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MITIGATING ADJACENT CHANNEL INTERFERENCE PROBLEM IN DATA NETWORKS USING FINITE IMPULSE RESPONSE FILTER

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Abstract - One of the problems caused by adjacent channel interference in data networks is poor throughput. This paper shows how this problem can be mitigated by using Finite Impulse Response filter (FIR filter) to filter out the interfering signals and hence improve throughput. To achieve that, a simulink model of the environment under study with two adjacent interfering signals was developed. By simulation, the system performance in terms of bit error rate was evaluated with and as well as without FIR filter in the presence of the two adjacent channel interfering signals. When interfering signals were added to the data bearing signal, it was observed that the bit error rate (BER) at the receiving end of the network deteriorated. When the FIR filter was introduced the bit error rate improved tremendously. From theory, BER of a network is inversely proportional with the throughput of the network. Meaning that when BER is high throughput is low and viser. The BER of the simulated model under study with and without FIR filter in the presence of adjacent channel interference were compared, it was shown clearly that FIR filter improves throughput in data network with adjacent channel interference challenges, since it reduces tremendously the BER of the network.

Keywords: Adjacent channel interference, bit error rate, energy per bit, noise power spectral density ratio and throughput

1. INTRODUCTION

Following the success of cellular telephone services in the 1990s, the technical community has turned its attention to data transmission. Throughput is a key parameter in the measurement of the quality of wireless data links. Throughput can therefore be defined as the number of error free information bits received (HashamHaide, 2014). Every good data network provider desires that the amount of information bits transmitted should be equal to the amount of information bits received.

Network throughput in data communication is usually represented as an average and measured in bits per second (bps), or in some cases as data packets per second (Guowang, 2016). Throughput is an important indicator of the performance and quality of a network connection. A high ratio of unsuccessful message delivery will ultimately lead to low throughput and a highly degraded network (Deepak et al, 2015).

Many variables affect the throughput of a wireless data system including the packet size, the transmission rate, and the number of overhead bits in each packet, the received signal power, the received noise power spectral density, the modulation technique, and the channel conditions like interferences. From these variables, we can calculate other important quantities such as the signal-to-noise ratio, the bit error rate and the packet success rate. Throughput depends on all of these quantities (Eduard et al, 2016).

The major causes of low throughput in data networks are channel interferences, network congestion and packet losses due to other network imperfections. In the presence of interference, throughput is decreased because there is a high probability of receiving a corrupt packet of data. The packet loss problem is more in networks, in which the nodes are deployed randomly. Packet loss produces errors, and in the worst cases, packet loss can cause severe mutilation of received data, broken-up images, unintelligible speech or even the complete absence of a received signal (Rambabu & Gaikward, 2014).

In telecommunications**,** interference is anything which modifies, or disrupts a signal as it travels along a channel between a source and a receiver. The term typically refers to the addition of unwanted signals to a useful signal (Rafhael et al, 2018).

Maaly and Andrew (2011) defined Interference as a coherent emission having a relatively narrow spectral content, e.g., a radio emission from another transmitter at approximately the same frequency, or having a harmonic frequency approximately the same as another emission of interest to a given recipient, and which impedes reception of the desired signal by the intended recipient.

Interference degrades transmission signal quality and can cause the receiving end of a network to receive incomplete packets.

There are two major types of interference.

Co-channel interference, (CCI)

Adjacent channel interference, (ACI)

Co-channel interference, (CCI):

This occurs when a radio receiver receives signals from two different transmitters transmitting at the same frequency and carrying different messages. It can also be defined as two different radio transmitters using the same frequency. Thus, besides the intended signal a receiver gets signals at the same frequencies (co-channel signals) from an undesired transmitter located far away which leads to deterioration in the receiver's performance (Sheikh et al, 2014)

Adjacent Channel Interference, (ACI)

On the other hand, adjacent channel interfere (ACI**)** is caused by signals that are adjacent in frequency. Adjacent-channel interference (ACI) is basically interference that is created by extraneous power from a signal source in an adjacent channel. Inadequate filtering, such as incomplete filtering of modulation items in frequency modulation (FM) systems, bad tuning, or low quality frequency control, contribute to Adjacent-channel interference (Joao et al, 2016).

There are two main causes of Adjacent-channel interference.

Imperfect Filtering:

Present customers' demand is low cost of handset, i.e less cost and hence low quality filters which results in creation of additional interference. The alternate way is to use high quality (expensive), well designed filters at the base stations. So, adjacent channel interference is actually handled more at the base stations rather than at the handsets level. The problem can be severe if the interferer is very close to the subscriber's receiver. This is because the mobile unit in close proximity has a strong signal which causes adjacent channel interference. Thus resulting in crosstalk at the receiver or if the interference is in control channel, then one of the calls might get dropped (Rafhael et al, 2018).

Near Far effect: Another cause of adjacent channel interference is called the near far effect. What is the near far effect? Suppose Transmitter A and Transmitter B are operating on adjacent channels frequency; when the receiver is far from the desired transmitter and very close to the undesired transmitter, adjacent channel interference is exacerbated. If the interference is close to the base station of the radiating adjacent channel, while the sub-scriber is actually far away from the base station, the path loss exponent is close to four. This means that the signal strength goes down very fast to the power of four of the distance. So if the interfering handset is close to the base station, whereas the subscriber far away from the base station, the signal will get a lot of interference at the base station (Selma et al, 2015).

CONSEQUENCES OF ADJACENT CHANNEL INTERFERENCE

The Packet Loss

One of the consequences of adjacent channel interference is packet loss due to weak signal which is a direct result of adjacent channel interference (Campolo, 2014). Weak signal cannot carry data and whenever there is adjacent channel interference the resulting signal strength is weakened. Ultimately packet loss is due to high bit error rate which also reduces throughput in communication networks.

IMPROVING SIGNAL QUALITY MINIMIZES PACKET LOSS.

Low Network Throughput

When network signal strength is reduced due to the presence of adjacent channel interference, the amount of transmitted data that will be able to reach its destination will be highly reduced. Hence reduced signal strength will ultimately reduce throughput in data network.

Testing network throughput is important to ensure performance benchmarks are being met. Any deviations to expected throughput levels should be investigated and resolved. Below are a couple of free tools to test throughput of a network (Dan, 2016).

Bit Error Rate (BER)

When data is transmitted over a communication link, there is a possibility of errors being introduced into the system. If errors are introduced into the data, then the integrity of the system may be compromised. As a result, it is necessary to assess the performance of the system, and bit error rate, BER, provides an ideal way in which this can be achieved.

BER is calculated from the number of bits received in error divided by the number of bits received.

$$BER= \frac{BitinError}{Total\ bits\ Received}$$

BER can also be defined in terms of the probability of error (POE) given by

$$POE=0.5(1\text{-}erf)\sqrt{\frac{Eb}{No}} \qquad \textbf{(2.1)}$$

erf is the error function,

Eb is the energy in one bit

N_0 is the noise power spectral density (noise power in a 1Hz bandwidth).

The error function is different for each of the various modulation methods. The POE is a proportional to Eb/ N_0, which is a form of signal-to-noise ratio. The energy per bit, Eb, can be determined by dividing the carrier power by the bit rate (Eduard et al, 2016).

Energy Per Bit to Noise Power Spectral Density Ratio (EB/N_0)

Energy per bit to noise power spectral density ratio **(**Eb/N_0) is an important parameter in data transmission. It is a normalized signal-to- noise ratio (SNR) measure, also known as the "SNR per bit". It is especially useful when comparing the bit error rate (BER) performance of different digital modulation schemes without taking bandwidth into account. Eb/N_0 is equal to the SNR divided by the "gross" link spectral efficiency in (bit/s)/Hz, where the bits in this context are transmitted data bits, inclusive of error correction information and other protocol overhead (Deepak et al, 2015).

BER and Eb/N_0

Signal to noise ratios and Eb/N_0 figures are parameters that are more associated with radio links and radio communications systems. In terms of this, the bit error rate, BER, can also be defined in terms of the probability of error (POE). To determine this, three other variables are used. They are the error function (erf), the energy in one bit (Eb), and the noise power spectral density (which is the noise power in a 1 Hz bandwidth), N_0.

It should be noted that each different type of modulation has its own value for the error function. This is because each type of modulation performs differently in the presence of noise. In particular, higher order modulation schemes (e.g. 64QAM, etc) that are able to carry higher data rates are not as robust in the presence of noise. Lower order modulation formats (e.g. BPSK, QPSK, etc.) offer lower data rates but are more robust.

The energy per bit, Eb, can be determined by dividing the carrier power by the bit rate and is a measure of energy with the dimensions of Joules. N_0 is a power per Hertz and therefore this has the dimensions of power (joules per second) divided by seconds). Looking at the dimensions of the ratio Eb/N_0 all the dimensions cancel out to give a dimensionless ratio. It is important to note that POE is proportional to Eb/No and is a form of signal to noise ratio (Mohammad etal, 2010).

Relationship Between Es/N_0 and Eb/N_0

The relationship between Es/N_0 and Eb/N_0, both expressed in dB is expressed in equation 2.2 as follows:

$$\frac{E_s}{N_0}(dB) = \frac{E_b}{N_0}(dB) + 10\log_{10}(k) \quad \textbf{(2.2)}$$

where k is the number of information bits per symbol.

In a communication system, k might be influenced by the size of the modulation alphabet or the code rate of an error-control code. For example, if a system uses a rate-1/2 code and 8-PSK modulation, then the number of information bits per symbol (k) is the product of the code rate and the number of coded bits per modulated symbol: (1/2) log2(8) = 3/2. In such a system, three information bits correspond to six coded bits, which in turn correspond to two 8-PSK symbols. (Deepak etal , 2015)

Relationship BetweenEs/N_0 and SNR

The relationship between Es/N_0 and SNR, both expressed in dB, is shown in equation 2.3 as follows:

$$\frac{E_s}{N_0}(dB) = 10\log_{10}\left(T_{syn}/T_{samp}\right) + SNR(dB)$$

(2.3)

Equation 2.2 which is for complex input signal can be expressed as real input signal as shown in equation 2.4

$$\frac{E_s}{N_0}(dB) = 10\log_{10}\left(0.5T_{syn}/T_{samp}\right) + SNR(dB)$$

(2.4)

Where T_{sym} is the signal's symbol period and T_{samp} is the signal's sampling period. For example, if a complex baseband signal is oversampled by a factor of 4, then Es/N_0 exceeds the corresponding SNR by 10 log10(4).

the relationship between Es/N_0 and SNR for complex input signals can be derived as follows:

$$\begin{aligned} E_s / N_0 \text{ (dB)} &= 10\log_{10}\left((S \cdot T_{sym})/(N/B_n)\right) \\ &= 10\log_{10}\left((T_{sym}F_s)\cdot(S/N)\right) \\ &= 10\log_{10}\left(T_{sym}/T_{samp}\right) + SNR \text{ (dB)} \end{aligned}$$

Where

S = Input signal power, in watts

N = Noise power, in watts

B_n = Noise bandwidth, in Hertz

F_s = Sampling frequency, in Hertz

Note that $B_n = F_s = 1/T_{samp}$.

MITAGATING THE EFFECT OF ADJACENT CHANNEL INTERFERENCE

Finite Impulse Response (FIR) Filter

One of the techniques of reducing the effect of adjacent channel interference is by filtering out the interfering signal. And finite impulse response filter can completely reduce adjacent channel interference. Finite impulse response (FIR) filter, also known as non-recursive filters and convolution filters are digital filters that have a finite impulse response. It can guarantee a strict linear phase frequency characteristic and amplitude frequency characteristic. In the common case, the impulse response is finite because there is no feedback in the FIR (Bojja, 2017). Since the unit impulse response is finite, therefore FIR filters are stable system. FIR filters operate only on current and past input values and are the simplest filters to design. FIR filters perform a convolution of the filter coefficients with a sequence of input values and produce an equally numbered sequence of output values. The FIR filter has abroad application in many fields, such as telecommunication, image processing, and so on.

However, if feedback is employed yet the impulse response is finite, the filter still is a FIR. An example is the moving average filter, in which the Nth prior sample is subtracted (fed back) each time a new sample comes in. This filter has a finite impulse response even though it uses feedback: after N samples of an impulse, the output will always be zero (Pooja, 2015).

FIR filter minimizes jointly the mean square error value of the channel noise, Inter Symbol Interference and Adjacent Channel Interference (ACI). However, since this research work deals mainly with Adjacent Channel Interference, the derivations below are simplified to mitigate the effect of adjacent channel interference.

Consider the model of a communication system in which the output signal y(x) is a combination of the transmitted signal and adjacent channel interference. Eq. (2.5) below, defines an error component that indicates the deviation from the desired signal s(x)

$e_0 = y(x) - s(x) = i(x)$ **(2.5)**

In order to minimize the above error component, we first evaluate the mean square error (MSE). Assuming uncorrelated ACI, the MSE can be expressed as $E\{e_0^2\} = E\{i(x^2)\}$

$E\{e_0^2\} = \sigma_{aci}^2$ **(2.6)**

Where $E\{.\}$denotes the expected value of the argument and $\sigma_{aci}^2$is the variance of the ACI, which is same as the average power.

The ACI term can be elaborated as in equation 2.7 as follows. After receive filtering, the time domain signal is

$i_R(t) = i_T(t) * h_r(t)$ **(2.7)**

where

$i_R(t)$and$i_T(t)$ are the time domain representations of the received and the transmitted signals respectively and $h_r(t)$is the impulse response of the receive filter, which might be either rectangular or root raised cosine. The variance of ACI (2.8) can be expressed as

$\sigma_{aci}^2 = E\{i_R(t^2)\} = \int_{-1/2}^{1/2} s_i(v)\, |H_R(v)|^2 dv$ **(2.8)**

Where

$s_i(v)$is the power spectrum of the ACI signal and

$H_R(v)$is the Fourier transform of the receive filter response.

The power spectrum of the ACI (2.9) can be defined as

$S_i(v) = \sum_{-\infty}^{\infty} r_i(k) e^{-j2\pi kv}$ **(2.9)**

Where $r_i(k)$is the autocorrelation sequence of ACI as shown in equation 2.10

$r_i(k) = E\{i_T(nT) i_t((n+k)T)\}$ **(2.10)**

The interference signal $i_T(t)$ in equation 2.11 and 2.12 can be represented as

$i_T(t) = s_2(t) + s_3(t)$ **(2.11)**

$i_T(t) = \sum_{p=-P}^{p=P} \sqrt{\frac{2e_s}{T_s}} \cos(2\pi p B_c t + \theta_p) \sum_{i=-P}^{\infty} a_i h_T(t - iT - TP$ **(2.12)**

Where

$S_1(t)$And $S_2(t)$ are interfering signals,

θ_P and $T_P$are the phase shift and time delay of the ith symbol,

$B_c$is the frequency spacing between the adjacent channels,

$a$is the amplitude of the symbol and 2P is the total number adjacent channels (2.13).

$\sigma_{aci}^2 = h_R^T R_{aci} h_R$ **(2.13)**

Where

R_{aci} is the autocorrelation matrix of the ACI. The elements of $R_{aci}$are calculated by first calculating the autocorrelation vector of the interference signal and then forming a symmetrical matrix from its elements.

Now we define a Lagrange function (2.14) to be minimized as

$l(h_R) = \beta_{aci} A^2 h_R^T R_{aci} h_R$ **(2.14)**

And when along with constraints as in (2.15)

$h_\tau^T \omega o = 1$ **(2.15)**

In Eq. (2.15) weight parameter β_{aci}has been introduced in order to be able to experiment with parameter values to determine if non-unity values will lead to better BER performance. The minimizing solution is found by setting the derivative with respect to $h_R$to be zero. On taking the derivative, we get (2.16)

$h_R = \frac{P^{-1}\omega o}{\omega_o^T p^{-1} \omega_o}$ **(2.16)**

In the above equation, $P = \beta_{aci} A^2 R_{aci}$The bit energy at the receiver input is given as,$E_b = A^2 h_{TC}^T h_{TC}$, therefore P can be denoted as

$P = N_0 \frac{\frac{E_b}{N_0}}{h_{TC}^T h_{TC}} [\beta_{aci} R_{aci}]$ **(2.17)**

From the final derivations (2.17) it can be seen that in order to design this filter we need to know about the autocorrelation function of the interference and the transmit filter response.

The absolute and actual Adjacent Channel Interference in a M-QAM system follows gamma distribution. For this case the FIR filter will be use to combat the Adjacent Channel Interference. The FIR filter is used as a matched filter and is therefore incorporated in the demodulator circuit as shown in the Fig.2.1.

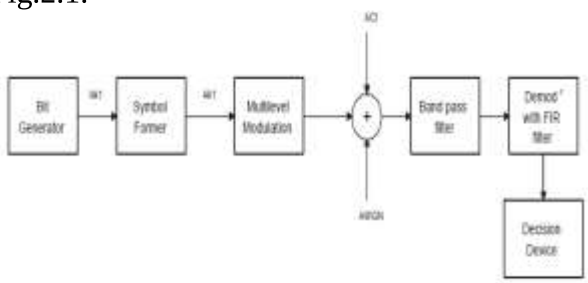

Fig. 2.1: M-QAM System

The results show that the adjacent channel interference in aM-QAM system follows exponential distribution, when the absolute value of the deviation is considered whereas it follows normal distribution when actual value of error is considered.

For the purpose of calculating probability of error, the one-sided distribution suffices, but for the purpose of filter design we need to consider the two sided distribution of error. Hence we can use the adaptive filter design in the M-PSK system after the demodulation stage as shown in Fig.2. 2 to combat ACI.

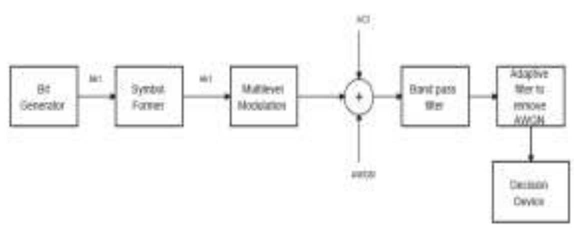

Fig. 2.2: M-PSK System

Throughput enhancement strategies can be classified in two groups according to their purpose: the first group tries to increase transmission rate in order to send more data in the same time slot and the second one tries to reduce the interference generated by adjacent channel(s) or co- channel(s).

However, the strategy employed in this work is reduction of the generated interference which degrades the throughput of the network.

Adjacent channel interference between nodes in a data network increases bit error rate (BER) which causes the receiving end of a network to receive incomplete packets/message and consequently reduces throughput (sum of the data rates that are delivered to all terminals in a network) of the network (Andra, 2017).

Therefore minimizing or eliminating packet loss is necessary for getting the best performance out of a data network, because it will increase the throughput at which data is received at the receiving node of the network. Mitigating this problem of adjacent channel interference involves eliminating the invading nearby channel. One of the ways of doing that is by filtering out that nearby adjacent channel, the process which ultimately improve the network performance (Rambabu, 2014)

Finite Impulse response filter (FIR) is one of the best filters used to filter adjacent channel interference because its impulse response is of finite duration, (settles to zero in finite time). The impulse response is finite because lack of feedback guarantees that the impulse response will be finite (Manjit, et al, 2012).

This paper therefore presents the design and simulation (in a MATLAB SIMULINK environment) of Finite Impulse Response (FIR) filter, which guarantees an efficient suppression of adjacent channel in a received data carrying signal and thus enhancing throughput of the network.

3 RESEARCH DESIGN

Adjacent channel interference in a typical data network was modeled in MATLAB SIMULINK environment (Fig. 3.1); interfering signals with different power gain and frequency offset were also included in the modeled network. The effect of the adjacent channel interference on the transmitted signal in a data network was designed to be observed in a spectral form.

To mitigate the observed effects of adjacent channel interference (ACI) on a transmitted signal in a data network, FIR filter that will filter out the interfering adjacent channel was developed and incorporated also in the SIMULINK model. The model contains a transmitter; which creates a PSK modulated signal and applies a square root raised cosine filter, two interferers; interferer 1 and interferer 2 capable of modifying the power gain each of interferer was used. The simulation adds interferers to original BPSK modulated signal created by the transmitter using a sum block with noise added by additive white Gaussian noise channel. Bit error rate (BER) is measured after filtering and demodulating the received signal in the receiver. By default both interferers are active.

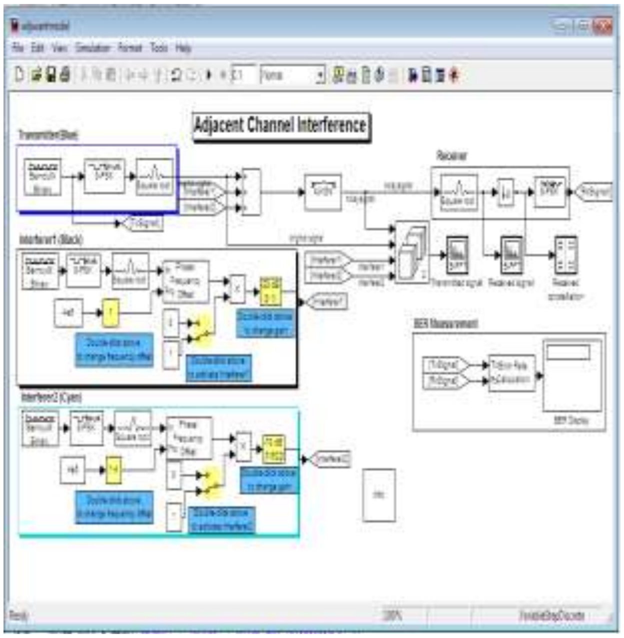

Fig.3.1: Simulink Model with Adjacent channel Interference

4. SIMULATIONS

The model developed (Fig. 3.1) was simulated using frequency offset 0-2Hz, Gain -20dB, spread factor 4.256, pulse shaping roll off factor 0.22, chip rate 3.8 MCPS through BPSK modulation for different value of Eb/No selected from the SIMULINK menu option as shown in table 4.1.

The simulation models the effects of adjacent channel interference on a BPSK modulated signal which includes two interferers, Interferer1 and Interferer 2 whose power gains were modified in the simulation works. The simulation adds interference to BPSK modulated original signal created by the transmitter using a sum block, noise is added by AWGN channel. The value BER is measured for different value of Eb/No before and after filtering with FIR filter.

Table 4.1: Input parameters used for the simulations

Parameter	**Value**
Eb/N0	30 dB
Modulation	BPSK
Chip rate	3.84MCPs
Spreading factor	4.256
Channel bit rate	5.76Mbps
Pulse shaping roll off	0.22
Noise Interference	2
Frequency offset	0 – 2 kHz
Gain	-20 dB
Symbol Duration	1s
Input signal power	1/8 watt
Input signal	Amplitude
Roll off factor	0.22
Channel	AWGN

Table 4.2 Parameters of the FIR filter used for the simulations

Parameter	**Value**
Filter Order	7
Sampling frequency	30MHz
Input Sampling per symbol	8
Group delay	6
Rollof factor (0 to 1)	0.18
Sampling offset	0
Down Sampling factor	4
Passband Attenuation	0.3dB
Side band attenuation	35dB

5. RESULTS

The results for the bit error probability of 8-PSK with adjacent channel interference obtained using the MATLAB program are shown in Fig. 5.1 (BER versus Eb/No).This system was simulated over a range of information bit Eb/No values 3.0dB to 8.0dB. These Eb/No values were adjusted for coded bits and multi-bit symbols to get noise variance values required for the AWGN block. BER results for each Eb/No value was collected and the measured and simulated result is visualized as shown in Figs 5.1 &5.2.

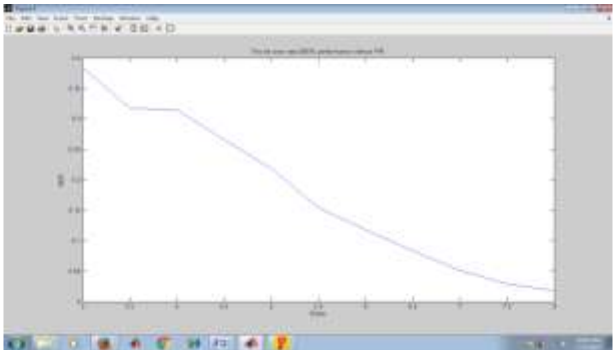

Fig. 5.1: Simulated values of BER dependence on Eb/No, 8-PSK modulation, AWGN in adjacent channel interference conditions without FIR filter

Fig. 5.1 above shows a graph of bit error rate against ratio of bit energy to noise spectral density (Eb/No) without FIR filter. From the graph it can be observed that with highest Eb/No used (8.00), the bit error rate is still very noticeable due to the presence of adjacent channel interference in the network.

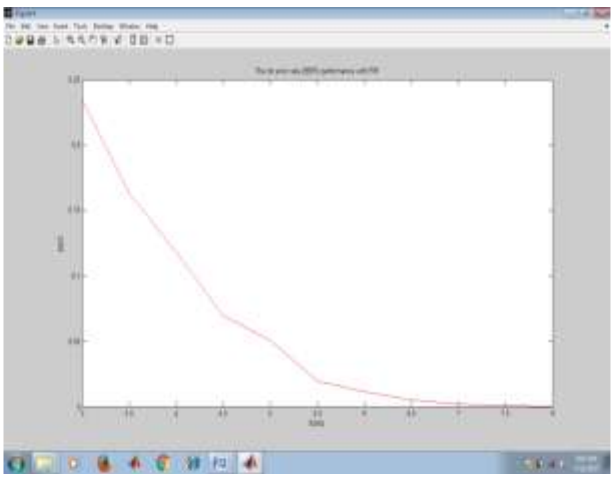

Fig. 5.2: Simulated values of BER versus Eb/No, 8-PSK modulation, AWGN in adjacent channel interference conditions with FIR Filter.

Fig.5.2 shows the graph of bit error rate (BER) against noise power spectral density (Eb/No) when FIR filter is in the system. From the graph it can be observed that at 7.5000 value of Eb/No, the BER has been reduced to almost zero which will ultimately increase the throughput of the network because the adjacent channel interference has been mitigated.

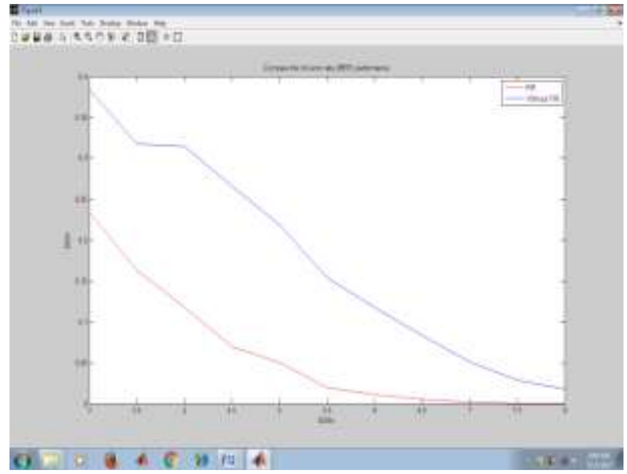

Fig. 5.3: Comparison of the simulated values of BER versus Eb/No dependence on PSK modulation, AWGN in adjacent channel interference conditions with & without FIR filter.

Fig.5.3 compares the result obtained when FIR filter is implemented and when it is not implemented in a data network. From the curve, it can be observed that at Eb/No =7.5000, the BER has been reduced to almost zero when FIR filter is implemented, while in the absence of FIR filter at Eb/No =8.0000, the interfering signals are still very noticeable on the transmitted signal.

Fig 5.4 shows the spectral diagram of the influence of adjacent interfering signals (adjacent interference signals I and II) on a transmitted signal.

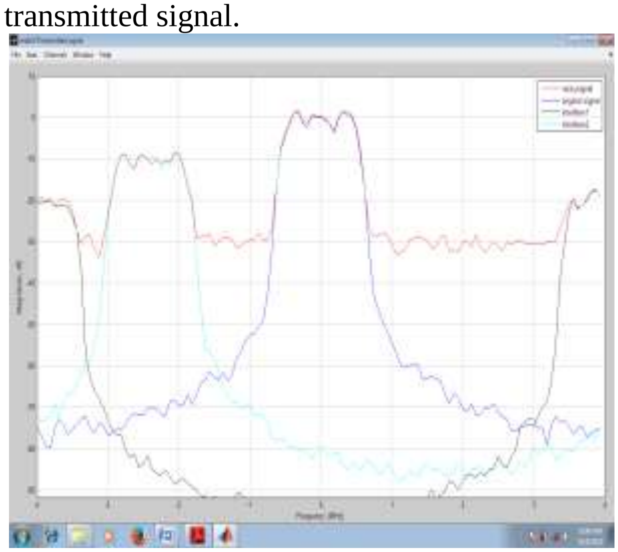

Fig.5.4: The spectrum of the influence of interference signals I &II the original transmitted signal which results in a noisy transmitted signal. The blue color represents

the transmitted signal, the black represents interference signal I, cyan color represents interference signal II, and the red color represents the resulting noisy transmitted signal.

From the Fig 5.4, the transmitted signal spectrum scope shows the interfering signals slowly moving from the adjacent channel band into the frequency band of the original signal. The BER values slowly deteriorate as the offset decreases, because the 8-PSK constellation points become difficult to demodulate. If the negative dB gain is decreased, the BER worsens, especially in the presence of adjacent-channel interference.

The spectrum in figure 5.5 shows the received signal when the adjacent channel interference has been filtered using FIR filter**.**

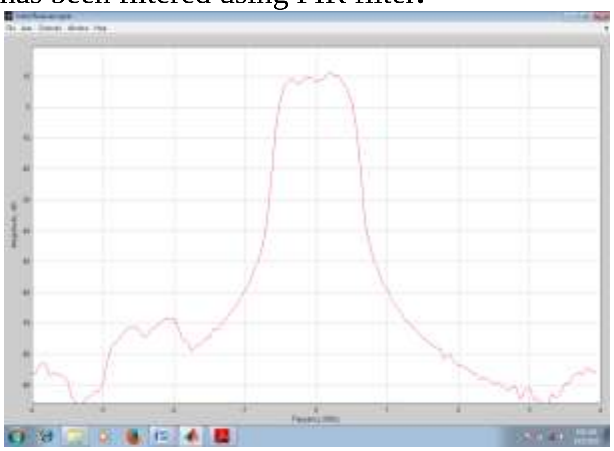

Fig.5.5: The spectrum of the received signal with FIR filter in the system.

6. DISCUSSIONS

The simulation models the effects of adjacent channel interference on a BPSK modulated signal. The model includes two interferers, Interferer1 and Interferer 2 with modifiable power gain. The simulation adds interference to BPSK modulated original signal created by the Transmitter using a sum block, noise is added by AWGN channel. The value BER is measured for different value of Eb/No before and after filtering with FIR filter.

The resulting bit error rate (BER) at the output of the receiver with respect to Eb/No are shown in Fig. 5.1, 5.2 without filter and with no filter. Since (Eb/No) is defined as the ratio of bit energy per symbol to noise power spectral densities in dB increasing this ratio causes less overall bit error rate and decreasing this ratio causes higher bit errors rate. The system performance was observed severally degraded when there was no filter Fig.5.1, but highly improved with the FIR filter (Fig 5.2). Thus to reduce throughput problem through achieving low BER in a network with the challenge of adjacent channel interference, good filtering of the received signal is a basic tool. And among different types of filters that can be used, FIR filter has shown a very good performance.

From the experimentations it was observed that decreasing the frequency offset of an interfering signal the gain block that corresponds to that interferer, the "Transmitted signal" spectrum scope shows the interfering signal slowly moving from the adjacent channel into the frequency band of the original signal but eventually causing co-channel interference (Fig.5.4). The experiment clearly shows that the BER values slowly deteriorate as the offset decreases, because the 8-PSK constellation points become difficult to demodulate. If the negative dB gain is decreased, the BER worsens, especially in the presence of adjacent channel interference and hence the system throughput will be badly affected since throughput depends the system BER.

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