly reduce the computational complexity at the expense of reduced accuracy. But, as we are not going to use the result for any purpose other than for finding a match, we can still use this technique. From the detected preamble index, we can obtain the IDcell and Segment number information which informs the MS that BS has transmitted the DL sub frame using the IDcell in the particular segment.

DL can be divided into a three segment structure (minimize frequency interference). Each segment uses one preamble out of 3 sets. (Refer Figure 2)

The preamble carrier-sets are defined according to the equation below:

$$PreambleCarrierSet_n = n + 3.k$$

where $PreambleCarrierSet_n$ specifies all subcarriers allocated to the specific preamble n is the number of preamble carrier-set indexed 0 to 2, k is a running index from 0 to 283 for 1024 FFT.

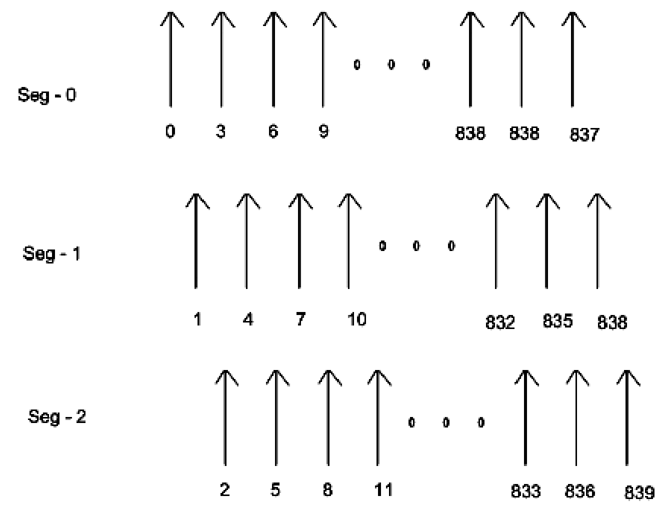


Figure 2. Preamble carrier values for different segments s = 0,1,2

Here, *n* denotes the number of preamble carrier-set indexed 0...2 k is a running index 0...567 for *2K FFT*, 0 to 283 for *1024 FFT*, 0 to 142 for *512 FFT* and 0 to 35 for *128 FFT*.

Boosted BPSK modulation with a specific PN code Replicas in time domain is used. The series modulated depends on the segment used and IDcell parameter. The value of the PN is obtained by converting the series to a binary series. Thus obtained series shall be mapped onto the preamble subcarriers in ascending order and starting mapping the PN from the MSB of each symbol to the LSB (0 mapped to +1 and 1 mapped to –1)

Each segment uses a preamble composed of a carrier-set in the following manner:

a) Segment 0 uses preamble carrier-set 0

b) Segment 1 uses preamble carrier-set 1

c) Segment 2 uses preamble carrier-set 2

Therefore, each segment will eventually modulate each third subcarrier. Figure 2 depicts the preamble of segment 1 where subcarrier 0 will correspond to the first subcarrier used on the preamble symbol [1]. Each preamble data is transmitted on every 3^{rd} subcarrier within the preamble symbol and the offset of the preamble subcarrier helps mobile or subscriber station determine sector of the cell [1].

For example, in the case of 1024 FFT for segment 0, the carrier starts with 86, 89... For segment 1, the carrier starts with 87, 90… whereas segment 3, the carrier set starts with 88, 91.. etc. The sample implementation of this process is given in the following Pseudo code which has three parts viz. Packet detection using Cyclic Prefix, Preamble detection using conjugate symmetry and finding index number.

Pseudo code:

```
Preamble Data Generation
Preamble symbol at the output of FFT:
D1 = fft_size;
midval =  midval_get(fft_size);
seg1 = seg(index);
midval =  midval + seg1;
r_new = zeros(1024,1)
u = str2num(data_fft');
  for i = 1:size(u,1)
  u(i) = 4 * sqrt(2) * (1/2 - u(i));
  end
Cyclic Prefix Insertion
cp_length = fft_size/8;
cp_insert=[ifft_out(fft_size-cp_length+1:fft_size) ifft_out];
tx_signal = cp_insert;
Channel Modeling
channel = SUI_Channel(N_SUI,G,BW);
channel = ITU_Channel(ITU_type,G,BW)
chan_signal = filter(channel,1,tx_signal);
a = randn(1,700);
b = randn(1,700);
rand_noise = complex(a./(16*max(a)),b./(16*max(b)));
rx_signal = [rand_noise chan_signal rand_noise];
Packet Detection
corr_out =
     xcorr(rx_signal(1:len1D1),rx_signal(D1+1:len1));
abs_corr = abs(corr_out);
 [maxval,indx1] = max(abs_corr);
plot(abs_corr(1:length(rx_signal)-1));
indx = indx1(1);
rx_data = rx_signal(indx+1:indx+D1+cp_length);
rx_data = rx_data(cp_length+1:end);
len2 = length(rx_data);
Preamble Detection/index calculation
corr_out_second=xcorr(rx_data(1:len2-
                              D1/2),rx_data(D1/2+1:len2));
abs_corr_second = abs(corr_out_second);
[maxval,indx] = max(abs_corr_second);
```

IV. RESULTS AND DISCUSSIONS

The Sample Preamble modulation series per segment and IDcell for the 1024 FFT have been taken from IEEE 802.16 e standard document. Figure 3 shows the preamble detection graph based on both signed and simple correlation method for 1024 FFT as discussed in section 3.3. It is observed that preamble index 36 is detected using both simple as well signed correlation method. Figure 4 shows sample preamble sequence detection under SUI-1 channel condition for 1024-FFT.

Here, it is observed that index 11 is detected with a correlation score of 280. FSER (Frame Synchronization Error Rate) is calculated as ratio of the number of errors (i.e. wrongly detected preamble) to total number of sequences. For example, when the number of error is 1, then FSER is (1/114) * 100 = 0.877. As discussed earlier, Figure 5 and 6 represent Preamble delay correlation using cyclic prefix and conjugate symmetry respectively.

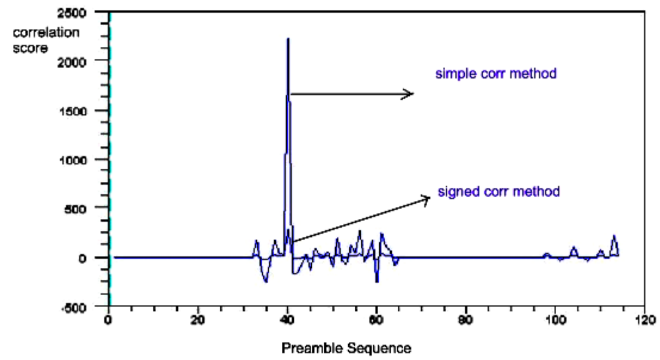


Figure 3. Preamble detection graph and analysis (signed and simple correlation method

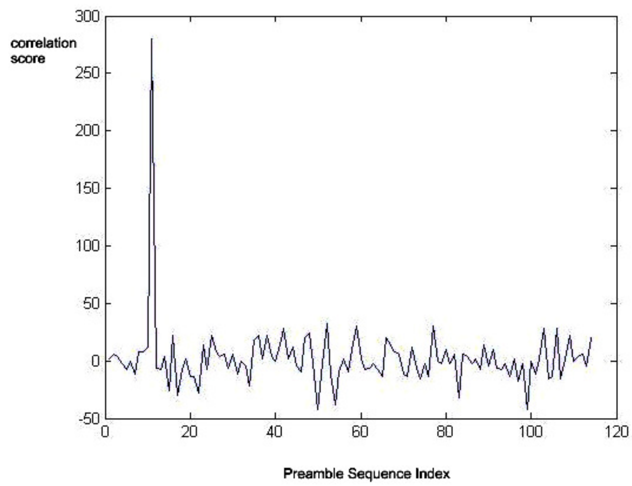


Figure 4. Index 11 SUI-1 for 1024 FFT

To evaluate the preamble detection, we used varying channel models such as ITU-A, ITU-B, SUI-1, SUI-2, SUI-3, SUI-4, SUI-5 and SUI-6. For experimentation purposes, simulation is done in Matlab over hundred iterations with the parameters provided in Table 3. We also assume that the channel comes with addition of AWGN (Additive White Gaussian Noise) with each of the channel models. The SNR values such as 20, 16, 12, 8, 4, 0,-4,-8, and -12 are considered for experimentation purposes. Figure 7 and Figure 8 depict the error rate for different channels for 1024 FFT and 512 FFT respectively. But the plots in Figure 9 illustrate the variation of error rate with respect to different bandwidths of FFT sizes for a particular channel.

The key observations from these graphs can be summarized below:

a) The frame error rate decreases when SNR (Signal to Noise Ratio) is more. In other words, when noise increases, error rate also increases for all types of channels as expected.

b) SUI-1 and SUI-2 has less error rate compared to other models due to flat fading (type C Terrain Category). As the coherence bandwidth of the channel is larger than the bandwidth of the signal, all frequency components of the signal will experience the same magnitude of fading.

c) It is observed that FSER is comparatively lesser for 1024-point FFT data than 512 FFT data. This is because of the interpolation property. i.e., (n)th sample of the 512 FFT output would match with the (2n - 1)th sample of the 1024 FFT, for a one based indexing.

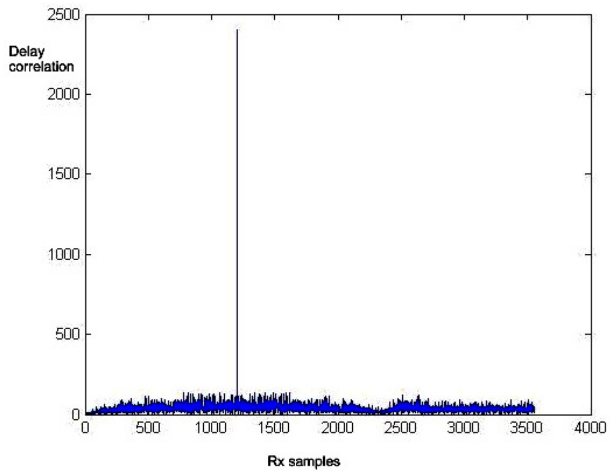


Figure 5. Preamble delay correlation using cyclic prefix (SNR 10 dB)

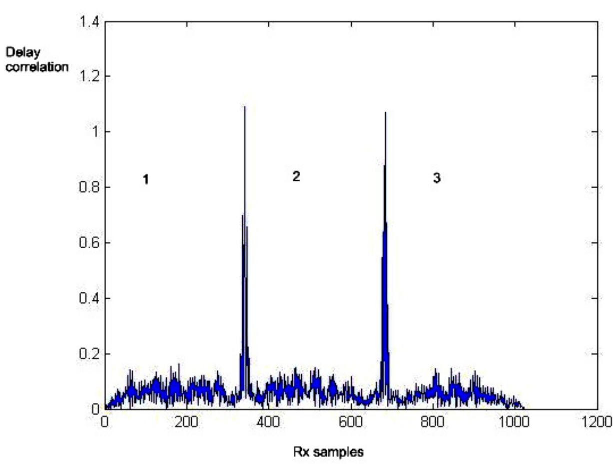


Figure 6. Preamble delay correlation conjugate symmetry search (SNR 10 dB)

d) ITU-R B Pedestrian channel model has less error rate than ITU-R A Vehicular channel model for both 512 and 1024 FFT data. The reason is primarily due to the difference in velocity of movement. Due to this, error is more in vehicular than pedestrian models.

e) Further, it is observed that in case of 1024 FFT, SUI4 has low error rate than SUI3 and in 512 FFT, the reverse condition holds. i.e. SUI 3 has lower error rate than SUI4. Similarly, in case of 1024 FFT data, SUI5 has lower error rate than SUI6 and in 512 FFT data, SUI6 has lower error rate than SUI5. This is due to the delay spread which is high and low in SUI 6 and SUI 5 respectively.

TABLE III. SIMULATION PARAMETERS

Parameter	Value
Bandwidth (FFT)	5MHz(512), 10 MHz(1024)
Cyclic Prefix	1/8
Frame Duration (TDD)	5 ms
Symbol Time	102.86 μs
Channel models	SUI-1,2,3,4,5,6, ITU-R Vehicular A, Pedestrian B

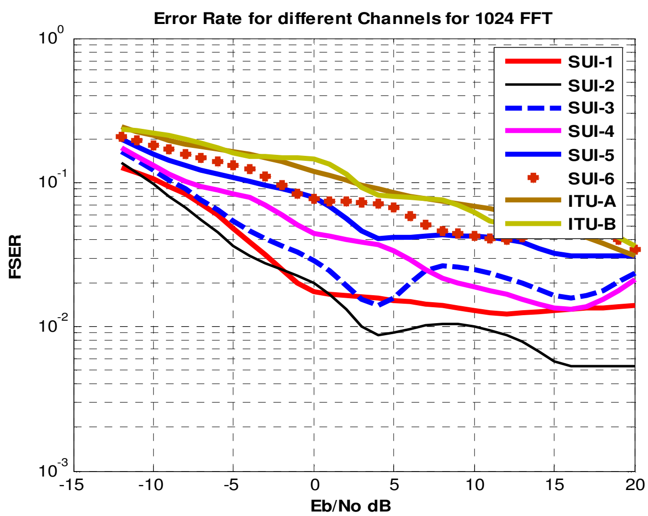


Figure 7. Error rate for different channels bNo Vs. Pr (FSER) Bandwidth 10 MHz (1024 FFT)

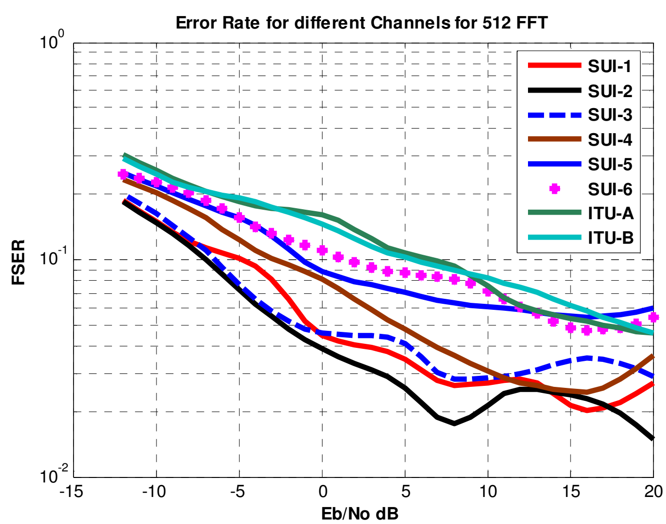
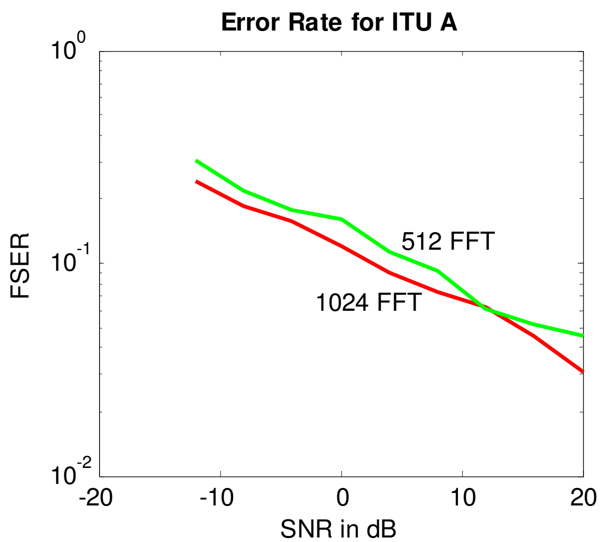
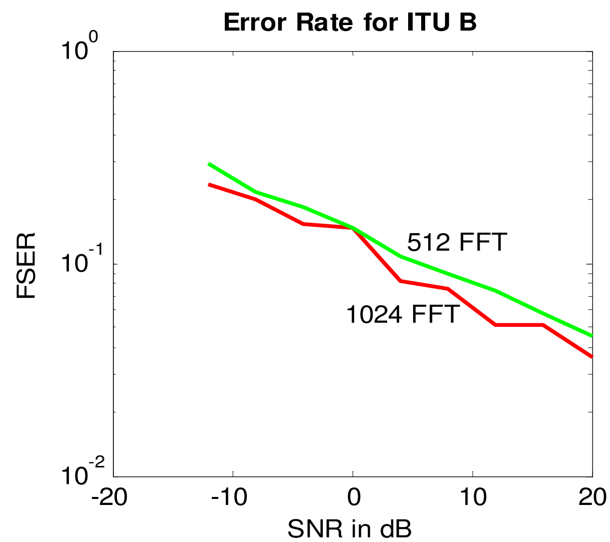
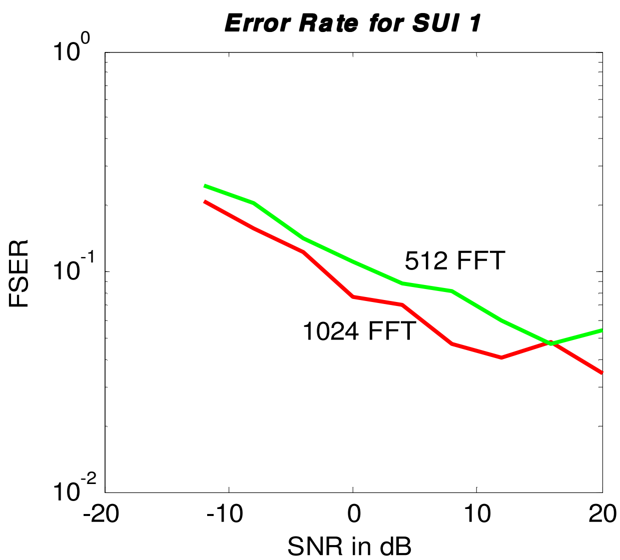


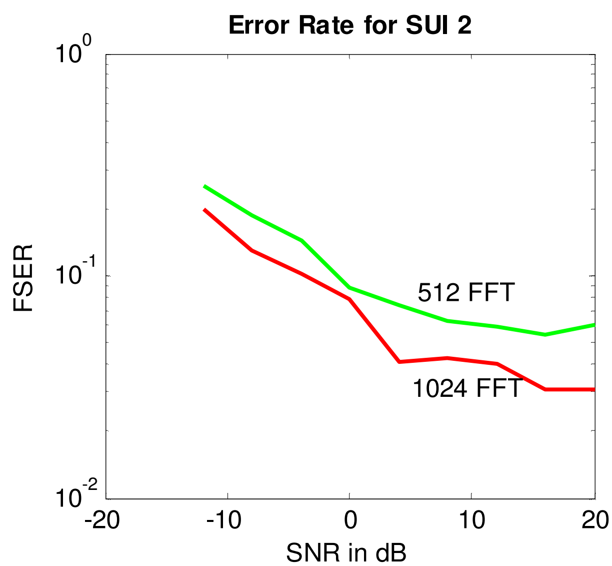
Figure 8. Error rate for different channels

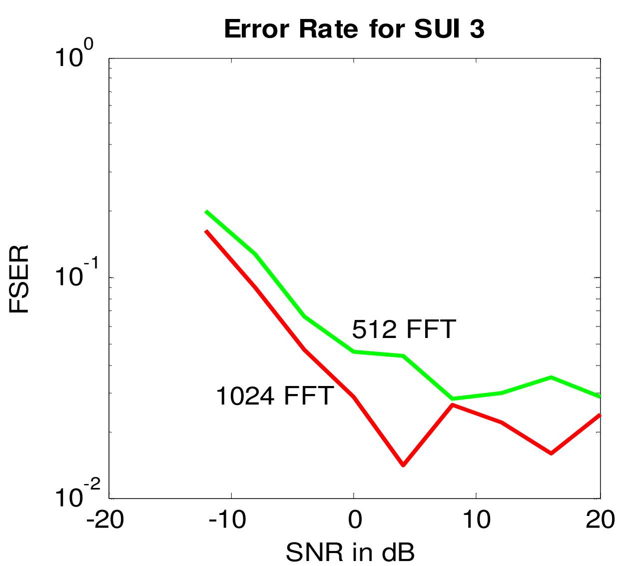
EbNo Vs. Pr (BER) Bandwidth 5 MHz (512 FFT)

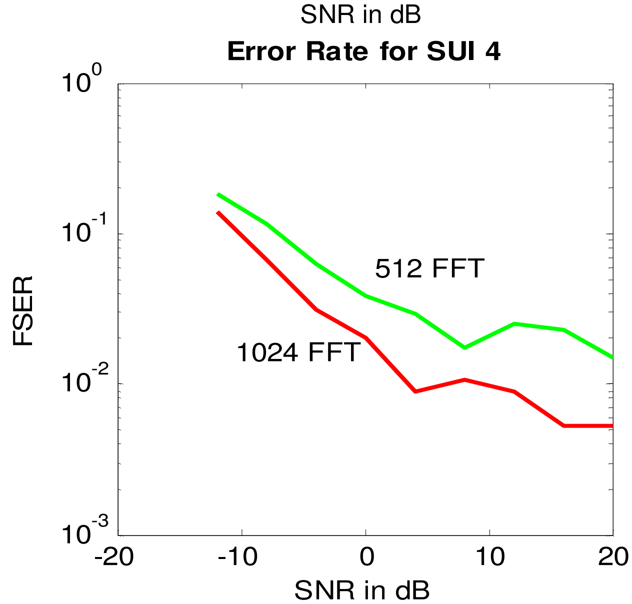

Error Rate for ITU A
FSER
SNR in dB
512 FFT
1024 FFT
-20
-10
0
10
20


Error Rate for ITU B
FSER
SNR in dB
512 FFT
1024 FFT
-20
-10
0
10
20


Error Rate for SUI 1
FSER
SNR in dB
512 FFT
1024 FFT
-20
-10
0
10
20


Error Rate for SUI 2
FSER
SNR in dB
512 FFT
1024 FFT
-20
-10
0
10
20


Error Rate for SUI 3
FSER
SNR in dB
512 FFT
1024 FFT
-20
-10
0
10
20


Error Rate for SUI 4
FSER
SNR in dB
512 FFT
1024 FFT
-20
-10
0
10
20

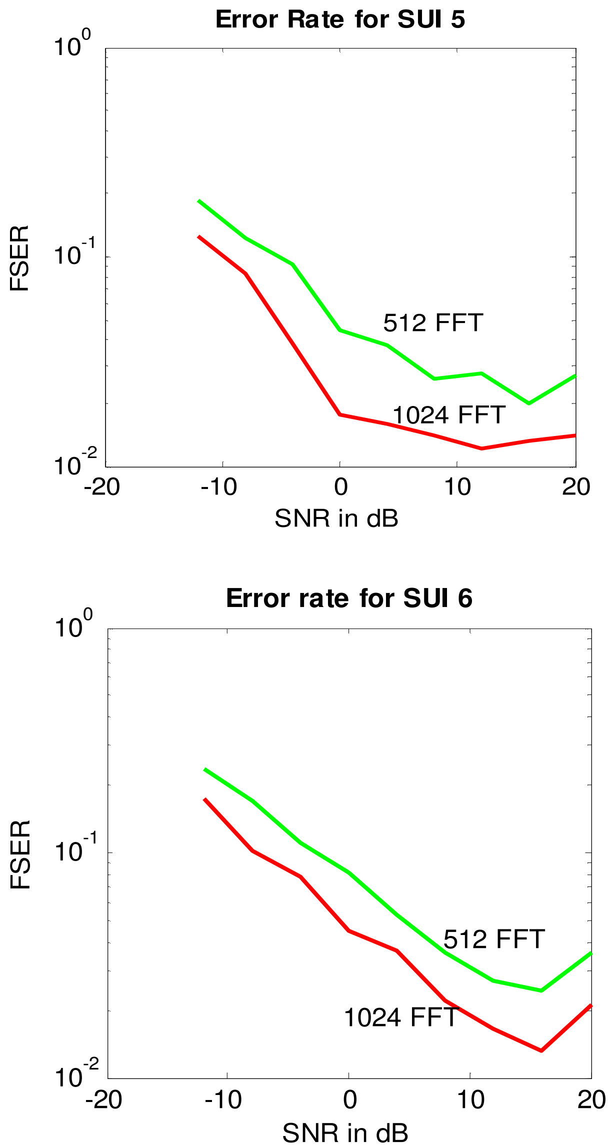


Figure 9. Plots of Error rate for various Channels

V. CONCLUSION

We have provided extensive results and plots by comparing each of the error rate behavior different channel models as SUI1, SUI3, SUI4, SUI5, SUI6, ITU-A Vehicular and ITU-B Pedestrian. We have analyzed the behavior of channels for two bandwidths 10 MHz (1024 FFT) and 5 MHz (512 FFT). It is observed that FSER is less for higher FFT size such as 1024 compared to lower FFT size 512. It is also noted that SUI-1 and SUI-2 has less error rate due to flat fading. Also, ITU-R B Pedestrian has comparatively reduced error rate than ITU-R Vehicular channel models as far as preamble detection is concerned.

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