Performance Analysis of IEEE 802.11a WLAN Standard based on various Channels

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ABSTRACT

In modern world, the Wireless Local Area Network standards are playing a key role in exchanging the information between the transmitter and receiver. In this paper, IEEE 802.11a WLAN standard is chosen to investigate the effects of various channels like Additive White Gaussian Noise channel (AWGN), Phase Noise (PN) of MIMO radio channel and Multipath Fading channel. IEEE 802.11a operates on 5GHz, as compared to other IEEE standards such as IEEE 802.11b/g, it has been interference free, since the 2.4GHz band is heavily used. The Bit Error Rate (BER) versus Signal-to-Noise ratio (SNR) are measured for above channels using Agilent’s Advanced Design System (ADS) Software at the throughput of 24Mbps. And compared with ideal case of BER to SNR value of 10⁻⁵. The result shows the performance of the wireless system.

Keywords: BER, WLAN, IEEE 802.11a, AWGN, PN, Multipath Fading Channel

1. INTRODUCTION

In Wireless data Communication, IEEE 802.11a is an Orthogonal Frequency Division Multiplexing (OFDM) system very similar to Asymmetrical Digital Subscriber Loop (ADSL) Discrete Multi-Tone (DMT) modems sending several subcarriers in parallel using the Inverse Fast Fourier Transform (IFFT), and receiving those subcarriers using the Fast Fourier Transform (FFT). In 802.11a the transmission medium is wireless and the operating frequency band is 5 GHz. The OFDM of the 802.11a [1] system provides a Wireless LAN with data payload communication capabilities of 6, 9, 12, 18, 24, 36, 48 and 54 Mbps. The support of transmitting and receiving at data rates of 6, 12, and 24 Mbps is mandatory in the standard. The 802.11a system uses 52 subcarriers that are modulated using binary or quadrature phase shift keying (BPSK/QPSK), 16 Quadrature Amplitude Modulation (QAM), or 64 QAM. Forward Error Correction (FEC) coding (convolutional coding) is used with a coding rate of 1/2, 2/3, or 3/4.

Using the 5 GHz band gives 802.11a a significant advantage, since the 2.4 GHz band is heavily used to the point of being crowded. Degradation caused by such conflicts can cause frequent dropped connections and degradation of service. However, this high carrier frequency also brings a slight disadvantage: the effective overall range of 802.11a [1] is slightly less than that of 802.11b/g; 802.11a signals cannot penetrate as far as those for 802.11b because they are absorbed more readily by walls and other solid objects in their path and because the path loss in signal strength is proportional to the square of the signal frequency. On the other hand, OFDM has fundamental propagation advantages when in a high multipath environment, such as an indoor office, and the higher frequencies enable the building of smaller antennas with higher RF system gain which counteract the disadvantage of a higher band of operation. In this paper the performance of the various channels were measured in receiver section as shown in the figure 1 Receiver Wireless Test Bench Block Diagram using Agilent’s Advanced Design System (ADS) software to design the receiver wireless test bench at throughput of 24Mbps.

Orthogonal Frequency Division Multiplexing (OFDM) [3,5] physical layer that splits an information signal across 52 separate subcarriers to provide transmission of data rates from 6 Mb/s to 54 Mb/s at the 5 GHz unlicensed national information infrastructure (U-NII) band. While the IEEE 802.11a standard increases the available data rates from 11 Mb/s to 54 Mb/s, its operation at the 5 GHz band cannot provide interoperability with IEEE 802.11 and IEEE 802.11b devices.

![Figure 1 Receiver Wireless Test Bench Block Diagram](image-url)

2. CHANNEL ENVIRONMENTS

In this paper different channel environments had been observed

2.1 ADDITIVE WHITE GAUSSIAN NOISE (AWGN) CHANNEL

This type of noise is present in all communications systems and is generated by electrical devices and atmospheric and thermal conditions. This type of noise is modeled as a random process and the AWGN routine
simulates the real effect of random noise encountered by a transmitted signal. The routine multiplies each bit of the transmitted signal by a randomly generated number and by the standard deviation of the signals energy to produce a noisy signal. The intensity of the noise can be adjusted using the Signal to Noise Ratio (SNR) option. The higher the SNR is the less the noise affects the signal. The AWGN [5] channel is a good model for many satellite and deep space communication links. It is not a good model for most terrestrial links because of multipath, terrain blocking, interference, etc. However, for terrestrial path modeling, AWGN is commonly used to simulate background noise of the channel under study, in addition to multipath, terrain blocking, interference, ground clutter and self-interference that modern radio systems encounter in terrestrial operation.

2.2 PHASE NOISE (PN) OF MIMO RADIO CHANNEL

Phase noise is the frequency domain representation of rapid, short-term, random fluctuations in the phase of a waveform, caused by time domain instabilities ("jitter"). Generally speaking, radio frequency engineers speak of the phase noise of an oscillator, whereas digital system engineers work with the jitter of a clock. An ideal oscillator would generate a pure sine wave. In the frequency domain, this would be represented as a single pair of Dirac delta functions (positive and negative conjugates) at the oscillator’s frequency, i.e., all the signal's power is at a single frequency. All real oscillators have phase modulated noise components. The phase noise components spread the power of a signal to adjacent frequencies, resulting in noise sidebands. Oscillator phase noise often includes low Frequency flicker noise and may include white noise.

Consider the following noise free signal:

\[ v(t) = A \cos(2\pi f_0 t) \]  

Equation.1

Phase noise is added to this signal by adding a stochastic process represented by \( \phi \) to the signal as follows:

\[ v(t) = A \cos(2\pi f_0 t + \phi(t)) \]  

Equation.2

Phase noise is a type of cyclo stationary noise and is closely related to jitter. A particularly important type of phase noise is that produced by oscillators. Phase noise is typically expressed in units of dBc/Hz, and it represents the noise power relative to the carrier contained in a 1 Hz bandwidth centered at a certain offsets from the carrier.

2.3 MULTIPATH FADING CHANNEL

Multipath fading [2, 3] is a common phenomenon in wireless signal transmission. When a signal is transmitted over a radio channel, it is subject to reflection, refraction and Diffraction. Fundamentally, mobile radio communication channels are time varying, multipath fading channels. In a radio communication system, there are many paths for a signal to travel from a transmitter to a receiver. Sometimes there is a direct path where the signal travels without being obstructed. In most cases, components of the signal are reflected by the ground and objects between the transmitter and the receiver such as buildings, vehicles, and hills or refracted by different atmospheric layers. These components travel in different paths and merge at the receiver. Each path has a different physical length. Thus, signals on each path suffer different transmission delays due to the finite propagation velocity. The superposition of these signals at the receiver results in destructive or constructive interference, depending on the relative delays involved. The fact that the environment changes as time passes leads to signal variation. This is called time variant. Signals are also influenced by the motion of a terminal. A short distance movement can cause an apparent change in the propagation paths and in turn the strength of the received signals.

3. MEASUREMENTS

3.1 BIT ERROR RATE

A receiver's performance is determined by its ability to receive and demodulate a wanted signal in the presence of noise and/or other interfering signals. Although there are several measurements used to test a receiver’s performance, all of them measure the same quantity under different conditions. The measured quantity is the bit error rate. BER is the probability that a transmitted bit will be received and detected in error. Of course, better receivers have a lower BER.

Different wireless standards give different names to various BER measurements such as: Minimum Input Power Sensitivity, Minimum Input Level Sensitivity, Adjacent Channel Rejection, Adjacent Channel Selectivity, Reference Sensitivity Level, Dynamic Range, Blocking, and Intermod. As mentioned earlier, all the above measurements are BER measurements under different conditions. These different conditions include additive white Gaussian noise (AWGN), modulated interference signals, and CW interference signals. The interference signals can be in band and/or out of band. Typically, the standards specify that the BER should not exceed a certain value for certain power levels of the wanted and interfering signals, and a certain frequency offset between the wanted signal's channel frequency and the frequency of the interfering signals.

3.2 \( \text{E}_{b}/\text{N}_0 \) DEFINITION

Bit error rate (BER) and frame and packet error rate (FER/PER) are typically reported with respect to \( \text{E}_{b}/\text{N}_0 \). This note defines \( \text{E}_{b}/\text{N}_0 \) and relates it to signal to noise ratio (SNR). Distinction is made of local and system \( \text{E}_{b}/\text{N}_0 \).
For this discussion, the following figure illustrates a typical RF communication system receiver block diagram.

![Diagram of a typical RF communication system receiver block diagram](image)

**Figure 2 Typical RF Communication System Receiver Block Diagram**

In the diagram, the initial two blocks represent the transmitted signal and the propagation channel between the transmitter and receiver antennas. The transmitted signal contains data with bit time T_b with bit rate R bits/sec. The propagation channel includes significant attenuation and propagation effects (phase, amplitude, multi-path fading, etc.).

A is the receiver antenna output.

B is a mid-point within the receiver system.

C is the receiver system pre-detection point.

RX DUT 1 is the receiver frontend and contains any lossy lines before the receiver and receiver front-end amplifiers, filters, and mixers. For this discussion it is defined with gain in dB (G_1) and noise figure in dB (NF_1).

RX DUT 2 is the receiver backend and contains content before detection and includes amplifiers, filters, matched filter, and sampler. For this discussion it is defined with gain in dB (G_2) and noise figure in dB (NF_2).

BER is then measured, typically with suitable DSP algorithms.

At each A, B, and C point in the system, there is a measurable value for the signal (S_A, S_B, S_C) and noise density (N_{OA}, N_{OB}, and N_{OC}), where the signal is in Watts (W) and noise density is in Watts/Hz (W/Hz).

In this system, the received desired signal has additive thermal noise contributions from the propagation path available at the receiver antenna output and from the receiver noise figures. Other noise contributors are ignored, such as interfering signals and nonlinear intermodulation products. Thermal noise at the receiver antenna output is typically defined in terms of noise temperature in Kelvin. Call this T_A. Note that 290 K (16.85o C) corresponds to a noise power density of -173.975 dBm/Hz value.

The receiver antenna output noise power density is:

\[ N_{OA} = k T_A \]

where \( k \) is Boltzmann's constant.

Receiver noise figures can also be represented in terms of noise temperature in Kelvin: \( T = 290 \) (F-1) where \( F = 10(N_0/10) \). The RF DUT 1 and 2 have associated noise temperatures at T_1 and T_2 respectively.

\[ T_1 = 290 \left(F_1 - 1\right) \]
\[ T_2 = 290 \left(F_2 - 1\right) \]

\( T_1 \) represents the equivalent noise temperature due to RF DUT 1 defined at the input of RF DUT 1 and has associated noise power density: \( k T_1 \). This results in definition for \( N_{OB} \) as:

\[ N_{OB} = G_1 \left(k T_1\right) + G_1 \left(k T_1\right) = G_1 \left(k T_1\right) \]

Equation.3

\( T_2 \) represents the equivalent noise temperature due to RF DUT 2 defined at the input of RF DUT 2 and has associated noise power density: \( k T_2 \). This results in definition of \( N_{OC} \) as:

\[ N_{OC} = G_2 \left(k T_2\right) + G_2 \left(k T_2\right) + G_2 \left(k T_2\right) + G_2 \left(k T_2\right) = G_1 \left(k T_1\right) + G_1 \left(k T_1\right) / G_2 \]

Equation.4

SNR is related to Eb/No in the following way:

\[ SNR = S/N = \left( Eb/T_b\right) \left( N_0 N_{BW}\right) = \left( Eb R\right) \left( N_0 N_{BW}\right) \]

\[ = Eb/N_0 x R/N_{BW} \]

Equation.5

Where:

**SNR** = signal-to-noise ratio (unit less)

**S** = signal power (W)

**N** = noise power (W)

**E_b** = bit energy (W/sec)

**T_b** = bit time (sec)

**NBW** = receiver noise bandwidth (Hz)

**N_0** = noise power density = N / N_{BW} (W/Hz)

**R** = data rate = 1/T_b (1/sec)

\[ E_b/N_0 = E_b/N_0 \]

\[ \text{Thus, we now see the relationship between } E_b/N_0 \text{ and } S/N_0 \text{ and } S/N. \]

\[ E_b/N_0 = S/N x N_{BW}/R = S/N_0/R \]

Equation.7

**S/N_0** and **E_b/N_0** values may be considered as local or system values. Local values are specific to the receiver system point where they are evaluated (points A, B, or C in the diagram); system values are independent of the receiver system point where they are evaluated.
Local values of $S/N_o$ and $E_b/N_0$ are directly measurable at each point in the system and are typically the preferred $S/N_o$ and $E_b/N_0$ values used by RF/analog designers. At points A, B, and C, the local $S/N_o$ values are:

$$S_A / N_{OA} = S_A / (k T_a)$$

$$S_B / N_{OB} = (S_A G_1) / (k (T_a + T_1))$$

$$S_C / N_{OC} = (S_A G_1 G_2) / (k (T_a + T_1 + T_2) G_1)$$

System values of $E_b/N_0$ and $S/N_o$ are directly measurable only at the pre-detection system point (point C in the diagram). These are the system values because they characterize the overall system performance. The system values are typically the preferred $S/N_o$ and $E_b/N_0$ values used by System/DSP designers.

In all cases,

$$E_b/N_0 = S/N_o / R$$

At point C, the local $E_b/N_0$ and $S/N_o$ values are the same as the system $E_b/N_0$ and $S/N_o$ values.

4. RESULTS & DISCUSSION

a. IEEE 802.11a Additive White Gaussian Noise (AWGN) Channel at throughput of 24 Mbps

The WLAN system performance with 24 Mbps data rate and channel coding under AWGN. A burst length of 1000 bytes is simulated.

b. IEEE 802.11a Phase Noise (PN) of MIMO Radio Channel at throughput of 24 Mbps

The WLAN system performance with 24 Mbps data rate and channel coding under phase noise distortion. A burst length of 128 bytes is simulated. In this phase noise distortion test, two cases of phase noise are used to measure PER/BER.

<table>
<thead>
<tr>
<th>S.No</th>
<th>$E_b/N_0$ (dB)</th>
<th>$E_b/N_0$ (dB)</th>
<th>$E_b/N_0$ (dB)</th>
<th>$E_b/N_0$ (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
<td>0.019</td>
<td>7</td>
<td>0.007</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>0.004</td>
<td>8</td>
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<td>3</td>
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<td>9</td>
<td>2.24E-01</td>
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<tr>
<td>4</td>
<td>10</td>
<td>1.37E-04</td>
<td>10</td>
<td>3.62E-05</td>
</tr>
<tr>
<td>5</td>
<td>11</td>
<td>1.61E-06</td>
<td>11</td>
<td>2.60E-06</td>
</tr>
</tbody>
</table>

Table 1 BER versus SNR

<table>
<thead>
<tr>
<th>S.No</th>
<th>Additive White Gaussian Noise channel (AWGN)</th>
<th>Phase Noise (PN) of MIMO radio channel</th>
<th>Multipath Fading channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
<td>0.019</td>
<td>7</td>
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<td>2</td>
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<tr>
<td>5</td>
<td>11</td>
<td>1.61E-06</td>
<td>11</td>
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</table>
CONCLUSIONS
The performance of the IEEE 802.11a WLAN system has gone through under different channels. When the Signal-to-Noise Ratio (SNR) increases then Bit Error Rate (BER) decreases. In this paper the results are analyzed based on the performance of the WLAN system in various channels at throughput of 24Mbps. For Additive White Gaussian Noise (AWGN) Channel the SNR at 10dB with BER of 1.370E-4 and for Phase Noise (PN) of MIMO Radio Channel the SNR at 10dB with BER of 3.32E-5 and for Multipath Fading channel the SNR at 10dB with BER of 1.36E-4 as shown in the Table 1. From this we can conclude that Phase Noise (PN) of MIMO Radio Channel has best performance ability compared to other noise channels.

ACKNOWLEDGMENTS
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