International Journal of Scientific Engineering and Research (IJSER)
ISSN (Online): 2347-3878
Index Copernicus Value (2015): 56.67 | Impact Factor (2017): 5.156

Study of Cognitive Radio Performance in Relation to Signal to Noise Ratio and Modulation Scheme

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Abstract: ***In this paper the variation of Bit Error Rate (BER) with the order of Quadrature Amplitude Modulation (QAM) scheme and the power channel gain of different fading channels(Additive White Gaussian Noise , Rayleigh fading & Rician fading) for different order of QAM has been compared by taking the acceptable SNR threshold in radio communication has been analyzed. The relationship between transmitter power and bit error rate has been established. As the transmitter power and BER is inversely proportional to each other the result shows that 64 QAM is better than other order of QAM for optimizing transmitter power level. It has been observed that Additive White Gaussian Noise (AWGN) channel gives better BER value and power channel gain than those for the Rayleigh and Rician fading channel.***

Keywords: BER, M-QAM, SNR, Fading, Transmitter Power

1. Introduction

Cognitive radio refers to a smart radio that has the ability to sense the external environment and make intelligent decisions to adjust its operation and transmission parameters according to the current state of the environment. Spectrum searching and sharing is an important task of cognitive radio systems. Due to the sensing and auto selection abilities of cognitive radio, it can change the modulation techniques which lead to efficient communication between a transmitter and a receiver, thereby resulting in efficient usage of spectrum[6]. In wireless communication network, proper utilization of radio frequency spectrum is the prime consideration. The frequency spectrum is not used efficiently due to flexibility in allocation of its license for use. These licenses are controlled by government agencies and they are assigned to the service provider for long duration and huge geographical area[4]. The ability to study environment, and more importantly the spectrum is termed as sensing. To enable adaptability, this is one of the most important components. It allows radio in cognitive radio network to be aware of the environment and automatically act for better performance. This is also required if the radio needs to change its technology at different locations and time[5]. Cognitive Radio technology is capable of changing the dynamic spectrum of the network. Cognitive Radio provide real-time interaction with the environment [1]. Naturally there are many difficulties which have to be overcome. Transmitter power should be optimized. BER should be as low as possible. An acceptable SNR value is very important and it depends on the power channel gain. In OFDM system Binary Phase Shift Keying (BPSK) has been used as the modulation scheme of the CR network [2]. The main aim of this work is to optimize the transmit power according to the modulation technique to get an acceptable SNR range at the receiver end. Cognitive Radio is the new emerging technology where orthogonal frequency deviation multiplexing can be adopted[7]. Instead of BPSK, we are trying to introduce different orders of QAM (4 QAM, 16 QAM, 64 QAM, 256 QAM) in cognitive radio network because BPSK is able to transmit one bit per symbol where as QAM is able to transmit 2, 4,6,8 bits per symbol depending upon the order of QAM. So QAM can be used to double, four times, six times and eight times the data rate and still use the same bandwidth or to half, one fourth or one sixth of the bandwidth for the same data rate. In BPSK modulation, one bit is carried by one single analog carrier.

Here we have shown how the BER varies with respect to the QAM.BER is related with transmit power of the transmitter. Here we also have shown how BER varies with respect to orders of QAM according to the fading channel at the receiver end. At the receiver end SNR must be within acceptable range. Here we have calculated the power channel gain for acceptable SNR range and for different fading channel.

2. Relationship between Transmit Power and Modulation Scheme

In this paper Quadrature Amplitude Modulation (QAM) is considered as our preferred modulation scheme to optimize transmit power. QAM is an important modulation scheme and it is widely used for radio communication .It is a signal in which two carriers shifted in phase by 90 degrees are modulated. The output consists of both amplitude and phase variations. QAM increase the transmission efficiency of radio communication. In this paper more common forms include 4 QAM, 16 QAM., 64 QAM and 256 QAM are discussed[10]. For calculation of average energy of transmission for 4 QAM, 16 QAM, 64 QAM and 256 QAM.*I/Q* diagrams are particularly useful because they mirror the way most digital communications signals are created using an modulator. [10]

4QAM: 4 QAM defined as four phase Quadrature Amplitude Modulation. This digital modulation technique consists of 4 possible state of the signal.For 4 QAM two bits per symbol can be sent and symbol rate is half of bit rate.

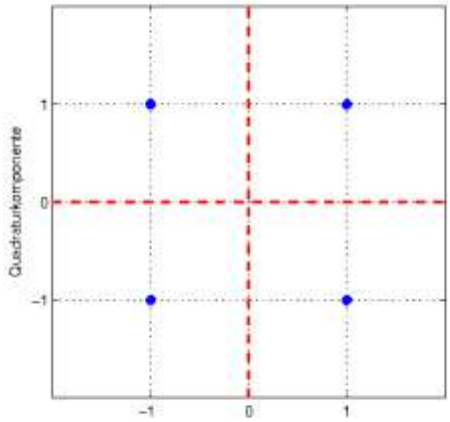

Figure 1: Constellation diagram of 4 QAM

16 QAM: 16 QAM have 16 possible combination of signal and defined as 16 state Quadrature Amplitude Modulation. There are four values of I and four values of Q occurs, this gives the total of 16 possible signal.in this modulation scheme 4 bits per symbol can be sent and symbol rate is one fourth of bit rate.

Average symbol energy=40*a^2

Average bit energy

$$=\frac{(4*2*a^2)+(4*10*a^2)+(4*10*a^2)+(4*18*a^2)}{16} \quad (2)$$

$$=10*a^2$$

- Average symbol energy = average bit energy *4
  = 40*a^2

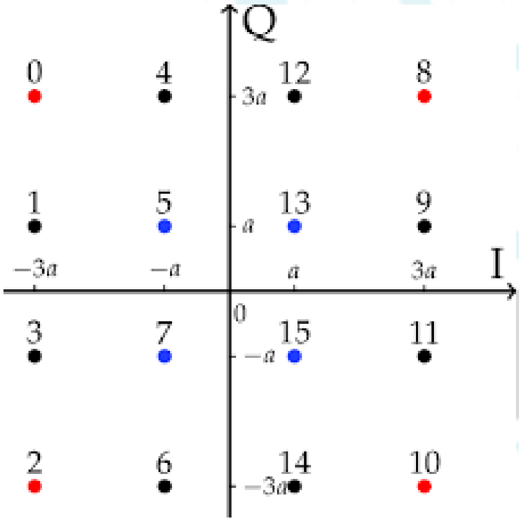

Figure 2: Constellation diagram of 16 QAM

64QAM: 64 QAM have 64 possible signal combinations and defined as 64 state Quadrature Amplitude Modulation . 64QAM is very efficient, supporting up to 28-mbps peak transfer rates over a single 6-MHz channel. But 64QAM's susceptibility to interfering signals makes it will suited to noisy upstream transmissions with each symbol represents 6 bits. 64 QAM is a complex modulation technique with high efficiency.It is also used for sending data downstream over a coaxial cable. Here symbol rate is one sixth of bit rate.

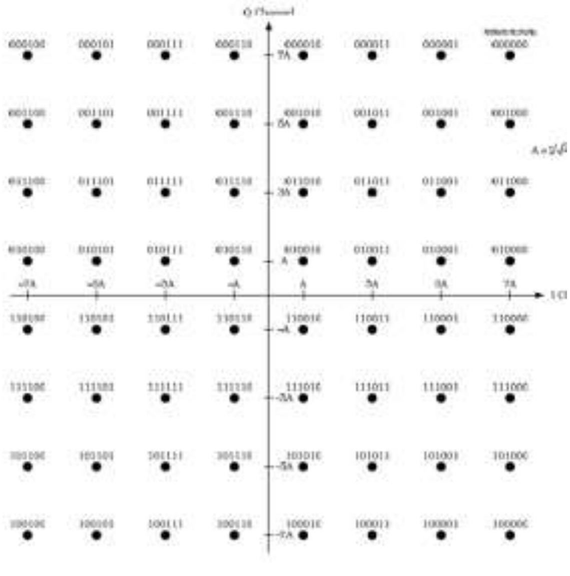

Figure 3: Constellation diagram of 64 QAM

256QAM: 256 QAM defined as 256 state Quadrature Amplitude Modulation. This modulation scheme have 256 possible signal combinations with each symbol representing 8 bits. Here symbol rate is one eighth od bit rate.

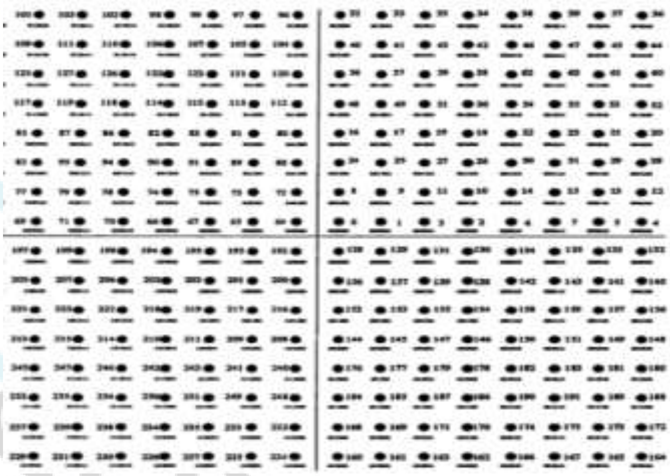

Figure 4: Constellation diagram of 256 QAM

Table 1: Average energy and Average symbol energy of different order of QAM

M QAM	Average Energy	Average symbol energy
4 QAM	2*a^2	4*a^2
16 QAM	10*a^2	40*a^2
64 QAM	60*a^2	360*a^2
256 QAM	204*a^2	1632*a^2

QAM increase the transmission efficiency of radio communication. In this paper more common forms include 4 QAM, 16 QAM., 64 QAM and 256 QAM are discussed[10]. For calculation of average energy of transmission for 4 QAM, 16 QAM, 64 QAM and 256 QAM.*I/Q* diagrams are particularly useful because they mirror the way most digital communications signals are created using an modulator. [10]

3. Relationship between Bit Error Rate (BER) and Transmitter Power

In digital transmission or digital communication system, the number of bit errors is the number of received bits of a data stream over communication channels that have been altered due to noise, interference, distortion or bit synchronization errors in the system. Minimizing BER and power simultaneously generate a divergence because of the single parameter i.e. transmit power, which affects minimization objective in a different manner. Obtaining the optimal set of decision variables for a single objective minimizes power and often the outcome is non-optimal set with respect to other objectives, e.g. minimize BER. In a communication system, the receiver side BER may be affected bytransmission channel noise, interference, distortion, bit synchronization problems attenuation wireless multipath fading etc. Bit error rate can be improved by choosing strong signal strength (unless this causes cross-talk and more bit errors) and a slow and robust modulation scheme or line coding scheme. Applying channel coding schemes such as redundant forward error correction codes can also improve bit error rate [9]. Since, BER is inversely related to the signal to noise ratio (SNR). SNR improves with high transmit power level which in turns decrease BER. However, high RF power level will lead to stronger interference with other nodes causes poorer BER at other nodes.

4. Relationship between Transmitter Power and Fading

Optimal common transmission power is the minimum power required to maintain the network connectivity satisfying a given BER threshold value. Increasing the bit rate improves the BER performance in wireless sensor network. The performance of the network gradually detoriates with the increase of fading severity. Optimal transmission power is seen to be significantly higher in Rayleigh fading environment as compared to path loss and the optimal power also increase with severity of Rayleigh fading to achieve the same BER threshold. There exists a critical bit rate below which a desired BER cannot be achieved with any amount of transmit power. Critical bit rate increases from around 4mb/s to 6mb/s in presence of Rayleigh fading for a given BER threshold value of 10^{-3}. Critical bit rate increase with increasing fading severity. Optimal transmit power required to maintain network connectivity satisfy a given maximum acceptable BER threshold value in shadow fading channel is more compared to Rician and Rayleigh fading channel. Optimal power increases with increase date rate and critical bit rate increases in presence of fading. The route BER in case of Rician fading channel is less as compared to Rayleigh fading channel.

5. Emulation and Results

Our purpose is to optimize the transmitter power for reliable operation of cognitive radio. We obtain the BER values for different order of QAM in the presence of different type of fading in channel. At the receiver end, the power channel gain has been calculated by taking Signal to Noise Ratio (SNR) above an acceptable threshold for radio communication in the presence of AWGN, Rayleigh &Rician fading. We can have an idea of the received power by using the BER values from the receiver end. Using the Friis equation we can obtain the transmitter power value by received power. This is optimized transmit power required for getting SNR above an acceptable threshold and BER , which is previously calculated for fading channel (Rayleigh, Rician, AWGN) and different order of QAM.

In this work, one of the important topic is the concept of fading in wireless communication , which is demonstrated mathematically and put the values in Origin to obtain the graph. In this section, the results obtained mathematically are discussed. It is necessary to explore what happens to the signal as it travels from the transmitter to the receiver. Then it is very easy to understand the concepts in wireless communications. As explained earlier, one of the important aspects of the path between the transmitter and receiver is the occurrence of fading. The RF (radio frequency) signals with appropriate statistical properties can readily be simulated. Statistical testing can subsequently be used to establish the validity of the fading models frequently used in wireless systems. The different fading models and mathematical approaches will now be described. The different results re demonstrated and graphs have been plotted with the results.[10][15]

Equation 3 shows the BER values of AWGN for different order of QAM[9]:

$$BER_{M-QAM,AWGN} = \frac{4}{\log_2 M}\left(1-\frac{1}{\sqrt{M}}\right)\sum_{i=1}^{\frac{\sqrt{M}}{2}} Q\left(\sqrt{\frac{3\log_2 ME_b}{(M-1)N_0}}\right) \quad \textbf{\textit{(3)}}$$

Where,
M = Order of QAM
E_b = Energy per bit+
N_0 = Noise power

Equation 4 shows the BER values of Rayleigh Fading for different order of QAM[9]:

$$BER_{Rayleigh,M-QAM} = \frac{2}{\log_2 M}\left(1-\frac{1}{\sqrt{M}}\right)\sum_{i=1}^{\frac{\sqrt{M}}{2}}\left(1-\sqrt{\frac{1.5(2i-1)^2\gamma'\log_2 M}{M-1.5(2i-1)^2\gamma'\log_2 M}}\right) \quad \textbf{\textit{(4)}}$$

Where,
M = Order of QAM
E_b = Energy per bit
N_0 = Noise power
$\gamma' = \frac{E_b}{N_0}$

Equation 5 shows the BER values of Rician Fading for different order of QAM [14]:

$$BER_{Rician} = \frac{1}{2} erfc\left[\frac{K\left[\frac{E_b}{N_0}\right]}{\left(K+\frac{E_b}{N_0}\right)}\right] \quad \textbf{\textit{(5)}}$$

To obtain BER of 10^{-5}, using QAM an AWGN channel requires $\frac{E_b}{N_0}$ of 8.35 dB, Rician channel requires $\frac{E_b}{N_0}$ of 20.5 dB and Rayleigh channel requires $\frac{E_b}{N_0}$ of 34 dB [12].

The variation of BER with the order of QAM (M-QAM), as indicated table 2, has been plotted in Fig 5 for different fading models. As can we seen from Fig 5, the AWGN fading channel gives the best result and Rayleigh fading channel gives the worst result .BER has a tendency to increase with the increasing order of QAM .

Table 2: BER values in different fading channel for different order of QAM

M-QAM	BER value in AWGN channel	BER value in Rayleigh fading channel	BER value in Rician fading channel
4 QAM	$2.184*10^{-5}$	0.416	0.15
16 QAM	0.00367	0.594	0.33
64 QAM	0.035	0.88	0.5
256 QAM	0.087	1.36	0.95

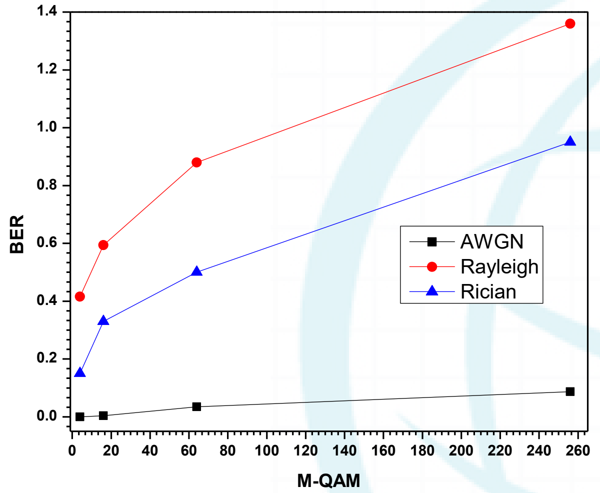

Figure 5: BER variation in different fading channel for different order of QAM

Power channel gain calculation for acceptable of SNR in AWGN, Rayleigh &Rician fading channel for different order of QAM

$$SNR = \frac{E_b}{N_0}|h|^2 \log_2(M) \tag{6}$$

Where,
$|h|^2$=Power Channel Gain
M = order of QAM

Table 3: Values of Power channel gain for acceptable range of SNR in AWGN, Rayleigh &Rician fading channel for 4 QAM

SNR (dB)	Power channel gain for AWGN channel	Power channel gain for Rayleigh channel	Power channel gain for Rician channel
14	0.83	0.20	0.341
14.65	0.87	0.21	0.36
15.20	0.91	0.223	0.37
15.85	0.94	0.233	0.386
16	0.95	0.24	0.39

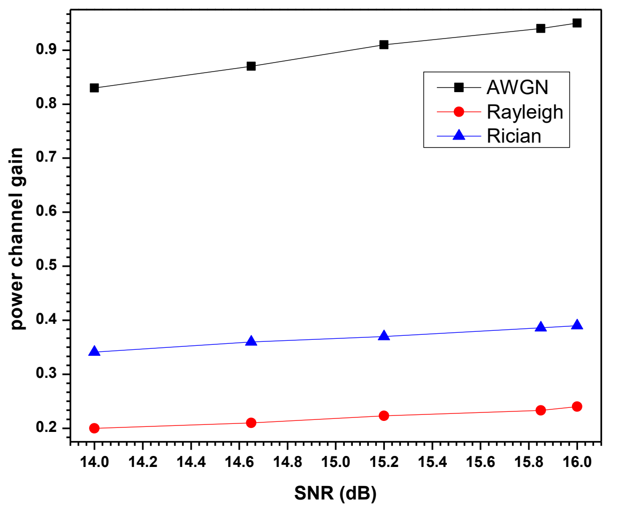

Figure 6: Power channel gain variation for acceptable range of SNR in AWGN, Rayleigh &Rician fading channel for 4 QAM

Table 4: Values of Power channel gain for acceptable range of SNR in AWGN, Rayleigh &Rician fading channel for 16 QAM

SNR (dB)	Power channel gain of AWGN fading channel	Power channel gain of Rayleigh fading channel	Power channel gain of Rician fading channel
14	0.42	0.102	0.170
14.65	0.44	0.107	0.178
15.20	0.455	0.111	0.185
15.85	0.47	0.116	0.193
16	0.48	0.118	0.195
16.5	0.494	0.121	0.201
17	0.51	0.125	0.207
17.35	0.52	0.127	0.211
18.20	0.544	0.133	0.221
19	0.56	0.140	0.231
21	0.62	0.156	0.256

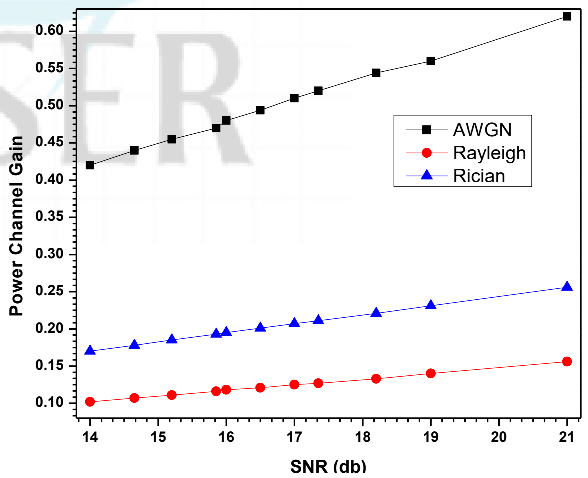

Figure 7: Power channel gain variation for acceptable range of SNR in AWGN, Rayleigh &Rician fading channel for 16 QAM

Table 5: Values of Power channel gain for acceptable range of SNR in AWGN, Rayleigh &Ricia fading channel for 64 QAM

SNR (dB)	Power channel gain of AWGN fading channel	Power channel gain of Rayleigh fading channel	Power channel gain of Rician fading channel
14	0.28	0.068	0.113
14.65	0.292	0.071	0.119
15.20	0.303	0.074	0.123
15.85	0.316	0.077	0.128
16	0.320	0.078	0.130
16.5	0.33	0.080	0.134
17	0.34	0.0833	0.138
17.35	0.346	0.085	0.141
18.20	0.363	0.090	0.147
19	0.38	0.093	0.154
21	0.419	0.102	0.17

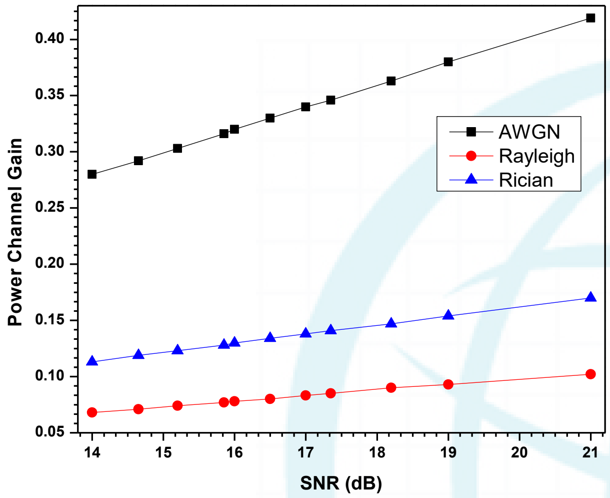

Figure 8: Power channel gain variation for acceptable range of SNR in AWGN, Rayleigh & Rician fading channel for 64 QAM

Table 6: Values of Power channel gain for acceptable range of SNR in AWGN, Rayleigh & Rician fading channel for 256 QAM

SNR(dB)	Power channel gain of AWGN fading channel	Power channel gain of Rayleigh fading channel	Power channel gain of Rician fading channel
14	0.209	0.0514	0.0853
14.65	0.22	0.0538	0.0893
15.20	0.23	0.0558	0.0926
15.85	0.24	0.0582	0.0966
16	0.245	0.0588	0.0975
16.5	0.247	0.0606	0.100
17	0.254	0.0629	0.103
17.35	0.26	0.0637	0.105
18.20	0.272	0.0669	0.110
19	0.284	0.0698	0.127
21	0.314	0.0772	0.128

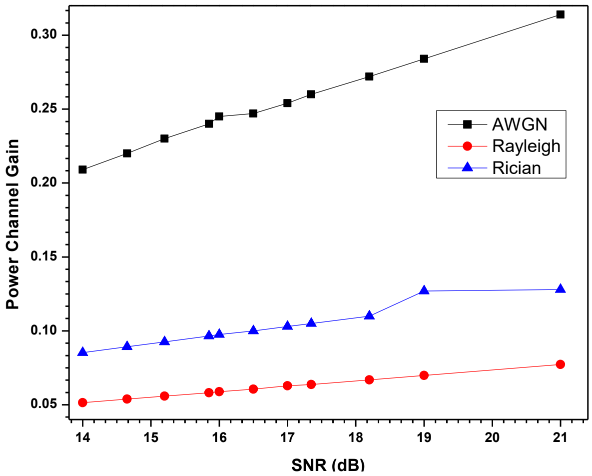

Figure 9: Power channel gain variation for acceptable range of SNR in AWGN, Rayleigh & Rician fading channel for 256 QAM

4.2 Obtaining a relationship between BER and transmitter power

To establish a relation between BER and transmit power.

$$BER = Q\left(\sqrt{\frac{2P_r}{(R_b N_0)}}\right) \qquad (7)$$

where,
P_r=received power
R_b=bit transmission rate
N_o=noise power
R_b= 54Mbps (wifi WLAN 802.11G/A)
According to Friis Formula,

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\prod d)^2} \qquad .(8)$$

Putting the value of P_r from Friis formula in the previous equation, we get

$$BER = Q\sqrt{\frac{2P_t G_t G_r \lambda}{(4\prod d)^2 R_b N_0}} \qquad (9)$$

Where

$$Q(x) \approx \left[\frac{1}{(1-a)x + a(x^2+b)^{\frac{1}{2}}}\right]\frac{1}{(2\prod)^{\frac{1}{2}}} e^{-\frac{x}{2}} \qquad (10)$$

Solving Q(x) for the equation No.8, we can say that

$$BER \infty \frac{e^{-\frac{P_t}{2}}}{2\sqrt{P_t}} \qquad (11)$$

6. Conclusion

Cognitive or intelligent radios are highly reliable because of its ability to identify frequency channels with better SNR value. The detection of such a less noisy channel is difficult because of some inherent problems associated with radio communication. We identify some of those problems namely fading, the SNR variation due to in transmitter power, the BER variation due to various modulation techniques. We studied the result under different conditions are arrived at some results which give us a better understanding of the source of the problems. The variation of BER with the order of QAM (M-QAM), as indicated in Table 2, has been plotted in Fig 5 for different fading models. As can be seen from Fig 5, the AWGN fading channel gives better result than that possible with the Rayleigh and Rician fading channel. BER has a tendency to increase with the increasing order of QAM. BER decreases with the increasing transmitter power because BER is inversely proportional to the transmitter power as shown in equation no.10. So we can conclude that less transmitter power is needed for higher order of QAM, i.e. 256 QAM and high transmitter power is needed for lower order of QAM, i.e. 4 QAM and 16 QAM. So we can say in 64 QAM, BER is higher but is within acceptable range. Also low transmitter power is required than that for lower order of QAM. Hence the 64 QAM is our preferred one for optimizing the transmitter power in cognitive radio. The power channel gain of different fading channel for different order of QAM has been compared by taking the acceptable SNR threshold in radio communication. These values of power channel gain for 4-QAM, 16-QAM, 64_QAM & 256_QAM for different fading channel as indicated in Table 3, Table 4, Table 5 & Table 6 respectively have been plotted in Fig 6, Fig 7, Fig 8 & Fig 9 respectively. From our observation we can say that the power channel gain is better in AWGN than Rayleigh fading and Rician fading. Losses are more in Rayleigh fading and Rician fading.

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