Performance Evaluation of Pulse Shapers In Bluetooth

A. S. Shirsat, S. A. Shirsat, D. M. Yadav

Abstract: Bluetooth uses Frequency Shift Keying modulation scheme with Gaussian pulse shaper. Pulse shapers reduce the sidelobe amplitudes and obtain phase continuity. This paper addresses the various pulse shaping techniques and their performance for Bluetooth network. MATLAB based simulation is carried out for BER and throughput performance of Bluetooth for various frequency pulse shapers. It is clear from the simulated results that Raised Cosine pulse shaper offers throughput enhancement of 3.96kbps at 10 dB Eb/No.

Keywords:Adaptive Frequency Hopping, Bit Error Rate, MATLAB,Personal Digital Assistance.

I. INTRODUCTION

Bluetooth is a short range, low power commercially available wireless technology, designed to connect gadgets of different functions such as computers, cameras, notebook, telephones, speakers,and printers [1], [2]. It operates in unlicensed ISM band, 2.4GHz. Numerous services open in this ISM band, such as Wi-Fi, ZigBee, Cordless phones and microwave ovens [2]-[6]. Modulation scheme, transmission power and range of these devices are dissimilar, but cause interference to one another [7]-[9]. Bluetooth is an ad-hoc network, which forms networks spontaneously reducing the need for cables. Bluetooth supports two different transmission modes, Basic rate called mandatory mode uses shape binary frequency modulation to minimizetransceiver complexity, and an optional mode called enhanced data rate, which uses a PSK modulation scheme. Enhanced data rate uses $\pi/4$ DQPSK and 8DPSK with symbol rate 1Mbps.

In this paper, an attempt is made to study the effect of various frequency pulse shapers in continuous phase modulation (GFSK). Bluetooth performance parameters such as Bit Error Rate (BER) and throughput are calculated for various frequency pulse shapers for FSK modulation scheme [10], [11]. A MATLAB based simulation is carried out in terms of BER and Bluetooth network for FSK at Gaussian, raised cosine, rectangular, spectral cosine and tamed FM. BER obtained from the simulated results is used to calculate throughput for each frequency pulse shaper. From the result obtained, it is clear that raised cosine frequency pulse shaper gives better BER and throughput, while rectangular frequency pulse has poor performance in basic Bluetooth. Spectral cosine and Tamed FM have moderate performance as compared to raised cosine frequency pulse shaper.

This paper is organized as Section II reviews work related to Bluetooth. Section III deals with the Bluetooth basics. GFSK Modulation scheme with various frequency pulse shapers is presented in Section IV. Section V discusses.Simulation block diagram and methodology used. Results obtained are presented in Section VI. Finally,the paperis concluded in Section VII.

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II. RELATED WORK

Recently rigorous studies have conducted to increase the throughput of Bluetooth in a noisy heterogeneous environment. Here, important contribution through little work carried out till date. Basic rate Bluetooth uses the GFSK modulation technique. Higher level modulation schemes are employed to achieve a high data rate. This increases the bit error rate and consequently, reduces throughput in Bluetooth. The performance of such a system degrades rapidly in heterogeneous radio technologies. QAM modulation scheme used in Bluetooth enhances throughput at the cost of high power by maintaining less distance [1]. A Synchronous Connection Oriented with Repeat Transmission (SCORT) scheme is developed for voice transmission. In this technique,the voiceis transmitted with a new voice packet with repeated request transmission. This scheme enhances the throughput in the presence of WLAN at the cost of high Eb/No [2]. Authors calculated throughput by changing distance between Bluetooth Transreceiver where abrupt change occurs in throughput. This performance degrades more rapidly in the presence of WLAN. Authors suggested dynamic power control, intelligent frequency hopping and dynamic channel selection techniques to improve the throughput in the heterogeneous environment [3]. A new technique of reduction in retransmission time is developed with convolution code and error control hamming code (15, 10). This lowers computational complexity, at higher values of SNR. It is desired that the system is better for 2DH1 and 2DH5 packets to get high throughput. Convolutional code reduces retransmission probability [12].

The author suggested a novel and cost-effective method used for GFSK receiver optimization. In this technique, Unscented Kalman Filtering is used to enhance the performance of Bluetooth such as BER and frame error rate (FER). The system performance is best in AWGN channel at low

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Eb/No values [8]. Channel quality is estimated for Bluetooth based on received signal strength using power spectrum. In this technique, packet size is made adaptive and transmitted based on the channel quality. Authors applied this scheme to basic rate (BR) Bluetooth for GFSK and PSK modulation techniques [13]. Bluetooth Low Energy consumes low power, is one of the strong candidates for the internet of things to transmit voice and data. The author proposed BlueVoice application to transmit audio at 16 KHz using ADPCM. For high-quality audio this much throughput is not enough; therefore there is a need to enhance the throughput by compressing the signal with less complex algorithm [14]. Different solutions are investigated in various literature, to enhance the throughput of Bluetooth. Depending on Eb/No, BER and throughput are important parameters for the BR Bluetooth. It is required to enrich the throughput at estimated Eb/No, BER has to be lower. The dependency of BER value on windowing function in voice transmission of Bluetooth is studied.

III. BLUETOOTH BASICS

Bluetooth is anad-hoc network intended to replace cables in electronic devices. It allows the wireless connectivity in unlicensed 2.4GHz ISM band. Bluetooth is a low power, short range, low cost, solution in wireless communication. It uses frequency hopping technique to avoid the interference from collocated radio access technologies such as WLAN, ZigBee, Microwave and cordless phones [16].

1.1 Bluetooth Architecture

Bluetooth supports two types of networks. These networks are

- Piconet
- Scatternet

Piconet: It is a small network consisting of eight stations out of which, only one station called as master, holds the control of transmission, and other stations act as a slave. All the slaves are synchronized with a master as one to one or one to many, as shown in Figure 1.

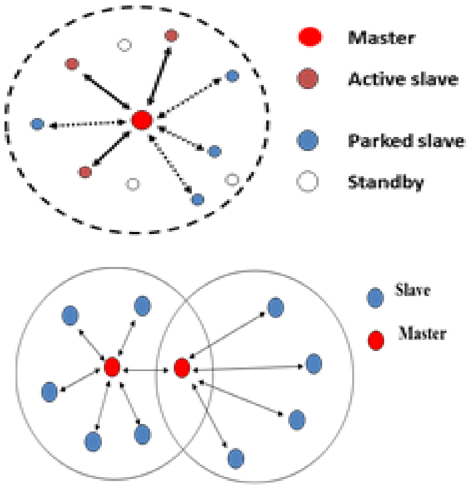

Fig.1. Bluetooth piconet and scatternet

Scatternet: Two or more piconets can be combined to form a scatternet. Figure 1 shows scatternet. A station can be a member of one or more piconets. Sometimes secondary station in a piconet can be primary in another piconet. This station can receive messages from the primary in the first piconet and acting as a primary in another piconet, can deliver same to secondary in the second piconet.

1.2 Performance Parameters of Bluetooth Networks

Performance of wireless communication networks can be measured with the help of error rate. Error rate states as no of errors in a data stream over a communication channel that haschanged under the influence of noise, distortion or synchronization error. If the bit has an error, it is referred as Bit Error Rate (BER), while if the packet has an error, it is referred to asPacket Error Rate (PER). Symbol Error Rate (SER) is defined as the ratio of a number of symbols changed to the total number of symbols transmitted.

Bit Error Rate: In digital communication, the numbers ofthe bit received at the destination have altered due to noise, interference, distortion. The **bit error rate** (**BER**) is the number of bit in errors out of a total number of bits transmitted. BER is the number of bits in error divided by the total number of transferred bits during a certain time interval. The bit error ratio gives an estimation of the bit error probabilityp_e.

$$Bit\ Error\ Rate\ = \frac{\text{No of Bits altered}}{\text{Total No of Bits Transmitted}} \quad (01)$$

Throughput

: This parameter is used to know the speed of the data transmission over a network. It states as the actual rate at which the information is sent over the channel. It is measuredin terms of bits per second or frames per seconds. The maximum value of throughput is equal to theoretical bandwidth. Throughput (DT) can be calculated as; (02)

$$Throughput\ = \frac{\text{No of Frames}}{\text{Second}} * \frac{\text{Number of bits}}{\text{Frames}}$$

$$DT = (1 - PER) * M * DR \quad (03)$$

$$PER = (1 - BER)^{PL} \quad (04)$$

Where - Number of bits/symbol (1 for GFSK),
PER - Packet Error Rate,
BER - Bit Error Rate,
DR - Max data rate for the packet,
DT - Throughput.

1.3 Bluetooth Links

Synchronous Connection Oriented (SCO) Link: Bluetooth supports the transmission of both data and voice with one asynchronous data link and upto three synchronous voice links. Voice transmission in Bluetooth takes place with the help of SCO Link. The synchronous link provides a point-to-point voice communication. In Bluetooth voice, packets are transmitted and received at regular intervals from master to slave. A master can support upto three synchronous links to a single slave or to multiple slaves. Slave supports maximum two SCO links to diverse masters. SCO packets never retransmitted even if a packet gets damaged. In Bluetooth,the audio communication transfer rate is maximum 64 kbps for audio speech frequencies of upto 4 KHz. For music, it is essentially beyond 4 KHz frequency. HV packets are used for high-quality voice transmission. These packets use a Cyclic Redundant Code with no retransmission. Three different types of packets supported by Bluetooth are HV1, HV2,and HV3. In HV1 packet 10 bytes information is transmitted at a rate of 1/3 Forward Error Correction (FEC). HV1 packet is sent every two-timeslot. HV2 packet has 20 bytes of information. 2/3 FEC protection is provided to this packet. The packet transmission rate is four-time slots. HV3 packet carries 30 information bytes, without any protection. This packet is transmitted for every six-time slots. One more packet supported by Bluetooth is DV packet. DV packet consists of data and voice. Here payload is divided into a voice field by one-thirdbit and a data field by up totwo-third bits.

Asynchronous Connection-Less (ACL) Link: In Bluetooth, data transmission is through ACL link. If an error occurs, those packets must be transmitted again. In the case of ACL transmission, the system pauses for an acknowledgment from the receiver. It sents the packets repetitively till an acknowledgment is received. The receiver checks the packet and confirms the cyclic redundancy code (CRC) to make sure that the packet is received properly. The ACL link provides a packet switched connection among the master and slaves. The ACL packets have seven classes of packets. There are data-medium rate packets, and data-high rate packets three each and one AUX Pocket. Data Medium (DM) packet uses 2/3 FEC code. It contained CRC code with 16-bit; with retransmission done when acknowledgment not received. The time slots for DM packets 1, 3 and 5 for DM1, DM3,and DM5 respectively. DH packets are similar as to DM packets. However, in these packets, FEC encoding is not applied to the payload. AUX: This is similar to a DH1 packet. These packets are never retransmitted, and not coded with CRC [17]-[19].

1.4 Basic Rate and Modulation

GFSK (Gaussian Frequency Shift Keying) modulation scheme is used inBluetooth. This modulation scheme uses 1MHz bandwidth, which is robust as it is used in ISM band. For this bandwidth data rate is limited to 1Mbps with modulation index range 0.3 to 0.32 and bandwidth bit period product 0.5. Here logic high is sent with positive frequency deviation, while negative frequency deviation for a logic low. Demodulation can be possible by using FM discriminator.

Aforementioned, the modulation scheme GFSK is also termed as Continuous Phase Frequency Shift Keying (CPFSK). In this high-frequency components of the modulated signal are reduced due to continuous phase variation. The shape of this signal is like half sinusoidal shape. Due to filter GFSK signal becomes smoother and with stabilized instantaneous frequency stabilized. Various frequency pulse shaper functions are used to reduce the side lobe amplitudes to obtain the phase continuity. Different frequency pulse shapers are

- Gaussian
- Raised Cosine
- Rectangular
- Spectral Raised Cosine
- Tamed FM

Advantages of GFSK signal are enlisted as below.

- The envelope is constant, so it can directly apply to the class c power amplifier.
- Narrow main lobe to reduce the adjacent channel interference.
- Lower level side lobes increase the spectral efficiency.
- Low-cost demodulator.
- The Gaussianfilter whose time domain and frequency domain response is Gaussian.

The bandwidth time product of GFSK signal can be expressed by Eq. 05.

$$\text{BT Product} = \frac{\text{Filter Bandwidth}}{\text{Bit Rate}} = \text{B}\,\text{T}_\text{b} = \frac{\text{B}}{\text{f}_\text{b}} \qquad (05)$$

1.5 GFSK Modulation scheme for Bluetooth

A. Gaussian:

The Eq gives the general impulse response of Gaussian filters in the time domain. 06.

$$h(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} H(\omega)\, e^{i\omega t} d\omega = e^{-\frac{1}{2}(\frac{t}{\tau})^2} \qquad (06)$$

Where $H(\omega) = \sqrt{2\pi}\ \ \tau\, e^{-\frac{1}{2}(\tau\omega)^2}$

τ - Constant

GFSK signal in the time domain represents as follows

$$S_{GFSK}(t) = Re[\left(\sqrt{\frac{2E_b}{T_b}}\, e^{j2\pi\, mi\, \Delta f t}\right) e^{j2\pi f_c t}] \qquad (07)$$

$$S_{GFSK}(t) = \sqrt{\frac{2E_b}{T_b}} \cos(\,2\pi f_c t + \,2\pi\, mi\, \Delta f\, t) \qquad (08)$$

Where $1 \leq mi \leq M$ and $0 \leq t \leq T_b$, mi modulation index, Tb bit period.Here carrier is shifted by $mi\ \Delta f$. It is required to avoid the large spectral side lobes.

Let $d(t) = \sum_{n=0}^{n} I_n\, g(\tau - nT_b)$ be the signal, g(t) be the rectangular pulse with amplitude 1/2Tb and I_n amplitude obtained by mapping. The complex baseband transmitted signal will be given by the Eq. 09.

$$S_{TR}(t) = Re[\,A\ e^{j\,\varphi_m(t)}] \qquad (09)$$

Here A represents the amplitude of the transmitted signal and $\varphi_m(t)$ integrated phase given in Eq. 10.

$$\varphi_m(t) = \pi\, mi \sum_{-\infty}^{t} [\,I_n\, g(\tau - nT_b)d\tau] + \varphi_0 \qquad (10)$$

Where

I_n - Mapped to ± 1 as per binary input data

φ_0- Initial phase of the carrier signal, $\varphi_0 = 0$ to avoid the loss of generality.

B. Raised Cosine:

The raised cosine function is easy to realize and can have good phase continuity. It is often used to minimizethe bandwidth which lies in between B and 2B as$B \leq (B = \frac{R_b}{2}) \leq 2B$.

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$$P(t) = \begin{cases} \frac{1}{2B} & \textit{For flat portion } 0 \le |f| \le f_1 \\ \frac{1}{4B}\{1 - Sin\left[\frac{\pi(|f| - B)}{2B - 2f_1}\right]\} & f_1 \le |f| \le 2B - f_1 \\ 0 & |f| \ge 2B - f_1 \end{cases} \quad (11)$$

The relation between frequency parameter f_1 and the bandwidth B is related as in Eq. 12.

$$\alpha = 1 - \frac{f_1}{f_m} \quad (12)$$

Where

α - Roll off factor (Excess bandwidth) and

B_T - Transmission bandwidth.

$$B_T = 2B - f_1 = b(2 - \frac{f_1}{B}) = B(1 + \alpha) \quad (13)$$

Following are the few observations from above Eq.13.

- It is easy for realization.
- Sine shape time response and passing through $t = \pm T_b, 2 \pm T_b, \ldots$
- α Reduces the amplitude of side lobes.
- At $\alpha = 0$, the bandwidth $B = 2 f_b T_b$

C. Rectangular GFSK:

Rectangular frequency pulse shaper is very easy to implement. Fourier transform of this frequency pulse shaper is a sync function. In the frequency, domain convolution gives rise to ripples in the passband and large oscillations in the stop band. This stop band oscillation leads to spectral leakage. Eq.14 gives implementation function of the rectangular function.

$$x(t) = \begin{cases} 1 & |t| < \frac{\tau}{2} \quad i.e - \frac{\tau}{2} < t < \frac{\tau}{2} \\ 0 & |t| > \frac{\tau}{2} \quad i.e - \frac{\tau}{2} > t > \frac{\tau}{2} \end{cases} \quad (14)$$

In frequency domain $X(f) = \tau \, sinc(\frac{\omega\tau}{2})$

IV. MATLAB SIMULATION

In this section, the Bluetooth Simulink model and BER calculation in MATLAB are given.

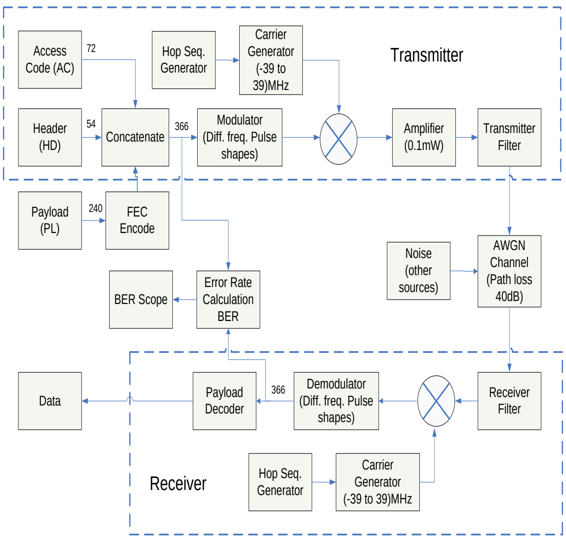

Fig. 2. Bluetooth MATLAB Simulink Model

1.6 Bluetooth Simulink Model

Figure 2 shows the block diagram of MATLAB Simulink model of Bluetooth. It consists of a Bluetooth transmitter, receiver and AWGN channel. In Bluetooth paired communication, a transmitter acts as master and receiver in slave mode. Input data is given to Bluetooth master, where packets are formed with payload along with the header and trailer information. These packets are formed by adding 72 bits access code, 54-bit header with forward error correction (FEC). FEC adds error correction bits to the packets. Headers consist of slave address, packet type code and flow control bits. These packets are then encoded, and then the modulation process is carried out by applying various frequency pulse shaper. Hopping sequence is generated and synchronized at transmitter and receiver. In the radio layer, the CRC adds packets and the hops are accepted as inputs. Packets are zero padded to complete the time slots. This information is modulated using Gaussian Frequency Shift Key (GFSK) modulation. The hopping sequence is transformed to give FHSS. The FHSS data is multiplied with modulated information to spread. This data is transmitted over Additive White Gaussian Noise (AWGN) transmission channel at 1mW output power. At receiver, the signal is decoded and checked for the bit error performance. The bit error rate is used to calculate data throughput. MATLAB based simulation is carried out for BER and calculated throughput [21]-[24].

1.7 BER and Throughput Calculation

To calculate the BER for the particular modulation technique, MATLAB provides a tool known as the bertool. In BER tool the Monte Carlo simulation is used for calculation. It has various options to be correctly filled into for computing the BER and plotting a graph.

- First, set the Eb/No range.
- In the Simulink model, browse to the model.
- Assign the name of the variable in the model that takes the input at the point of BER calculation.
- Under Simulation limits, enter the appropriate values for the number of errors or number of bits to evaluate.
- BER is plotted with different values of Eb/No.
- Calculate throughput from BER.
- Plot the throughput with respect toEb/No.

By calculating the values of throughput, the variation in throughput is plotted with different values of Eb/No.

V. Results and Analysis

This section gives MATLAB based simulation results of bit error rate performance of Bluetooth for various pulse shapers. Figures 3-7 show BER performance of Bluetooth. Simulation results show that bit error rate performance of Bluetooth depends on an Eb/No and frequency pulse shaper. The throughput is calculated for voice packets. The throughput of Bluetooth increases with an increase in Eb/No. In the communication system, BER variation with the ratio of bit energy (Eb) to noise energy (No) is one of the performance

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parameters. GFSK Modulation scheme is used with various frequency pulse shapers. Hence it is required to check the BER and throughput performance of these frequency pulse shapers.

It can conclude that the BER performance improves in Spectral Raised Cosine frequency pulse shaper. This performance is comparable to that of Raised Cosine frequency pulse shapers. Gaussian pulse shaper has time domain and frequency domain response as Gaussian. This frequency pulse shapergives moderate BER performance. This frequency pulse shaper has a narrow main lobe that reduces the adjacent channel interference and has low-level side lobe to enhance spectral efficiency. Performance of Tamed FM is worst compared to other frequency pulse shapers.

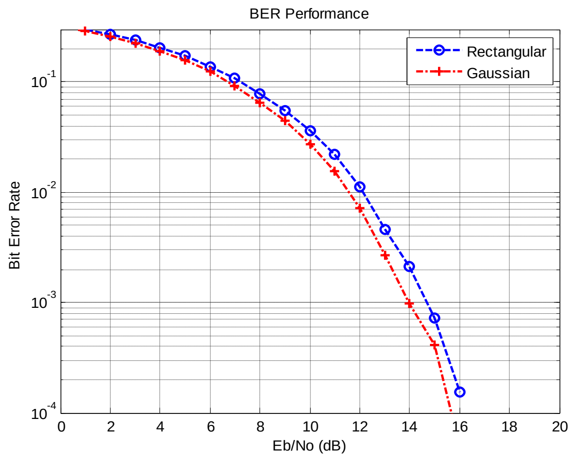

Fig.3. BER performance of GFSK modulation for rectangular and Gaussian pulse shaper

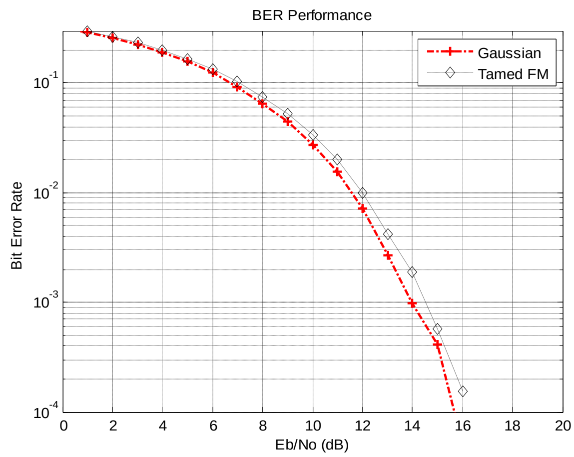

Fig. 4. BER performance of GFSK modulation for tamed FM and Gaussian pulse shaper

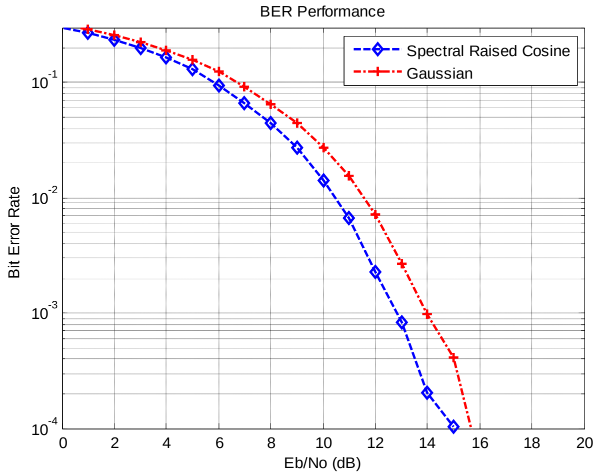

Fig.5. BER performance of GFSK modulation for spectral raised cosine and Gaussian pulse shaper

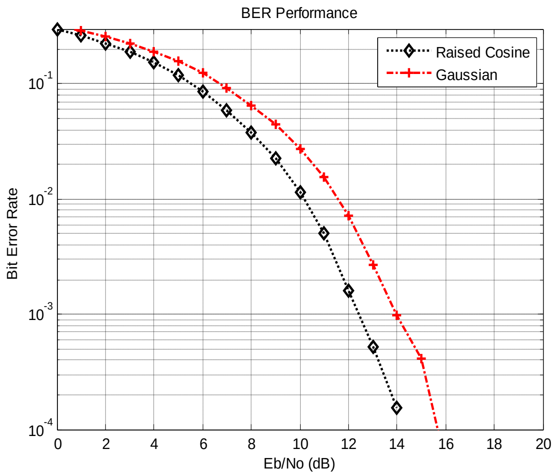

Fig.6. BER performance of GFSK modulation for raised cosine and Gaussian pulse shaper

Figures 8-13 depicts the throughput performance of Bluetooth for different frequency pulse shapers without any interference. Throughput performance of Raised Cosine frequency pulse shaper is promising, while Tamed FM is poor. Gaussian frequency pulse shaper provides adequate performance. When Eb/No lies in the range of 10-16 dB, Raised Cosine frequency pulse shaper outperforms the Gaussian frequency pulse shaper. It offers throughput enhancement of 3.96kbps at 10 dB Eb/No. Figure 14 demonstrates the throughput performance of Bluetooth for Raised Cosine frequency and Gaussian frequency pulse shapers in the presence of Wi-Fi interference. It degrades in the presence of Wi-Fi. Effect of Wi-Fi on Raised Cosine frequency pulse shaper is less compared to Gaussian frequency pulse shaper. The throughput of Raised Cosine frequency pulse shaper reduces by 24.517kbps whereas for Gaussian frequency pulse shaper it deteriorates by 26.104kbps at 16dB Eb/No.

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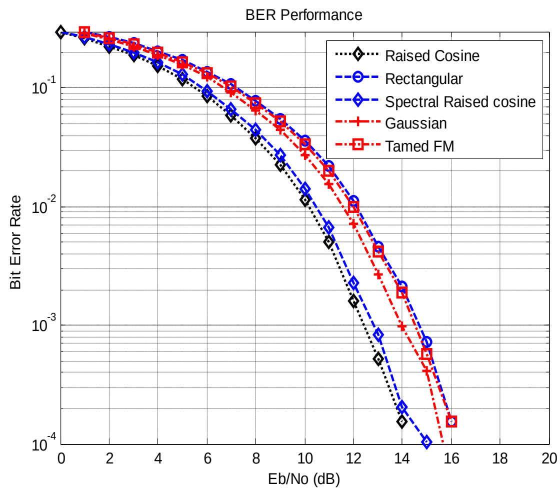

Fig.7. BER performance of GFSK modulation with various frequency pulse shapers

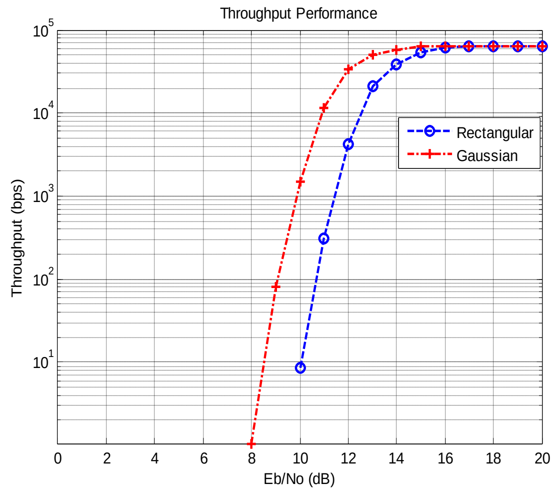

Fig.8. Throughput performance of GFSK modulation for rectangular and Gaussian pulse shaper

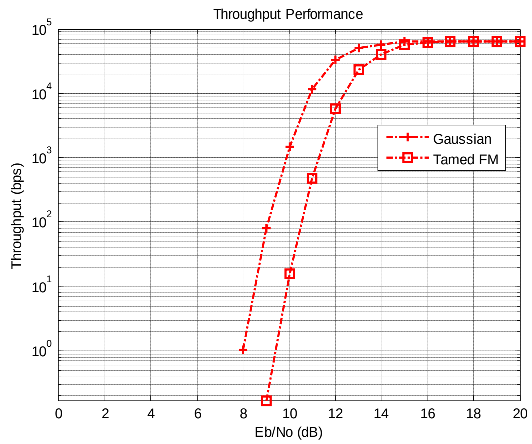

Fig.9. Throughput performance of GFSK modulation for tamed FM and Gaussian pulse Shaper

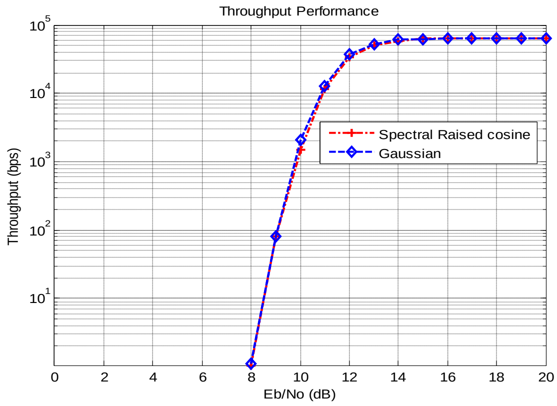

Fig.10. Throughput performance of GFSK modulation for spectral raised cosine and Gaussian pulse shaper.

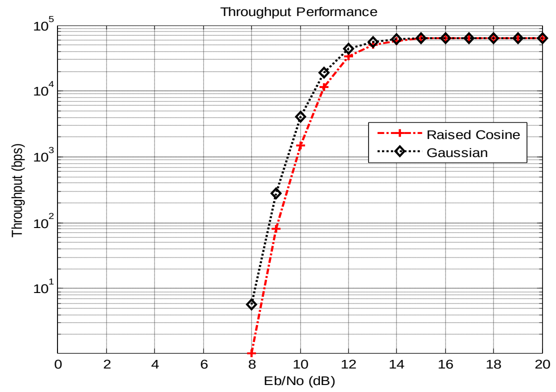

Fig. 11. Throughput performance of GFSK Modulation for raised cosine and Gaussian pulse shaper.

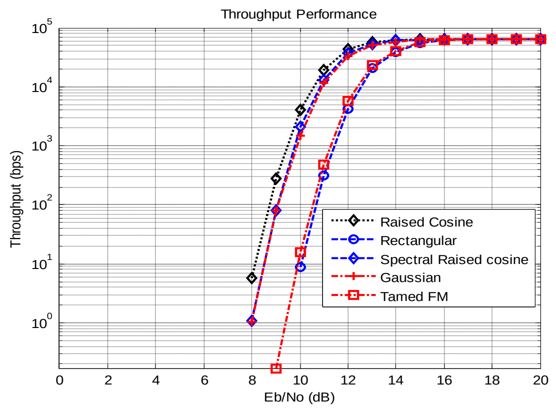

Fig.12. Throughput performance for GFSK modulation with various frequency pulse shapers

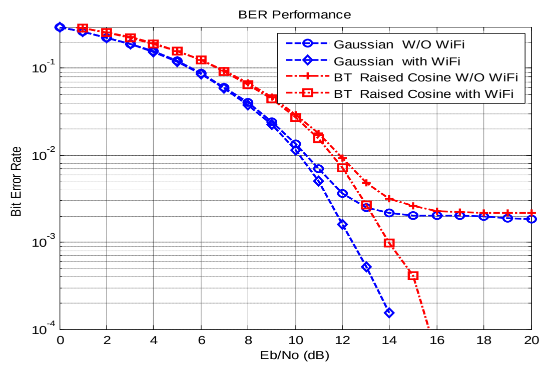

Fig.13. BER performance of

GFSK modulation for Gaussian and raised cosine pulse shapers with & W/O WiFi.

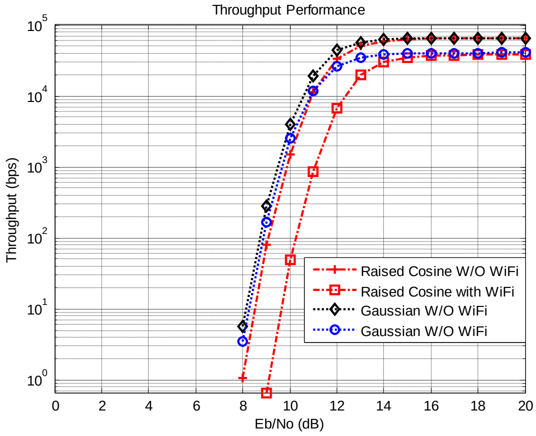

Fig.14. Throughput Performance of GFSK Modulation for Gaussian and raised cosine pulse shapers with & W/O WiFi

VI. Conclusion

In this paper, different frequency pulse shapers for GFSK modulation for Bluetooth are studied. Performance of these pulse shapers is analyzedwith respect to BER and throughput. The BER performance of Raised Cosine frequency pulse shaper is superior followed by Spectral Raised Cosine frequency pulse shaper. Tamed FM frequency pulse shaper performs worst followed by rectangular frequency pulse shaper at the cost of more than 3 dB Eb/No. Simulation results reveal that the Raised Cosine frequency pulse shaper offers more throughput enhancement compared to Spectral Raised Cosine frequency pulse shaper. The Rectangular frequency pulse shaper performs worst trailed by tamed FM frequency pulse shaper for throughput. Raised Cosine frequency pulse shaper, has good BER and throughput performance than all other frequency pulse shapers in both homogeneous and heterogeneous environment.

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