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Abstract

A growing trend has been observed in recent research in wireless communication systems. However, several limitations still exist, such as packet loss, limited bandwidth and inefficient use of available bandwidth that needs further investigation and research. In light of the above limitations, this paper uses adaptive modulation under various parameters, such as signal to interference plus noise ratio (SINR), and communication channel 19s distances. The primary goal is to minimize bit error rate (BER), improve throughput and utilize the available bandwidth efficiently. Additionally, the impact of Additive White Gaussian Noise (AWGN), Rayleigh and Rician fading channels on the performance of various modulation schemes are also studied. The simulation results demonstrate that our proposed technique optimally improves the BER and spectral efficiency in the long-range communication as compared to the fixed modulation schemes under the co-channel interference of surrounding base stations. The results indicate that the performance of fixed modulation schemes is suitable only either at high SINR and low distance or at low SINR and high distance values. Moreover, on the other hand, its performance was suboptimal in the entire wireless communication channel due to high distortion and attenuation. Lastly, we also noted that BER performance in the AWGN channel is better than Rayleigh and Rician channels with Rayleigh channel exhibiting poor performance than the Rician channel.

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Abstract: A growing trend has been observed in recent research in wireless communication systems. However, several limitations still exist, such as packet loss, limited bandwidth and inefficient use of available bandwidth that needs further investigation and research. In light of the above limitations, this paper uses adaptive modulation under various parameters, such as signal to interference plus noise ratio (SINR), and communication channel's distances. The primary goal is to minimize bit error rate (BER), improve throughput and utilize the available bandwidth efficiently. Additionally, the impact of Additive White Gaussian Noise (AWGN), Rayleigh and Rician fading channels on the performance of various modulation schemes are also studied. The simulation results demonstrate that our proposed technique optimally improves the BER and spectral efficiency in the long-range communication as compared to the fixed modulation schemes under the co-channel interference of surrounding base stations. The results indicate that the performance of fixed modulation schemes is suitable only either at high SINR and low distance or at low SINR and high distance values. Moreover, on the other hand, its performance was suboptimal in the entire wireless communication channel due to high distortion and attenuation. Lastly, we also noted that BER performance in the AWGN channel is better than Rayleigh and Rician channels with Rayleigh channel exhibiting poor performance than the Rician channel.

Keywords: adaptive modulation; BER; different communication channels; M-PSK; M-QAM; SINR.

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1 Introduction

Nowadays, the systems and technologies used in the communication system are undergoing rapid technological changes all over the world due to a fast-growing demand for high data rates and quality of service (QoS) [1]. The next generation of wireless systems is required to provide high data rates without extra bandwidth, higher mobility, carrier frequency and link reliability [2]. It also requires a high voice quality, high transmit power and coverage, high quality and service as compared to the present cellular mobile standard. The fast-growing use of information networks and the increased data rates need to implement new technologies to improve the performance of wireless communication networks. Wireless communication affects the social life of human beings more and more with the rapid development of technologies [3]. The wireless communication system should be able to operate in different environments (rural, urban and suburban), including indoor and outdoor environments and in all kinds of multipath and time-varying fading channels.

Often the transmitter and receiver source is far away from each other and a direct line of sight (LOS) path is not possible between them. The propagation of radio signals that propagate through two or more paths from the transmitter to receiver can be assumed as multipath propagation [4]. Hence, the multipath channel is used between the two sources which are associated with some data loss. Reducing the effect of multipath fading in wireless communication and minimizing the effective error rate in a multipath fading channel is a challenging problem. The channel variation is a key factor that reduces the performance of a communication system [5]. The utilization of specific modulation and coding schemes in existing channels minimize the bit error rate (BER). This minimization of BER cannot be achieved by a high level of transmit power or extra bandwidth due to infrastructure-related constraints. Hence, recent research has been concentrated on achieving high spectral efficiency (SE) with minimum BER within a specific bandwidth, error-free transmission and link reliability by using advanced technologies such as Worldwide Interoperability for Microwave Access, orthogonal frequency division multiplexing (OFDM), adaptive modulation schemes, multi-input multi-output (MIMO), and Long-Term Evolution. Different mobile generations (such as 1G, 2G, 3G, 4G and 5G) use different modulation schemes and technologies. The mobile wireless generation commonly refers to a variance in the nature of the system, technology, frequency, speed, latency, data capacity, etc. [6]. The wireless communication system's efficiency is estimated from the BER [7]. The spectral efficiencies and BER depend on the modulation scheme, technology, and channel condition used in the mobile cellular communication system.

Different factors reduce the performance of a communication system such as interference, noise, propagation loss, limitation of bandwidth and fading due to multipath [8, 9]. The issues related to interference, hardware, and noise are quickly reduced in the digitally modulated systems as it resists noise, interference, and offers bandwidth efficiency, as compared to the analog modulated systems which needs higher bandwidth to transfer symbols. Digital modulation scheme is more compatible with current wireless technologies [10]. Digital modulation systems offer extra information transmitting capacity, higher quality transmission, data security, swift system availability, and RF spectrum assigning to support extra services [11, 12]. The best modulation scheme is dependent on many factors such as signal to noise ratio (SNR), BER, high QoS, power proficiency, and cost [13, 14]. The performance of every modulation system is determined by measuring its possibility of the error having a supposition that the signal is passing through the additive white gaussian noise (AWGN) channel [14].

Due to the increasing demand for low BER and high QoS in a wireless communication system, Hanzo and Torrance have recommended an adaptive modulation system, which refers to the alteration of different modulation schemes by a transmitter according to the channel situation [10]. Adaptive modulation needs accurate channel state information at the transmitter side [15]. The authors suggested that an adaptive modulation system should effectively utilize the available bandwidth to increase data rate and decrease BER by manipulating the wireless channel information existing in the transmitter. This capability of adaptive modulation shows high-performance improvement, particularly over the fading channel as compared to other systems, which are not manipulating channel knowledge at the transmitter side. Adaptive modulation is an attractive technology to improve the transmission efficiency over wireless fading channels with assured reliability [16]. Adaptive modulation is a technique to enhance the trade-off between BER and SE [5]. The fundamental idea of adaptive modulation is the estimation of channel variations and selecting the suitable transmission parameters like modulation mode, power and coding rate [17]. It allows a wireless system to find the highest digital order modulation scheme concerning the channel circumstances considering the interference, path loss as a result of a signal originating from another transmitter, the existing transmitter power margin, and the sensitivity of the receiver to attain low BER and better spectral efficiencies.

The adaptive modulation and coding (AMC) rely on measured SNR and BER to choose the required code rate and order of modulation. Higher-order modulation with higher coding rate will be used for the improvement of SE when the SNR is high. Specifically, if the SNR is high and BER is low, higher coding rate and modulation order like 3/4 and 156-quadrature amplitude modulation (156-QAM) can be used. In contrast, lower coding rate and order of modulation such as binary phase shift keying (BPSK) and 1/4 code rate to keep link availability during worse conditions [18]. However, the analytical approach is different from cognitive implementation since single user must wait for transmission and packet transmission can be unsuccessful due to colliding. The Enlightened Data Transport statistics for large packet transmission with AMC are obtained. The transmission of large packet allows multiple transmission slots depending on the behaviour of the secondary channel [19]. A spectral efficient adaptive modulation scheme is proposed and analysed for heterogeneous two-way relay network with a symbol-based network. The proposed scheme allows transceivers to use various modulation schemes at different bit rate and adjust these parameters to the channel conditions. The proposed rate adaptation scheme effectively alleviates the propagation of error from the relay to transceivers because the end-to-end BER has to be restricted by QoS. The two modulation schemes used by both transceivers belonged to the same class [20].

There are various modulation schemes which allows sending more bits per symbol for higher throughput. Nevertheless, it is known that modulation schemes such as 64-QAM and 16-QAM require better SNR to resolve any interference and noise. Thus, wireless systems were intended to adjust suitable modulation order according to channel situations [21]. To enrich BER in the MIMO OFDM system, dynamic adaptive modulation schemes with forward error correction code are employed. From the results of BER vs. SNR relations of said system, high modulation schemes send high data rates and have less immunity to noise [22]. The authors in [23] have shown how interference can be minimized by using modulation and coding. A very few attempts were made to focus on switching mechanisms to reduce the detrimental effects of interference in dense networks. Even though QAM improve the performance transmission for radio communication, it is more noise prone and since it contains an amplitude content, linear amplifiers that are less effective and consuming more energy are necessary for transmitter use. In case of a limited source of power, N-minimum shift keying modulation schemes are preferred over N-QAM adaptive modulation, as former modulation does not suffer seriously from the non-linear amplification of the transmitter, which distorts the signal later. OFDM systems make full efficient use of the available spectrum by splitting the channel into narrowband flat fading sub-channels [24]. The high order QAM and coding with higher code rate are used to boost the throughput of the wireless channel to enhance the SE. The low order of QAM shows a greater risk of demodulation error while the coding scheme with higher coding rate results in less correction. The SE and QoS performance of the wireless channel are conflicting, and the trade-off is necessary. Choosing the modulation and the coding scheme carefully will accomplish the trade-off. The AMC technique is commonly used in the existing wireless systems to increase data rate and to fulfill the QoS specification over the time-varying channel [17]. In this study, we propose a novel adaptive modulation technique and analyze the overall performance of the system in different conditions. To the best of our knowledge, there is no work, which uses similar constraints and system model. The main contributions of the study are given below:

- A distance-based threshold is proposed for adaptive modulation scheme, with the objective to achieve the target BER in the long-range communication cellular system.
- This study presents the impact of co-channel interference of base stations (BSs) on the user and overall modulation schemes. The cumulative interference effect of BSs in the cluster is included as signal to interference plus noise ratio (SINR). The co-channel interference is added with the desired signal of the transmitter and is transmitted to the mobile user. Here the desired BS which transmits the signal to the user varies modulation scheme according to SINR in a different wireless channel to improve BER and throughput.
- Various modulation schemes and their BER performances are estimated and analyzed in both AWGN and realistic channel environments such as Rayleigh and Rician fading channels.

The rest of this paper is organized as follows. Section 2 contains a methodology. Section 3 is about the simulation results and discussion, and finally, conclusions are given in Section 4.

2 Methodology

The transmission of different modulated signals such as 64-QAM, 16-QAM, quadrature phase shift keying (QPSK), and BPSK from a transmitter to receiver, in the block diagram 1 is affected by attenuation, distortion, and interference due to the multipath channel impairment. The modulator selector which acts as a feedback path for the transmitter gets information about SINR and distance in a multipath channel which is estimated by the channel estimator, which in turn, is a part of the receiver. The modulator selector then gives this information to the transmitter to change modulation schemes according to the SINR and distance of modulated signal in the multipath channel. The model of adaptive modulation is given in Figure 1.

The equation for estimation of SINR [25, 26] of different modulated signals is given below

$$\mathrm{SINR} = \frac{P}{I + N} \tag{1}$$

where P is the power of central BS, I is the combined co-channel interference of six BSs on the assumed mobile user which is communicating and is at 3 km distance, making 35° angle with central BS and N is the channel noise power. Interference power between the user and surrounding BS is given in Eq. (2)

$$P = P_0\left(\frac{d_0}{d}\right)^n \tag{2}$$

where n is a constant path loss exponent with a value of 2 for free space and d_0 is the reference distance and we have taken it to be equal to 100 m because it is 100 m or 1 km in the outdoor environment. P_0 is the received power at a reference distance d_0 which is given below in Eq. (3)

$$P_0 = \frac{\lambda^2 P_t G_T G_R}{(4\pi)^2 d_0^2} \tag{3}$$

where the wavelength of the signal is λ, P_t is the transmitted power, G_T is transmitter antenna gain while G_R is the receiver antenna gain. To find $\mathbf{d}$, the distance between a user and interfering BSs, we first find $\mathbf{D}$, the distance between central BS and co-channel BSs as under:

$$\mathbf{D} = R\sqrt{3N} \tag{4}$$

where R is the radius of the BS and is assumed to be 6 km, $N = 7$ is the cluster size in our case. The six-co-channel BSs make an angle of 30°, 90°, 150°, 210°, 270°, 330° with the central BS. We can find the coordinates of each of the six co-channel BSs using the following equation

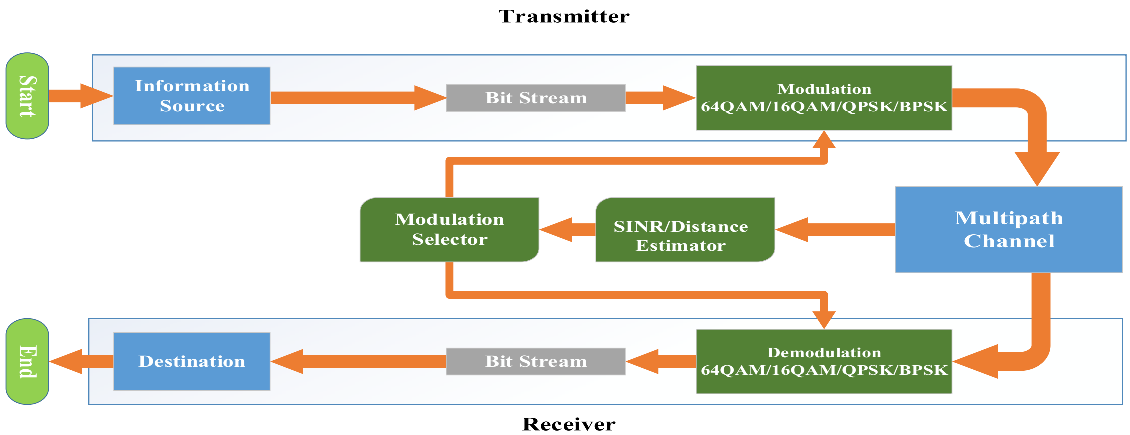

Figure 1: Block diagram of adaptive modulation system.

$$X = \mathbf{D}\cos(\theta) \tag{5}$$
$$Y = \mathbf{D}\sin(\theta) \tag{6}$$

here **D** is the distance and θ is the angle between the central and co-channel BS. In the same way, we can find the coordinates of all surrounding six BSs. The coordinates of the mobile user can also be found by the above equation by taking $\mathbf{D}' = 3$ km and $\theta' = 35°$. Thereafter, the distance between the mobile user and each surrounding BSs is measured by the following Euclidean distance equation,

$$\mathbf{d_i} = \sqrt{(X_i - X_{\text{mobile user}}) - (Y_i - Y_{\text{mobile user}})} \tag{7}$$

In the above equation X_i, Y_i, and $X_{\text{mobile user}}$, $Y_{\text{mobile user}}$ are the X and Y coordinates of the ith surrounding BSs and mobile user location respectively. After finding $\mathbf{d_i}$, we have found the interference power from the surrounding six BSs, whereas the interference power $P(I)$ is the summation of interference power of ith co-channel BSs as given in the following equation,

$$P(I) = \sum_{i=1}^{6} P(I)_i \tag{8}$$

To measure the probability of error of BPSK and QPSK in AWGN channel, we use the below equation,

$$P_b = Q\left(\sqrt{\frac{2E_b}{N_0}}\right) \tag{9}$$

here, E_b is the energy per bit while N_0 is the noise power per bit and Q function is equal to $Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^\infty \exp(t^2/2)dt$. The following Eq. (10) represents the probability of error of M-QAM [27, 28] modulated signal in AWGN channel,

$$P_b = 4\frac{\sqrt{M}-1}{\sqrt{M}}Q\left(\sqrt{\frac{3}{M-1}\frac{XE_b}{N_0}}\right) - 4\left(\frac{\sqrt{M}-1}{\sqrt{M}}\right)^2 Q^2\left(\sqrt{\frac{3}{M-1}\frac{XE_b}{N_0}}\right) \tag{10}$$

here $X = \log_2 M$ is the number of bits per symbol and M is the size of the modulation constellation. The $XE_b = E_s$, E_s is the energy per symbol, if E_s is used then P_b will be replaced by P_s and Eq. (10) can be also written as given below,

$$P_s = 4\frac{\sqrt{M}-1}{\sqrt{M}}Q\left(\sqrt{\frac{3E_s}{N_0(M-1)}}\right) - 4\left(\frac{\sqrt{M}-1}{\sqrt{M}}\right)^2 Q^2\left(\sqrt{\frac{3E_s}{N_0(M-1)}}\right)$$

The Eq. (11) is used to calculate the probability of error of MPSK in a fading channel environment

$$P_b = \frac{1}{\pi}\int_0^{(M-1)\pi/M}\prod_{l=1}^{L} M_{y_l}\left(-\frac{\sin^2(\pi/M)}{\sin^2\theta}\right)d\theta \tag{11}$$

The probability of error of MQAM in fading channel is given in Eq. (12)

$$P_b = \frac{4}{\pi}\left(1-\frac{1}{\sqrt{M}}\right)\int_0^{\pi/2}\prod_{l=1}^{L} M_{y_l}\left(-\frac{3/(2(M-1))}{\sin^2\theta}\right)d\theta - \frac{4}{\pi}\left(1-\frac{1}{\sqrt{M}}\right)^2\int_0^{\pi/4}\prod_{l=1}^{L} M_{y_l}\left(-\frac{3/(2(M-1))}{\sin^2\theta}\right)d\theta \tag{12}$$

The probability of error of MPSK and MQAM for Rayleigh and Rician channels is the same with the only difference being M_{y_l}. M_{y_l} for Rayleigh is in Eq. (13) and M_{y_l} for Rician channel is given in Eq. (14)

$$M_{y_l}(s) = \frac{1}{1 - s y_l} \tag{13}$$

$$M_{y_l}(s) = \frac{1+N}{1+N-s y_l} e^{\left[\frac{N s \bar{y}_l}{(1+N)-s\bar{y}_l}\right]} \tag{14}$$

where y_l is the SNR per symbol per branch and is equal to $\Omega_l \frac{XE_b}{N_0}/L$, Ω_l is the power of the fading amplitude r and is equal to $\Omega = E[r^2]$ and L is the number of diversity branches. N is the ratio of energy in the specular component to the energy in the diffuse component. $\bar{y}_l = y_l$ for identically distributed diversity. To find SINR and BER vs. distance relation, the mobile user moves around the BS in coverage area 6 km of velocity V, the frequency of the signal is f_c. The received signal power equation is given below

$$P(r) = P_t + G_r + G_t - L_c - P_{\text{loss}} \tag{15}$$

In Eq. (15), L_c is the transmission loss of the antenna signal, P_t is the transmitted signal power and P_{loss} is the path loss. The P_{loss} equation [29–31] is given below

$$P_{(\text{loss})} = 32.44 + 20\log_{10}(d) + 20\log_{10}(f_c) \tag{16}$$

where d is the distance from the central BS at which the SINR and BER are measured, and f_c is the frequency of the transmitted signal. The SINR in dB at distance d can be measured using the following Eq. (17)

$$\mathrm{SINR}\,(\mathrm{dB}) = P_{(r)}\mathrm{dB} - P_{(\mathrm{Noise})}\mathrm{dB} - P\,(I)\mathrm{dB} \tag{17}$$

Finally, the equation to calculate SINR is given as under

$$P\,(r) = P_t + G_r + G_t - L_c - \left(32.44 + 20\log_{10}(d) + 20\log_{10}(f_c)\right) - P_{(\mathrm{Noise})} - P\,(I) \tag{18}$$

3 Simulation results and discussion

In this section, we show the performance of various modulation schemes such as BPSK, QPSK, 16-QAM, and 64-QAM used for the adaptive modulation in terms of BER vs. distance and SINR vs. distance after including the co-channel interference of six BSs in AWGN, Rayleigh and Rician fading channels. We compare the performance of the adaptive modulation scheme with the performance of a fixed modulation scheme. The interference from co-channel BSs add to the desired signal and is transmitted to AWGN, Rayleigh and Rician channels. Figure 2 shows the distance and angle of central BS with six co-channel BSs and also shows the distance between the mobile user and co-channel BSs.

The mobile user is at 3 km, making 35° angle with central BS having a coverage area of 6 km experiencing co-channel interference from surrounding six co-channel BSs. The six co-channel BSs are equidistant 27.49 km from central BS making angles of 30°, 90°, 150°, 210°, 270° and 330° with the central BS (*see* Figure 2). Each co-channel BS has unique coordinates and has a different distance from the mobile user. The distance between each interfering BS and the targeted mobile user is 24.50 km, 25.88 km, 28.87 km, 30.46 km, 29.31 km and 26.35 km which can be seen in Figure 2. The mobile user experiences different levels of interference from each interfering BS. The changing position of a mobile user varies the distance and interference between that user and co-channel BSs. This causes a variation in BER and SINR of modulated signals such as BPSK, QPSK, 16-QAM and 64-QAM used for adaptive modulation in AWGN, Rayleigh and Rician channels. The performance of modulation schemes in wireless communication systems is determined by BER. The simulation parameter values are listed in Table 1.

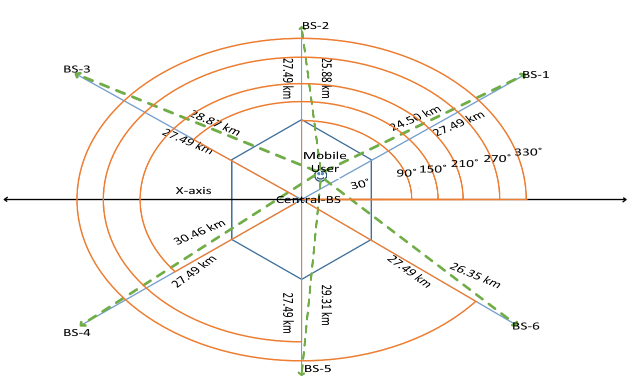

Figure 2: Illustration of distance and angle between co-channel BSs and central BS and distance between mobile user and co-channel BSs.

Table 1: Parameters used in simulation.

Parameters	Specification
Frequency	2 GHZ
Transmitted power P_t	43 dBm
Modulation schemes	BPSK, QPSK, 16-QAM, 64-QAM
Channels	AWGN, Rayleigh, Rician
Radius of cell	6 km
Wavelength	0.15 m
Reference distance d_o	100 m
$G_T = G_R$	5
Co-channel BSs	6
Distance between user and central BS	3 km
Simulation tool	MATLAB

3.1 AWGN channel

Figure 3 shows that the BER of various modulation schemes has a direct relationship with distance, while Figure 4 shows that the SINR has an inverse relationship with distance in the AWGN channel. Table 2 provides an explanation of Figures 3 and 4 by demonstrating the relationship between BER, distance and SINR. As can be seen in Table 2, BER and SINR have an inverse relation. The BER of different modulation schemes at different distances and SINR values in the AWGN channel has been given in Table 2. In Figure 3, BPSK and QPSK signals overlap with each other because the difference in BER of BPSK and QPSK is very low, and can also be seen this small BER difference in Table 2. The left side of 0 at x-axis in Figures 3 and 4, the values of distance are negative, it is noted here that the distance is a scalar quantity and it is always positive so distance cannot be negative. Here it is the directed distance which can be negative, zero and positive vector but the magnitude of directed distance will be always positive.

Figure 3 and Table 2 show that the BPSK has the lowest BER with a low data rate while 64-QAM has the highest value of BER with a high data rate in AWGN channel. This is

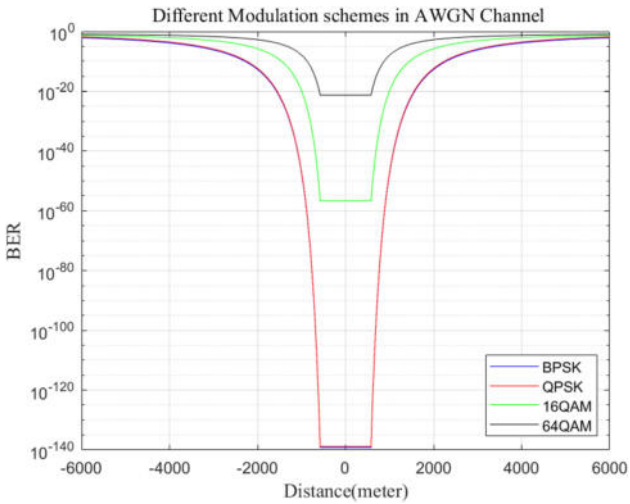

Figure 3: BER vs. distance of different modulation schemes in AWGN channel.

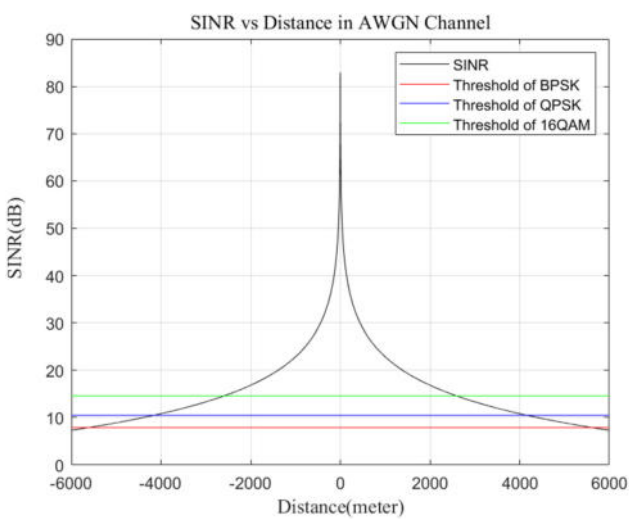

Figure 4: SINR vs. distance in AWGN channel.

due to the constellation diagram of modulation schemes. Constellation diagram of low order modulation schemes like BPSK and QPSK is relatively simple. In the BPSK constellation diagram, there is a 180° phase angle between the two message points [32] while in the QPSK constellation diagram, the four message points are equidistant and there is a 90° phase angle between two adjacent symbols that are far away from each other. Thus, BPSK and QPSK are more immune to a channel variation and the effect of noise, attenuation, distortion and other internal or external disturbances of fading channels lowering BER. The effect of channel on BPSK is low due to a large distance between two message points in the constellation diagram and cause low BER as compared to QPSK. The BPSK and QPSK are the most suitable signals during poor link stability, high transmission range and low SINR to suggest an appropriate BER in the transmission of BPSK and QPSK signal from transmitter to receiver.

The 16-QAM and 64-QAM have complex constellation diagram in the form of more amplitude level and phase, and that there might be more message points in IQ plane which are very close to one another. If the average energy of the constellation diagram of QAM remains constant, the symbols are required to be very near to one another that causes QAM less immunity to channel variations. The high order modulation schemes need high SINR to precisely demodulate transmitted signals because high order modulation schemes such as QAM are more exposed to noise, interference, non-linear distortion and multipath fading [33] thus causing high BER. The distortion, attenuation and noise effects of fading channels on a 64-QAM signal are more catastrophic in comparison to a 16-QAM signal due to more symbol points in a constellation diagram which are very close to each other thus causing high BER. The 16-QAM and 64-QAM signals are more suitable for transmission during favourable channel conditions and low

Table 2: BER vs. distance and SINR of various modulation schemes in AWGN channel.

AWGN Channel					
Distance (m)	SINR (dB)	BER			
		BPSK	QPSK	16-QAM	64-QAM
6000	7.299	0.00756	0.01501	0.04665	0.106
5000	8.882	0.001745	0.003484	0.02426	0.07886
4000	10.82	0.0001389	0.0002778	0.008064	0.04944
3000	13.32	6.252×10^{-7}	1.25×10^{-6}	0.0008141	0.01952
2000	16.84	2.039×10^{-13}	4.078×10^{-13}	1.685×10^{-6}	0.001785
1000	22.86	9.165×10^{-48}	1.833×10^{-47}	2.084×10^{-20}	1.315×10^{-8}
0	57	7.307×10^{-140}	1.461×10^{-139}	2.179×10^{-57}	5.818×10^{-22}

Table 3: Data rate and relative minimum distance between constellation points according to modulation schemes.

Modulation schemes	Relative minimum distance	Data rate
BPSK	1	1
QPSK	$\frac{1}{\sqrt{2}}$	2
16-QAM	$\frac{1}{\sqrt{10}}$	4
64-QAM	$\frac{1}{\sqrt{42}}$	6

transmission ranges causing less degradation. Table 3 describes the data rate and the minimum distance between adjacent symbols.

The BER, distortion, attenuation and the noise of a channel increase and SINR decrease as the physical distance between transmitter and receiver increases in a fading channel. The adaptive modulation varies in different order modulation schemes based on the switching threshold values of SINR and distance in AWGN channels to achieve target BER value of 10^{-2}, minimizing the effects of a wireless channel to enhance the BER performance, and thus increasing the throughput of the system. Throughput is the number of messages successfully delivered per unit time from transmitter to receiver in a wireless channel. The BER and SINR vary as the distance varies in a wireless channel. The low distance from the transmitter source causes low BER and high SINR resulting in high throughput while high distance causes high BER and low SINR thus minimizing the throughput. The threshold line of BPSK, QPSK, 16-QAM, and 64-QAM in Figure 4 shows the switching threshold values of SINR and distance while Figure 5 shows the switching threshold values of a distance of said modulation schemes in AWGN channel to achieve target BER value of 10^{-2}. The BER values are computed from Figure 3. Figure 5 shows that the 16-QAM and 64-QAM are employed for a large distance while QPSK and BPSK are employed for short-distance communication in the AWGN channel. This is due to the fact of low effects of AWGN channel on modulated signals and because the performance of higher order modulation schemes is better at favourable channel conditions, which are available near to the transmitter source.

3.2 Rayleigh channel

Figure 6 shows that BER of different modulation schemes varies with distance and like AWGN channel, the BER of BPSK, QPSK, 16-QAM, and 64-QAM have a direct relation with distance. Figure 7 shows that SINR varies with distance

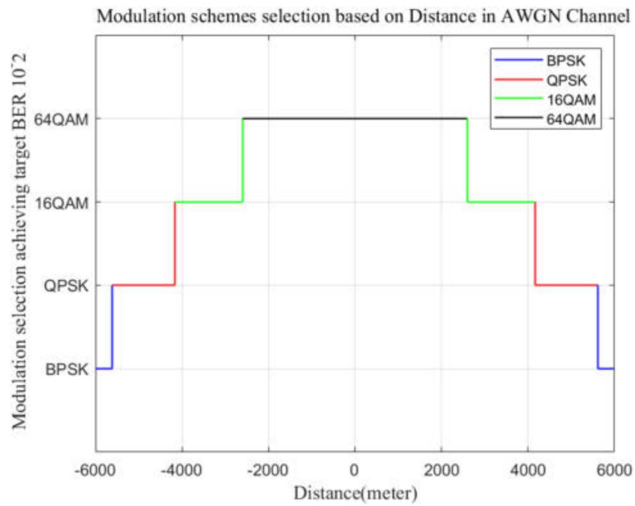

Figure 5: Illustration of distance-based selection of various modulation schemes in AWGN channel.

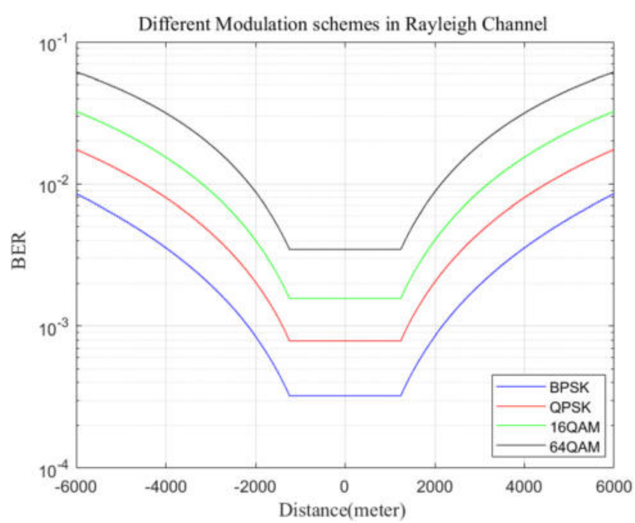

Figure 6: BER vs. distance of different modulation schemes in Rayleigh channel.

and have an inverse relationship in a Rayleigh fading channel. Table 4 describes Figures 6 and 7 and illustrates BER, distance and SINR relationship in Rayleigh channel. Table 4 exhibits that the BER and SINR have an inverse relation. Table 4 shows the BER of different modulation schemes at different distance and SINR values and shows that the BER of different modulation schemes is high at low SINR values in Rayleigh channel in comparison to the AWGN channel at same distance values (*see* Table 2). Thus, the performance of modulation schemes in Rayleigh channel is poor than in AWGN channel because of the non-line of sight path between transmitter and receiver, and a signal is transmitted to the receiver through many multipath tracks.

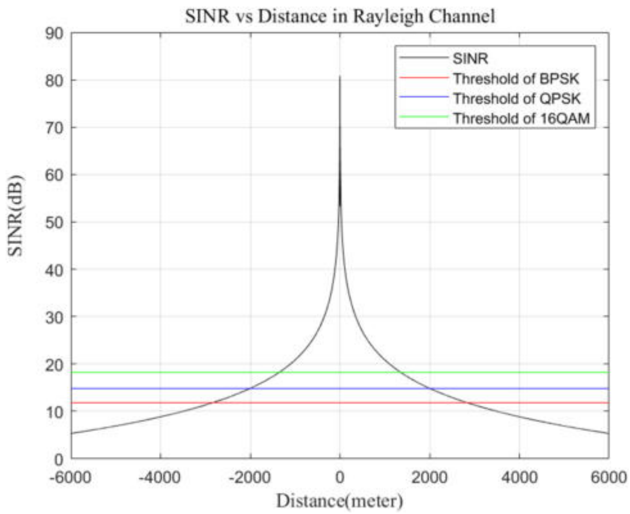

Figure 7: SINR vs. distance in Rayleigh channel.

The signal is affected by phenomena such as diffraction, reflection, scattering and absorption which causes high channel degradation, distortion and attenuation in the signal. Thus, it causes a large number of errors in BPSK, QPSK, 16-QAM and 64-QAM modulation techniques in Rayleigh channel as compared to AWGN channel. In the AWGN channel, the only noise is added to the modulated signal and the path loss in the AWGN channel is due to the distance between transmitter and receiver and as a result, the performance of a modulated signal is good in AWGN channel than Rayleigh channel. The variation of distance varies the BER, SINR, interference and path loss of modulated signal, which in turn vary the effect of multipath fading channels.

The BER of different modulation schemes is not decreasing further below 1000 m and is constant as shown in Table 4. The simulation results show that the same modulation schemes have different BER in different channels and different modulation schemes have different BER in the same channel (*see* Tables 2 and 4).

We use adaptive modulation schemes based on switching threshold values of SINR and distance to choose low order modulation schemes such as BPSK and QPSK in high transmission range with low SINR while we chose higher-order modulation schemes such as 16-QAM and 64-QAM in low transmission range with high SINR in Rayleigh fading channel to achieve target BER of 10^{-2}. This results in minimizing the BER, decreasing interference and mitigating the effect of different phenomena such as distortion, attenuation, and noise on modulated signals in a multipath Rayleigh fading channel. The threshold line of BPSK, QPSK, 16-QAM and 64-QAM in Figure 7 shows the switching threshold values of SINR and distance while Figure 8 shows the switching threshold values of distance of BPSK, QPSK, 16-QAM and 64-QAM signals in Rayleigh channel to achieve target BER value of 10^{-2}.

Figure 8 shows that the 64-QAM and 16-QAM are employed for short coverage area while QPSK and BPSK for large coverage area in Rayleigh channels as compared with AWGN (*see* Figure 5). This is due to high distortion, attenuation and path loss of multipath Rayleigh fading channel on modulated signals and hence the performance of QPSK and BPSK is good at unfavorable channel conditions as compared to 64-QAM and 16-QAM modulation techniques. In AWGN channel, the effect of channel is low and hence the 64-QAM and 16-QAM are selected for large coverage area while QPSK and BSPK are selected for short coverage area.

3.3 Rician channel

Figure 9 describes that the BER of different modulation schemes decreases or increases with a decrease or increase in distance respectively. Figure 10 shows that SINR increases or decreases with a decrease or increase in distance respectively in the Rician channel. Figures 9 and 10 are further described in Table 5. Table 5 shows BER, SINR and

Table 4: BER vs. distance and SINR of various modulation schemes in Rayleigh channel.

Rayleigh Channel					
Distance (m)	SINR (dB)	BER			
		BPSK	QPSK	16-QAM	64-QAM
6000	5.319	0.008564	0.01756	0.03264	0.06156
5000	6.903	0.005733	0.01235	0.02339	0.04607
4000	8.841	0.003591	0.008078	0.01556	0.03187
3000	11.34	0.001966	0.004591	0.008963	0.01903
2000	14.86	0.0008398	0.00202	0.003984	0.008706
1000	20.88	0.0003232	0.0007887	0.001564	0.003467
0	53.32	0.0003232	0.0007887	0.001564	0.003467

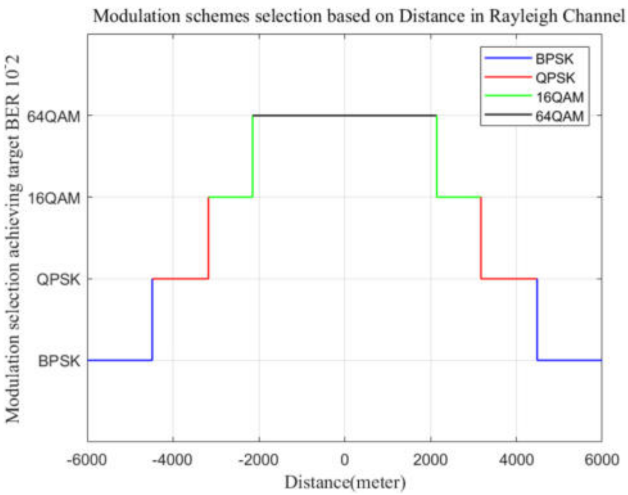

Figure 8: Illustration of distance-based selection of various modulation schemes in Rayleigh channel.

distance relation and also demonstrates that the BER of different modulation schemes decreases with increasing value of SINR and *vice versa* in the Rician channel.

Figure 9 and Table 5 show that the BER of different modulation schemes in a Rician channel is higher than in an AWGN channel (*see* Figure 3 and Table 2) and lower in Rayleigh channel (*see* Figure 6 and Table 4) at same distance values. Tables 2, 4 and 5 also show that the SINR of the Rician channel is lower than AWGN channel and higher than the Rayleigh channel at same distance values. Table 5 shows that the BER of proposed modulation schemes in Rician channel are constant like BER in Rayleigh channel at low distance values and are not decreasing further.

The Rician channel has low BER with high SINR in comparison to the Rayleigh channel which has high BER with low SINR. The Rician channel has high BER with low SINR as compared to AWGN which exhibits a low BER with high value of SINR. This is due to the signal received at the receiver through several weak multipath and at least one dominant LOS path in the Rician channel while there is no LOS path in Rayleigh channel and in AWGN channel only noise is added to the signal. This causes low channel degradation and hence minimal effects of phenomena such as diffraction, reflection, scattering and absorption of a signal that results in low distortion and attenuation in signal along with noise in the Rician channel thus causing low BER in comparison to Rayleigh channel and higher in comparison to AWGN channel.

The simulation results show that BPSK has the lowest BER and low data rate while 64-QAM has the highest value of BER with high data rate in all three wireless fading channels and this is due to constellation diagram which we have explained in detail in the AWGN channel section. The simulation results show that the performance of fixed modulation schemes is not suitable in the entire AWGN, Rayleigh, and Rician channels due to high distortion and attenuation, causing a high error in transmitted signal which degrades the system performance. The performance of fixed modulation schemes is better at a specific value of SINR and distance. The fixed modulation schemes are not bandwidth efficient because the same modulation scheme is used for good and poor channel circumstances.

The switching threshold values for distance and SINR of Rician channel are given in Table 6 according to which different order modulation schemes are varying to achieve

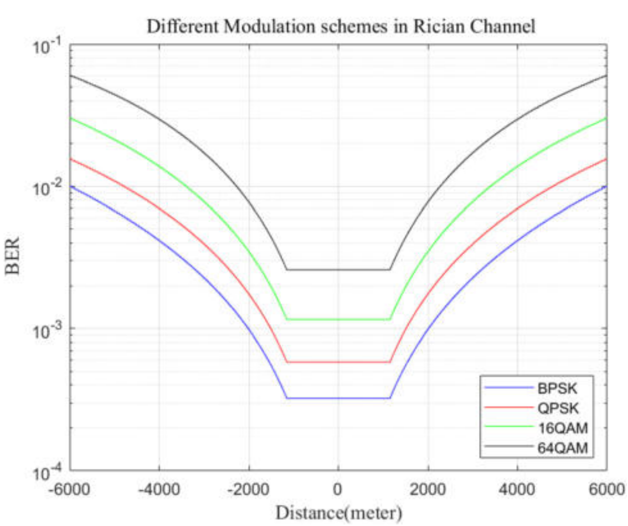

Figure 9: BER vs. distance of different modulation schemes in Rician channel.

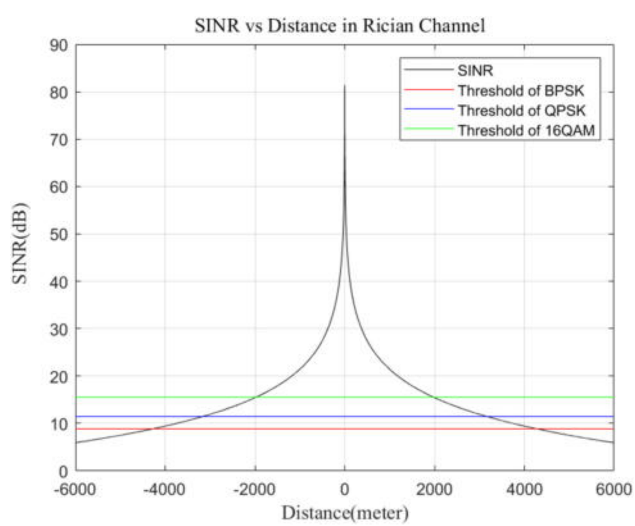

Figure 10: SINR vs. distance in Rician channel.

Table 5: BER vs. Distance and SINR of various modulation schemes in Rician channel.

Rician Channel					
Distance (m)	**SINR (dB)**	**BER**			
		BPSK	**QPSK**	**16-QAM**	**64-QAM**
6000	5.899	0.009971	0.01554	0.03007	0.05988
5000	7.482	0.006659	0.01079	0.02114	0.04396
4000	9.421	0.004159	0.006982	0.01379	0.02967
3000	11.92	0.002269	0.00393	0.007798	0.01718
2000	15.42	0.0009897	0.001756	0.003491	0.007787
1000	21.46	0.0003232	0.0005817	0.001157	0.002589
0	54.5	0.0003232	0.0005817	0.001157	0.002589

target BER value of 10^{-2}. This way enhances the performance of the Rician channel in terms of BER, decreasing interference from surrounding co-channel BSs, maximizing the throughput of the system, and reducing the fading effect of the Rician channel. The threshold lines of BPSK, QPSK, 16-QAM, and 64-QAM in Figure 10 show the switching threshold values of SINR and distance while Figure 11 shows the switching threshold values of a distance of BPSK, QPSK, 16-QAM, and 64-QAM to achieve target BER value of 10^{-2} in Rician channel.

Table 6 shows that the coverage area of 64-QAM and 16-QAM in a Rician channel is larger than in a Rayleigh channel and shorter than in an AWGN channel. Similarly, the coverage area of QPSK and BPSK in a Rician channel is shorter than in a Rayleigh channel and larger than in an AWGN channel. Figure 11 shows the coverage length of different modulation schemes in the Rician channel. Table 6 is the summarized form of all simulation results in AWGN, Rayleigh, and Rician channels. The BPSK, QPSK, 16-QAM, and 64-QAM vary according to the switching threshold values of distance and SINR given in Table 6 in AWGN, Rayleigh and Rician channels to achieve target BER. Table 6 explains the switching threshold values of different modulation schemes according to SINR and distance in Figures 4, 7, and 10 in AWGN, Rayleigh and Rician fading channels respectively. This also shows the explanation of the switching threshold values of different modulation schemes according to the distance in Figures 5, 8, and 11 in AWGN, Rayleigh and Rician fading channels respectively to achieve target BER. This shows that the performance of AWGN channel is better than Rayleigh and Rician channels with Rayleigh channel exhibiting poor performance than the Rician channel in terms of BER and SINR at the same distance values.

Figure 12 shows the radio coverage areas of BPSK, QPSK, 16-QAM, and 64-QAM modulation schemes in

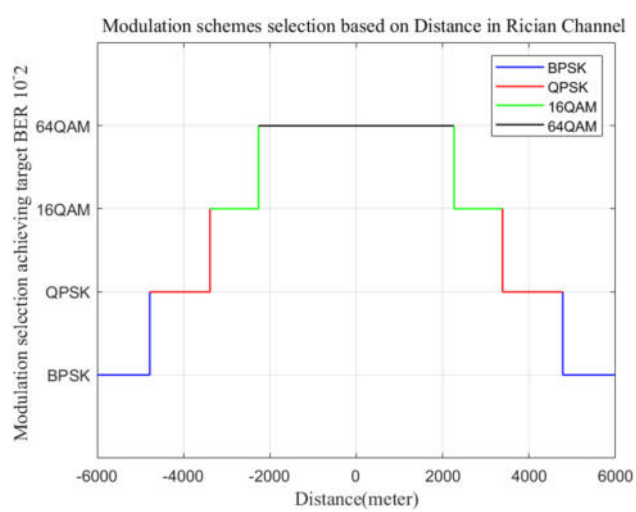

Figure 11: Illustration of distance-based selection of various modulation schemes in Rician channel.

Table 6: Illustration of switching threshold values of distance and SINR for various modulation schemes in AWGN, Rayleigh and Rician channels.

Distance (m)			**SINR (dB)**			**Modulation Schemes**	**Target BER**
AWGN	**Rayleigh**	**Rician**	**AWGN**	**Rayleigh**	**Rician**		
6000–5615	6000–4483	6000–4779	7.29–7.87	5.319–7.851	5.899–7.875	BPSK	10^{-2}
5615–4162	4483–3174	4779–3383	7.87–10.48	7.851–10.85	7.875–10.88	QPSK	
4162–2596	3174–2145	3383–2261	10.48–14.58	10.85–14.25	10.88–14.38	16-QAM	
2596–0	2145–0	2261–0	≥14.58	≥14.25	≥14.38	64-QAM	

AWGN, Rayleigh and Rician channels to achieve the target BER value of 10^{-2}. Figure 12 has been drawn based on the switching threshold values of a distance of various modulation schemes in AWGN, Rayleigh and Rician channels given in Table 6. The distance-based threshold values of various modulation schemes of AWGN, Rayleigh and Rician channels are shown in Figure 12 to illustrate the performance of different modulation schemes in the three aforesaid channels.

The same modulation schemes have different coverage areas in different channels and different modulation schemes have different coverage areas in the same or different channels. High order information rates such as 64-QAM and 16-QAM are more bandwidth efficient but degrade the performance of the system in terms of BER. Thus 16-QAM and 64-QAM require a high level of SINR because high order modulation schemes such as QAM is more exposed to noise, interference, non-linear distortion and multipath fading and high level of SINR is available at low transmission range, low fading, and favourable channel conditions. We employ low order information rates such as BPSK and QPSK at a low level of SINR because the performance of BPSK and QPSK is better than 64-QAM and 16-QAM causing low errors while low SINR level is available at high transmission range, high fading, and unfavourable channel conditions. Thus, using various modulation schemes for adaptive modulation is the optimum way of minimizing errors and maximizing the throughput of a system and hence achieving precise transmission of a signal to large radio coverage areas.

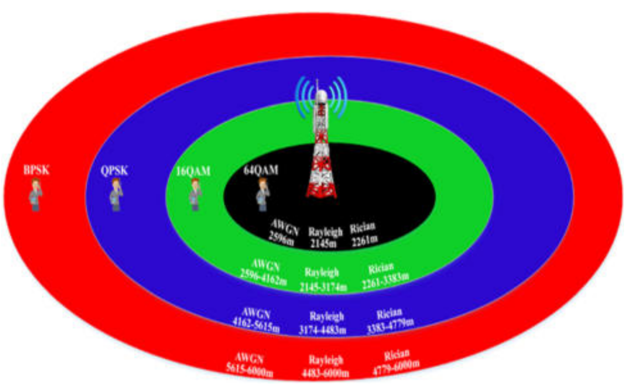

Figure 12: Illustration of distance-based selection of various modulation schemes in AWGN, Rayleigh and Rician channels.

The previous research works are studied and compared with our proposed technique based on several comparison criteria such as wireless channels, Distance, SINR, SNR, modulation types and outcome performance (BER). The following comparison Table 7 is added to compare our proposed work with previous published papers. As can be seen, the proposed work is better than the approaches proposed by other people.

4 Conclusions

In this study, the BER vs. SINR and distance and SINR vs. distance of BPSK, QPSK, 16-QAM and 64-QAM in AWGN, Rayleigh and Rician channels are discussed in detail. The simulation results show that our proposed solution for adaptive modulation gives better results in achieving target BER of 10^{-2} according to SINR and distance in AWGN, Rayleigh and Rician fading channels which reduces errors during signal transmission achieving high throughput as compared to fixed modulation schemes. A fixed modulation scheme is not suitable in these three whole wireless channels due to the high effects of noise, distortion, attenuation, and fading. The effect of co-channel interference from surrounding six BSs on a mobile user which is at 3 km distance with central BS is taken into consideration. The variation in the number of co-channel BSs, the distance between co-channel BSs and central BS, and the

Table 7: Comparison with the state-of-the-art.

Previous work	Technique	Modulation type	Channel	Distance	SINR	SNR	Outcomes in terms of considered performance criteria (BER)
[34]	Adaptive modulation	BPSK, QPSK, 16-QAM	Rayleigh	✗	✗	✓	10^{-2} dB
[35]	Adaptive Modulation	BPSK, QPSK, 16-QAM, 64-QAM	AWGN	✗	✗	✓	10^{-4} dB
[36]	Adaptive modulation	QPSK, 16-QAM, 64-QAM	AWGN, fading channel	✗	✗	✓	0.11239 dB
Proposed work	Adaptive modulation	BPSK, QPSK, 16-QAM, 64-QAM	AWGN, Rayleigh, Rician	✓	✓	✗	"AWGN = 0.00756–5.818 × 10^{-22} dB" "Rayleigh and Rician fading ≈ 10^{-3} dB" "10^{-6} to 5.818 × 10^{-22} dB in AWGN channel of proposed work as compared to [35] in same SNR range"

position of mobile user vary the co-channel interference, thereby varying the performance metrics such as BER, and SINR of a wireless communication system. The BER performance in the AWGN channel is better than in Rayleigh and Rician channels with Rayleigh channel exhibiting poor performance than the Rician channel. The BPSK has the lowest BER with low bandwidth-efficient while 64-QAM has the highest BER with more bandwidth-efficient due to simple and complex constellation diagram respectively in the three channels. The 64-QAM and 16-QAM have large while BPSK and QPSK have short coverage area in AWGN as compared with Rayleigh and Rician channels with Rician channel exhibiting 64-QAM and 16-QAM have large while QPSK and BPSK have short coverage area than Rayleigh channel. Thus, adaptive modulation selects high modulation schemes such as 64-QAM and 16-QAM at high SINR and short transmission range and low modulation schemes such as BPSK and QPSK at low SINR and high transmission range in the three proposed channels. The proposed adaptive modulation technique thus achieves the target BER value of 10–2, high throughput, minimize the fading effect of the channel, optimal utilization of the available bandwidth efficiently, reducing power consumption and achieving an enhanced radio coverage.

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