Comparing Performances of Bandpass Modulation in Wireless Communication Channels

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Abstract—The paper investigates the performances of different bandpass modulation techniques in Additive White Gaussian Noise (AWGN) Channel and Multipath fading channel. This study examines the inherent attributes of the digital modulation to overcome the channel impairments. It reviews digital modulation techniques. The two channels-AWGN and Multipath channels were modeled and simulated in MATLAB Environment. The evaluation of the different modulation techniques was carried on the modeled channels. This was carried out to understand the contributions of channel characteristics to effective wireless communication and made comparison between the two channels. The BER for simulated modeled channels agreed with the theoretical results. The performance of 64QAM is better compared to other bandpass modulation schemes in AWGN Channel. It was observed that the BER is higher in frequency selective channel as compared to the AWGN channel. It was also observed that multipath fading channel characteristic limits the data rate in wireless communication.

Index Terms—BER, communication channels, modulation and Noise

I. INTRODUCTION

Wireless communication is enjoying a fast growth period in history which is coupled with technology improvements that permit its widespread deployment. Such is the cellular concept developed by Bell Laboratories [1]. Mobile communication offers a full duplex communication using a radio to connect portable device to a dedicated Base station, which is then connected to a switching network. Microwave communication for line of sight propagation deployed for transmission between one station and the other. In a rapidly growing environment, overall system performance will depend on the ability to provide power and spectrum efficiency, adaptive to wireless fading and channel characteristics and support to changing UE traffics. This work is investigating the channel impairment to wireless communication as it affects increasing the data rate. Because of the growing trend in Mobile communication, the work focuses on this area. The effect of increasing the bandwidth to 20MHz is investigated.

II. WIRELESS CHANNEL CHARACTERISTICS

Wireless channel is an unguided channel and signals not only contain the direct Line of Sight LOS waves; but also a number of signals as a result of diffraction, reflection and scattering. This propagation type is termed Multipath [2] degrade the performance of the channel. Similarly, the channel may introduce Doppler effect when the transmitter or receiver moves.

A. Additive White Gaussian Noise Channel

Additive White Gaussian Noise (AWGN) channel is a good model for the physical reality of channel, as long as the thermal noise at the receiver is the only source of disturbance [3]. The impairment this channel caused to signal is the addition of Gaussian distributed noise. Mathematically, it can be illustrated as:

\[ r(t) = s(t) + n(t) \]  \hspace{1cm} (1)

Where \( r(t) \) is the received signal, \( s(t) \) is the transmitted signal and \( n(t) \) is the noise.

B. Multi Path Fading Channels

An alternative class of channel used to model communication system is fading channels because mobile reception is harshly affected by multipath propagation which results in Fading or Inter-Symbol Interference (ISI). This can be mathematically expressed as:

\[ r(t) = s(t) * h(t) + n(t) \]  \hspace{1cm} (2)

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C. Flat and Frequency Selective Fading Channel

Time dispersive signals are often affected by the delay spread. If the delay spread is less than the symbol period $T_s$, the signal channel is categorised as Flat fading which preserves the spectral characteristics of the signal at the receiver [2]. In contrast, if signal bandwidth is more than the coherence bandwidth or delay spread is more than the symbol period, then the channel is categorised as Frequency Selective fading and leads to ISI which degrades the channel.

III. CHANNEL MODELS

Andrea stated in [4] that deterministic channel models are rarely available. But to evaluate the performance of signals properly in fading channels, this work considered Flat and Frequency Selective fading channel and few of the models.

A. Rayleigh and Rician Fading Model

A wireless radio channel whose delay spread is less than the symbol period and the signal bandwidth is less than the coherence bandwidth where the channels are correlated, can appropriately be modelled as Rayleigh fading which assumes that a received multipath signal contains infinite or large number of arrival paths at the same time whose gain are statistically independent and no dominant path. Rayleigh distribution model is often used for fading signal with infinite or large number of arrival paths at the same time whose gain are statistically independent and no dominant path[4]. The phase component of the channel gain is Gaussian distributed and equation 2.8 is its probability density function (PDF) as stated by Rappaport[5]:

$$ f(r) = \begin{cases} \frac{r}{\sigma^2} e^{-\frac{r^2}{2\sigma^2}} & 0 \leq r \leq \infty \\ 0 & r < 0 \end{cases} $$

Where, $\sigma$ is the RMS value of received signal before detection. And according to [2], the average channel power is given by:

$$ E[r] = 2\sigma^2 $$

The received signal power is often weak in a fading channel and bit error occurs [3].

The theoretical average Bit Error Rate of Rayleigh fading channel model is given by [2] as stated in equation (5) below:

$$ AvBER = \frac{1}{2} \left( 1 - \frac{E_b}{N_0} \right) $$

Where $E_b$ is the bit energy and $N_0$ is the noise power.

Similar to the distribution properties of Rayleigh is the Rician Distribution model except for the presence of a dominant path with numerous weak paths. Inclusive in its pdf (equation 6 [2]) is the peak amplitude $A$ of dominant signal and zero-order Bessel function $I_0$ of the first kind:

$$ p(r) = \begin{cases} \frac{r}{\sigma^2} e^{-\frac{r^2 + A^2}{2\sigma^2}} I_0 \left( \frac{Ar}{\sigma} \right) & A \geq 0, r \geq 0 \\ 0 & r < 0 \end{cases} $$

B. Clarkes’ Fading Model

The model assumes all multipath signals arrive at the same time in horizontal direction and when the mobile user moves, each path will experience a different Doppler shift. Hence, a uniform probability density function (PDF) of the rays is assumed and a Doppler effect is introduced [6].

C. ITU Model

International Telecommunications Union published some generic test models that are commonly used in the communication industry. Depicted in [2] is the three common cases of the model- Indoor, Pedestrian and Vehicular. But in this work, the interest is in the Channel B type of the Pedestrian model with 6 rays, median delay spread (750 ns) and 55% probability of occurrence in an outdoor to indoor environment. Each tap is modelled using Rayleigh fading distribution characterised by Clarkes’ model to incorporate a model of the Doppler spectrum. From table 1, the rays are Rayleigh distributed with Classic Doppler spectrum defined [7] as:

$$ S(f) \propto \frac{1}{\sqrt{1 - \left( \frac{f}{f_d} \right)^2}} $$

for $f \in f_d, f_a$

Assuming all the paths arrives at the same time and are uniformly distributed, the PSD is modelled as [4]:

Theoretical average Bit Error Rate of Rayleigh fading channel model is given by [2] as stated in equation (5) below:

$$ AvBER = \frac{1}{2} \left( 1 - \frac{E_b}{N_0} \right) $$

Where $E_b$ is the bit energy and $N_0$ is the noise power.
\[\tilde{a}(t) = \sum_{i=0}^{N-1} a_i e^{j(2\pi f_i t + \theta_i)} \quad f \text{ or } f_i = f_d \cos \theta_i \] (8)

\[
S_h(f) = \mathcal{F}\{ R_h(\Delta t; \tau) \} = \begin{cases} \frac{f_{av}}{\sqrt{1 - \left( \frac{f}{f_d} \right)^2}} & |f| < f_d \\ 0 & |f| > f_d \end{cases} \] (9)

Where \( R_h \) is channel autocorrelation function, \( P_n \) is the average channel power, \( F \) is the Doppler shift in direction of travel for path \( \theta \), and \( \tilde{a} \) is the channel response in relation to Doppler shift.

### IV. BAND PASS MODULATION

Modulation is a process of transforming signal into waveforms that are compatible with the channel properties [8] and this is necessary in wireless communication where the antenna diameter must be at least equal to the wavelength of the carrier [9]. Advances in technology over the last decades have made digital transmission a widely acceptable and significant mode over the Analog transmission. A digital data is usually in the sequence of 0s and 1s, regardless of their generic source, i.e either it is inherently digital or a result of analog-to-digital conversion [0]. To transmit such data over the channel, a signal that represents the data and matches the channel property is generated. Since, there is a limitation in antenna size that can meet efficient signal transmission, data signal are super imposed on carrier-wave by shifting the information bearing signal to the frequency band of the channel [11]. Baseband signals can be translated to higher frequency range. This technique is known as bandpass modulation which is used in wireless and mobile communication, supporting small size antenna design for mobile equipments. Three main parameters-amplitude, phase, frequency can be exploited to produce a modulated signal [9], which leads to three generic modulation scheme namely Amplitude Shift Keying (ASK), Phase Shift Keying (PSK) and Frequency Shift Keying (FSK).

For a given digital data of finite bit sequence to be transmitted over a channel by a bandpass filtered signal \( s(t) \), a mapping process known as digital modulation is required between the bit sequence and possible signals [2,10]. The mapping rule is also needed for proper demodulation and detection at the receiver. Also, signals can consider information bits in groups known as symbols and generate one wave form for each group. That is, transmitted data can have \( M \) numbers of symbols in a signal constellation or word length and \( k \) numbers of bit within each symbol. The \( k \) numbers of bits contained per symbol is guided by

\[ k = \log_a(M) \] (10)

And \( M \in [2,4,8,\ldots,M] \). the general form of modulated signal \( s(t) \) is

\[ s(t) = A(t) \cos[w(t)t + \phi(t)] \] (11)

Where \( A \) is the amplitude, \( w \) is the frequency and \( \phi \) is the phase of the signal.

#### A. Phase Shift Keying

This is the modulation mode of where the phase \( \phi(t) \) parameter of the signal is varied.

The transmitted information is contained in \( M \) possible phase values. The values are also represented on the constellation maps. Hence for every phase value, \( k \) numbers of bit is represented. Increase in symbol rate gives a corresponding increase in bit rate and offers an advantage that while the symbol period remains constant, the bandwidth remains unchanged. The BER equation of M-PSK modulated signal in an AWGN channel [9] can be expressed as:

\[ P_b = \frac{1}{k} \text{erfc} \left( \sqrt{\frac{kE_b}{N_0}} \sin \left( \frac{\pi}{M} \right) \right) \] (12)

Where \( E_b \) is the signal energy, \( N_0 \) is the noise power, \( M \) is the number of phase of bit carrying data and \( k \) is the number of bit per symbol.

#### B. Quadrature Amplitude Modulation

QAM is a hybrid modulation technique that takes its implementation from combining variations of both the amplitude \( A(t) \) and phase \( \phi(t) \) of the signal. The structure is similar to that of PSK, but the amplitude takes on a different range of value pairs [9]. Which means it uses the amplitude of the quadrature carrier signal to carry the data. QAM produce a better distribution of signal states in the signal constellation and variety of shape can be achieved. Data is stored in \( M \) possible symbols that can be located at any amplitude and phase dimension. It can also achieve increase in bit rate without bandwidth expansion. However, due to its superior bit packing structure, it has a lower probability of error performance than PSK when \( M \) possible values are more than 8. Alsusa in [14] stated the bit error probability as shown below:

\[ P_b = \frac{1}{k} \text{erfc} \left( \sqrt{\frac{3kE_b}{2(M-1)N_0}} \right) \] (13)

#### C. Error Probability

A key performance metric of digital information transmission over a channel in communication system is the measure of errors in the transmitted bits or symbols. This is the amount of information error that is experienced when transmitting over a channel at certain Signal energy to Noise power Ratio (SNR), depending on the modulation scheme. It follows a simple...
statistical grading of the numbers of error and often referred to as Bit Error Rate (BER) or Symbol Error Rate (SER) [9].

V. IMPLEMENTATION
The implementation was carried out for the two channels as follows:

(a) AWGN channel: The communication channel was modeled as AWGN channel. BER target performance of each digital modulation scheme in AWGN channel was determined. Provided

(b) Multipath channel (Rayleigh Flat) Fading: 4 and 6 rays flat fading channels was simulated in MATLAB for Bandpass modulation techniques. The QPSK simulation program was introduced and then the channel code syntax was modified to generate a Gaussian number for the channel and theoretical BER Rayleigh fading channel was plotted. The SNR was further modified and the simulation was repeated for the increase in SNR to 30dB with steps of 5dB.

VI. RESULTS AND ANALYSIS

Based on the established Equations for different modulation scheme, the theoretic formulation was developed. To understand better the importance of BER measurement in different modulation, simulated BER results of some modulation schemes are provided in Fig.2 to Fig.12.

Fig. 2. Simulated and Theoretical 8PSK BER Performance in AWGN Channel
Fig. 3: Simulated and Theoretical 16QAM BER Performance in AWGN Channel

Fig. 4: Simulated and Theoretical 64QAM BER Performance in AWGN Channel
Fig. 5: Combined Simulated and Theoretical QPSK, 8PSK, 16QAM, 64QAM BER Performance in AWGN Channel

Figure 6: Simulated QPSK in Rayleigh Fading
Fig. 7: BER Comparison of Theoretical and Simulated QPSK in Rayleigh Fading Channel

Simulated and Theoretical BER performance for QPSK in Rayleigh Fading Channel

\[ \text{Simulated} \quad \text{Theoretical} \]

\[ \begin{array}{c}
\text{Eb/No} \\
0 & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 \\
\text{BER} \\
10^{-2} & 10^{-1} & 10^{0} & 10^{1} & 10^{2} & 10^{3} & 10^{4}
\end{array} \]

Fig. 8: Comparison of Theoretical and Simulated QPSK in Rayleigh Fading Channel at high SNR

Simulated and Theoretical BER performance for QPSK in Rayleigh Fading Channel

\[ \text{Simulated} \quad \text{Theoretical} \]

\[ \begin{array}{c}
\text{Eb/No} \\
0 & 5 & 10 & 15 & 20 & 25 & 30 \\
\text{BER} \\
10^{-4} & 10^{-3} & 10^{-2} & 10^{-1} & 10^{0} & 10^{1} & 10^{2}
\end{array} \]
Rayleigh Fading Channel with different Modulation Techniques, without Channel Coding and diversity of 1

Fig. 9: BER Performance of QAM in Rayleigh Fading Channel

Fig. 10: BER Performance of PSK in Rayleigh Fading Channel
Fig. 11: Comparing BER performance of PSK and FSK Rayleigh Fading Channel

Fig. 12: BER performance of QPSK in AWGN Channel and Rayleigh Fading Channel
In summary, the comparison between fading channel and non-fading channel is expressed above and supported by Fig. 13.

![Fig. 13: BER Curve of Fading and Non Fading Channel [3]](image)

It can be shown from the Fig. 6 that flat fading model channel of Rayleigh Fading statistics has a steady slope in its BER curve. With every increase in the Signal power, the Bit error in received signal reduces steadily. The comparison of the theoretical and simulated Bit error rate of QPSK signal in a Rayleigh fading channel (Fig 8) over an increasing signal power shows that the result are closely related especially at a low signal power but the simulated result tends to deviate as the signal power increases. The deviation can be assumed as a result of the randomness of large numbers of iterated value employed in the program, since the model is taking into account infinite arrival paths. Figure 9 compares the performance of the modulation in different channels. The BER Performance for various modulation techniques are presented to show the interactions between the fading channels and the techniques. The Bit Error Rate BER only improves slowly with a steady slope when plotted on a log normal scale which is contrast to a non-fading channel whose BER improves rapidly as shown in Fig 13. The result is supported by [3].

**RESULT DISCUSSION**

From Fig. 2, it was observed that the BER performance of AWGN channel improves rapidly and offers a better performance than Rayleigh fading channel. This is because Rayleigh fading channel is characterised by multipath signal and it is computed by average BER. The average BER is dominated by poor BER of individual path and variations in instantaneous BER. Hence, it offers a poorer performance. BER Performance. The results also show that the performance of 64QAM is better compared to the other modulation scheme.

**VII. CONCLUSION**

The performances of Bandpass modulation in AWGN channel and Multipath channel was investigated. The simulated results of BER agree with the theoretical values obtained for the modulation schemes. It was observed that BER performance of bandpass modulation in AWGN channel offers a better performance than in Rayleigh fading channel. This is expected as multipath effect limits the capacity of such channel.

**REFERENCES**


