Journal of Engineering and Applied Sciences 3 (4): 337-343, 2008
ISSN: 1816-949X

Wireless Data Transmission Based on Adaptive Modulation and ARQ Control

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Abstract: Radio transmissions need to be intelligent and reconfigurable to control quality of service (QoS). QoS can be controlled using both adaptive modulations in conjunction with hybrid type of error control mechanism at the data link layer. In this study adaptive modulation is used as a powerful technique to improve the tradeoff between spectral efficiency and Bit Error Rate (BER). The adaptation also takes into account the requirements of different traffic services such as required BER and packet loss. The receiver estimates the received Signal to Noise ratio (SNR) and sends the feedback information via a feedback channel to the transmitter, which determines the suitable modulation constellation to be used over the channel. The proposed adaptive communication system uses a combination of Forward Error Correction (FEC) and Automatic Repeat Request (ARQ) in order to get efficient and reliable real time data communication over wireless channel.

Key words: Wireless data transmission, adaptive modulation, ARQ control, Qos

INTRODUCTION

Future wireless communications systems tend to become multi-mode, multi-functional devices. These systems have to adapt to changing environmental conditions as well as to changing user demands. When the system can adapt to the environment, significant savings in computational costs can be obtained (Smit *et al*., 2003). Wireless local area networks were become increasingly popular, hence the challenge for the third and fourth generation of mobile radio systems were to transmit large quantities of data and fast internet access. To satisfy the increasing demand on high data rates, extensive research work had been done to improve the spectral efficiency such that more bits can be transmitted within a given bandwidth. The research directions were in the field of adaptive error control, adaptive modulation, adaptive power control, or a combination of such schemes (Gavin, 2001; Ekman, 2002; Falahati *et al*., 2004; Liu *et al*., 2004). One of an effective technique to enhance the quality of data communications is to adapt the communication parameters according to the channel condition. Adaptation may be achieved using modulation parameters such as symbol rate, modulation level and/or coding rate at the time of transmission. Forword Error Correction (FEC) and Automatic Repeat Request (ARQ) are two basic categories of error control techniques. Most of the work in this area has been done using block codes with error detection only, due to the packetized nature of the messages and the relatively low coding overhead allowed in many systems (Zhang and Kassam, 1999).

PROPOSED SYSTEM ARCHITECTURE

Proposed system architecture is presented in Fig. 1. Convolutional coding is used as FEC codes. The encoded data are punctured to generate high code rates from a mother code of rate ½. Each packet is transmitted using one of the modulation techniques with appropriate constellation size and fixed power. Upon decoding the packet, the receiver sends an acknowledgement back to the transmitter over an error free feedback channel.

Demodulation and regeneration are probably the most important elements in the digital receiver. Hence coherent demodulation is used in order to achieve an undistorted bit stream. The regenerated data are then fed through a baseband equalizer to reduce signal distortion. Perfect clock and carrier recovery is assumed.

Encoder/decoder: Channel coding is used in order to combat errors in the wireless communication system. The increased robustness is paid for a reduction in the net bit rate, this is because the code rate R_c

$$R_c = \frac{R_b}{R_e} \tag{1}$$

where, R_b is the original bit rate and R_e is the bit rate after the encoder.

An (n, k, m) convolutional code generates (n) encoded bits for every (k) information bits, where (m) refers to the memory of the encoder (Lin and Castello, 1983; Roman, 1997). The (n) encoder outputs at any given

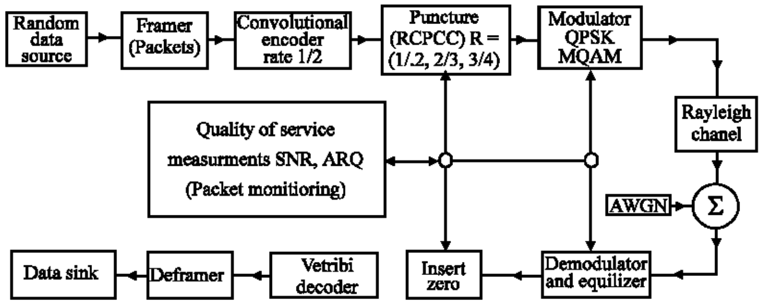

Fig. 1: Proposed system block diagram

time instant depend not only on the (k) inputs but also on (m) previous input blocks. The input data bits are convolved with the generator polynomial

$$G^j(D) = g_0^j + g_1^j D + g_{k-1}^j D^{k-1} \quad (2)$$

Where,

$$g_j \in (0, 1) \quad \text{and} \quad j = 1, 2, \ldots, n$$

Polynomials chosen depending on the code rate, the used feedback polynomial is:

$$G_1 = D^6 + D^5 + D^4 + D^3 + 1 \quad (3)$$

$$G_2 = D^6 + D^4 + D^3 + D + 1 \quad (4)$$

Octal (171 133) and constraint length of 7 is used to generate a rate ½ binary convolutional coded data.

Adaptive modulation: Several modulation types are involved in this investigation such as QPSK, 16QAM, 64QAM and 256QAM. The symbol error rate SER and hence BER for different modulation types are as follows (John, 2001; Wireless, 1997):

$$P_{sMPSK}(SNR) = 2Q\sqrt{2SNR}\,\sin(\pi/M) \quad (5)$$

where, Q(x) is the Q-function and SNR = E_s/N_0, the equivalent BER for QPSK is:

$$P_{bQPSK}(SNR) = Q(\sqrt{SNR}) \quad (6)$$

The SER for MQAM is given by:

$$P_{sMQAM}(SNR) = 2(1 - 1/\sqrt{M})\, Q(\sqrt{3SNR/(M-1)} \quad (7)$$

And the BER is

$$P_{bMQAM}(SNR) = P_{sMQAM}(SNR)/\log_2(\sqrt{M}) \quad (8)$$

The Probability Density Function (PDF) of the fluctuations in instantaneous received power x, in a Rayliegh channel are given by

$$F(x, X) = \frac{2\sqrt{x}}{X}\exp(-x/X) \quad (9)$$

where, X is average signal power. For any modulation scheme if P_G (SNR) is the Gaussian BER performance as shown in Eq. 5 through Eq. 8 then the upper bound for the BER performance in a Rayliegh channel is (Torrance and Hanzo, 1996):

$$P_r(SNR) = \int_0^\infty P_G(SNR).F(x,X)dx \quad (10)$$

Therefore the upper bound BER performance of an adaptive modulated signal may be computed from:

$$P_a(SNR) = \frac{1}{T}\Big\{2\int_{\ell_1}^{\ell_2} P_{QPSK}(SNR).F(x,X)dx + 4\int_{\ell_2}^{\ell_3} P_{16QAM}(SNR).F(x,X)dx + 6\int_{\ell_3}^{\ell_4} P_{64QAM}(SNR).F(x,X)dx + 8\int_{\ell_4}^{\infty} P_{256QAM}(SNR).F(x,X)dx\Big\} \quad (11)$$

where, l_1, l_2, l_3, l_4 are the thresholds between transmission of QPSK, 16QAM, 64QAM and 256QAM. T is the throughput of the adaptive modulation system and can be expressed as:

$$T = 2P_{rQPSK}(SNR) + 4P_{r16QAM}(SNR) + 6P_{r64QAM}(SNR) + 8P_{r156QAM}(SNR) \quad (12)$$

where, $P_{r,QPSK}$, $P_{r,16QAM}$, $P_{r,64QAM}$,$P_{r,256QAM}$ stands for the probabilities of the 4 modulation modes. The BER performance of Eq. 11 is simulated with switching levels ℓ_1 = 11.6dB, = 18 dB, ℓ_3 = 24dB and ℓ_4 = 30dB is shown in Fig. 2, note that all simulations taken for target BER = 10^{-4}.

Error control schemes: The end-to-end connection between the adjacent nodes in a network is handled by the link layer while the end to end transmission control is handled by the TCP. Therefore if the link layer is equipped with its own ARQ system through feedback of acknowledgement (ACK) or negative acknowledgment (NACK), then instead of rejecting an erroneous frame it would send back a NACK requesting re-transmission of the same data (Behrouz, 2003). ARQ strategy offers the best throughput when the channel is in a good state and when the channel is noisy, FEC offers the highest throughput. In order to overcome their individual drawbacks, the combination of these two basic classes of error control schemes called Hybrid ARQ scheme, which have been developed (Ekman, 2002). Two basic types of hybrid ARQ error control strategies have been considered. The type-I strategy, includes parity bits for both error detection and error correction in each transmitted packet. In type-II strategy (Lugand *et al*., 1989), the data packet is coded in 2 parts; bits for error detection only are appended to the data packet and send to the first transmission. If retransmission is requested, invertible parity bits on the original information packet are sent along with the same error detection bits. If there is no errors are detected on the second transmission, the original information are recovered by inverting the parity bits. If error are detected, then the two received packet are treated together at a rate of 1/2 code. This process is continues until either a free packet of error is received or error correction is possible.

The reason for using Hybrid type II ARQ system which provides incremental redundancy is to be used as a fall back, in the case that the SNR estimation fails. QoS which can be defined as a combination of throughput, reduced error rate, decreased delay and number of retransmissions will be used to specify the modulation constellation format depending on the type of the required services.

Adaptation range boundaries: Figure 3 shows the performance of QPSK, 16QAM, 64QAM, 256QAM over AWGN channel respectively. The aiming BER is chosen depending on the type of services required for different

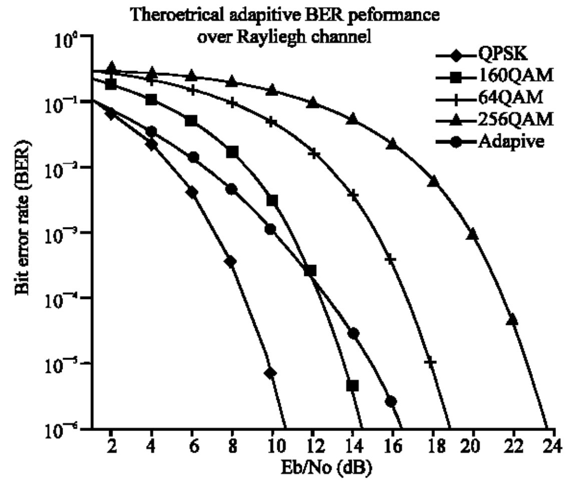

Fig. 2: Adaptive BER performance

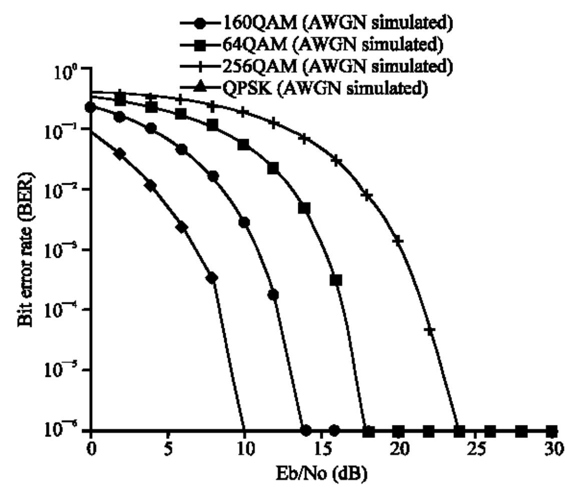

Fig. 3: BER performance over AWGN channel

Table 1: Qos requirements

Class	Qos
Data	BER = 10^{-5}
	ARQ retransmissions = 8
Voice	BER = 10^{-3}
	ARQ retransmissions = 3
Media	BER = 10^{-4}
	ARQ retransmissions = 3

types of applications. Table 1 shows 3 categories of parameter for the QoS requirements (target error rate and ARQ retransmission).

Proper selection of modulation switching levels is important to the performance of the adaptive modulation system. In order to adapt the modulation according to the channel variation the switching levels SNR_1 through SNR_4 should be set as shown in Table 2 which satisfy the requirement of maintaining target BER.

Table 2: Transmission mode

Model	Model 1	Model 2	Model 3	Model 4
Modulation	QPSK	16QAM	64QAM	256QAM
Coding raet	1/2, 2/3, 3/4	1/2, 2/3, 3/4	1/2, 2/3, 3/4	1/2, 2/3, 3/4
Received SNR	11.6≤SNR<18	18≤SNR<24	24≤SNR<30	30≤SNR
Bandwigth efficiency	1, 1.3, 1.5	2, 2.6, 3	3, 4, 4.5	4, 5.3, 6
Packet length	50 byte, 100 byte	50 byte, 100 byte	50 byte, 100 byte	50 byte, 100 byte

For target BER = 10^{-4} the switching levels can be calculated from the lowers function of BER expression or through the simulation with Additive Gaussian Noise.

Multiple transmission modes at the physical layer of the communication link are assumed to be available. Each mode is represented as pair of a specific modulation format in conjunction with a forward error correction code. When coding is used the bandwidth efficiency is reduced becouse of the redunduncy affect. Depending on the code rate, the net B.W. efficiency for each modulation is calculated as follows:

$$\text{BWefficiency (with coding)} = \text{BWefficiency (without coding)} \times \text{code rate}$$

Where the Bandwidth efficiency without coding are 2, 4, 6, 8 for QPSK, 16QAM, 64QAM, 256QAM, respectively. And code rate 1/2, 2/3, 3/4 are punctured code rates which is derived from convolutional code with mother rate 1/2 as shown in Table 2.

COMPUTER SIMULATION AND SYSTEM PERFORMANCE EVALUATION

The initial mode for first time transmission attempt was selected according to the throughput maximization for the current SNR. The motivation for such selection is that it enables the usage of rate compatibility criterion. Furthermore the packet error rate did not depend only on the SNR but depends on the channel state, then if the packet error rate performance of the current channel was better than average, then the selection of transmission rate is (¾) leading to throughput gain. On the other hand, if the channel packet error rate performance was worse than average then a gain can also expect. This was due to the hybrid type II ARQ system retransmits the erroneous packet with different mode at each attempt so a low packet error rate would be quickly achieved.

Different spectral efficient modulation types (QPSK, 16QAM, 64QAM, 256QAM) in conjunction with punctured convolutional encoder which allows the use of the same decoder for different coding rates were simulated. The performance of the different types of modulation was determined by means of calculation of the BER for different channel parameters such as signal to noise ratio.

A constant transmitted power was assumed and the channel quality was determined by means of the received SNR. The received SNR was assumed constant over the packet. The received packets were declared loss after error detection.

The number of transmitted symbols over the channel was greater than 10^6 symbols. In addition to the above simulations the BER performance of different modulation schemes transmitted over Rayliegh fading channel with different channel parameters was simulated.

Figure 4 represent the BER performance of QPSK modulated signal simulated over AWGN channel with different coding rates (R = 1/2, 2/3, 3/4) using Rate Compatible Punctured Convolutional Coding (RCPCC).

The simulation was carried on in the same manner to simulate the performance of QAM modulation with constellation size and different coding rates. Figure 5-7 shows the performance of 16QAM, 64QAM, 256QAM with different coding rates. It is clearly shows that a coding gain of approximately 1.2 dB for the coding rate of ¾ and a 3dB gain when coding rate ½ is used.

The using of RCPCC Rate Compatible Punctured Convolutional code rate changing from a mother code rate ½ allows the use of the same decoder at the receiver side.

Figure 8 shows the performance of different adopted modulation schemes over Rayliegh fgading channel with Doppler frequency of (f_d = 0 Hz) while Fig. 9 showes the same modulation techniques simulated over the same Rayliegh fading channel with Doppler Frequency (f_d = 20 Hz).

A 2-path Rayliegh fading channel was used to simulate the different modulation techniques as shown in Fig. 10. it is clearly shown from the above three figures that the BER performance of QAM modulation was affected more than QPSK modulation also the higher the constellation size 256QAM is the more sensitive to the channel degradation that was because the QAM uses the amplitude to modulate the signal, while the QPSK uses the phase to modulate the signal. In order to keep the BER below a certain threshold for different channel parameters, one must change modulation type or constellation size accordingly. This is because a different channel parameters are affecting the BER performance of specific modulation technique.

The BER performance of adaptive modulation was simulated over Rayliegh fading channel with different

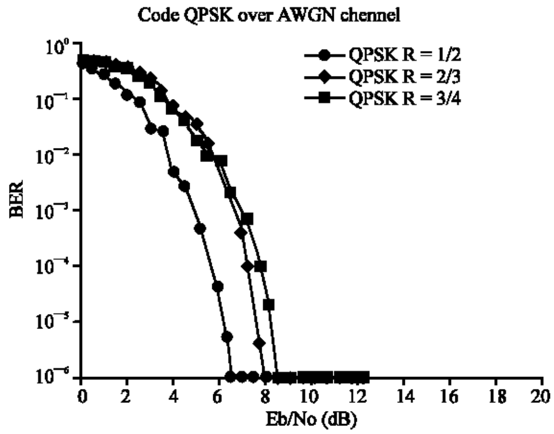

Fig. 4: BER performance of puncture coded QPSK

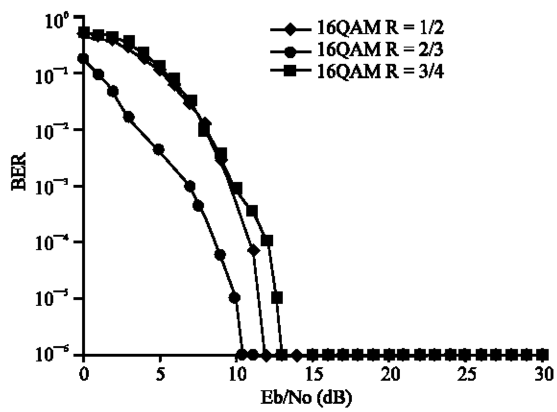

Fig. 5: BER performance of puncture coded 16QAM

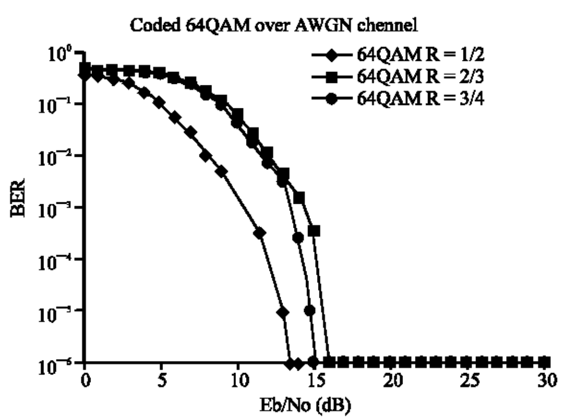

Fig. 6: BER performance of puncture coded 64QAM

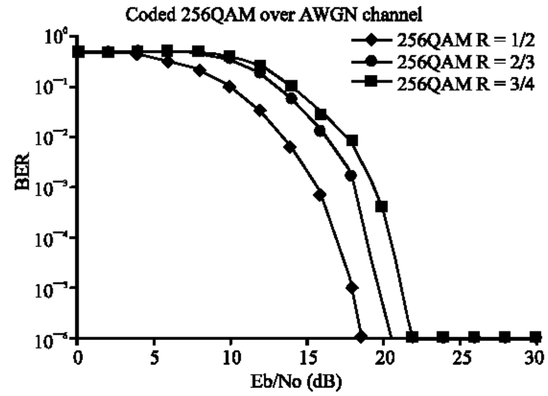

Fig. 7: BER performance of puncture coded 256QAM

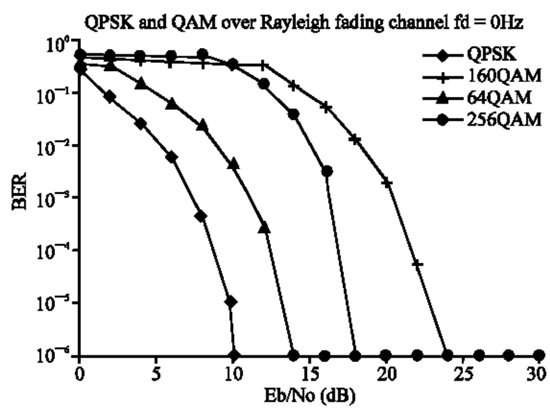

Fig. 8: Performance of modulation over Rayliegh channel fd = 0

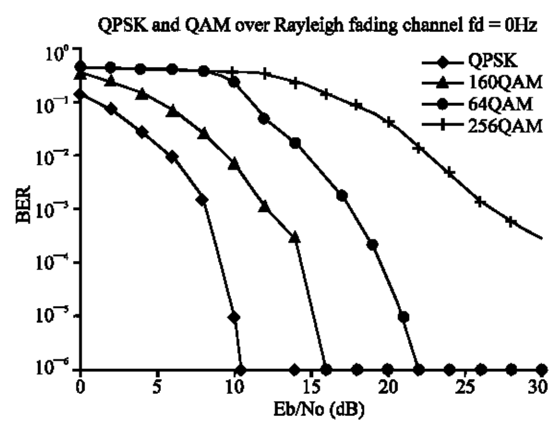

Fig. 9: Performance of modulation over Rayliegh channel fd = 20

Doppler frequency shifts. Figure 11 shows the performance when f_d = 5 Hz and Fig. 12 shows the performance when f_d = 20 Hz. The performance curve shows that a higher SNR is required for the different modulation techniques of adaptive system is optimized in order to get higher system throughput while keeping the BER below a certain threshold.

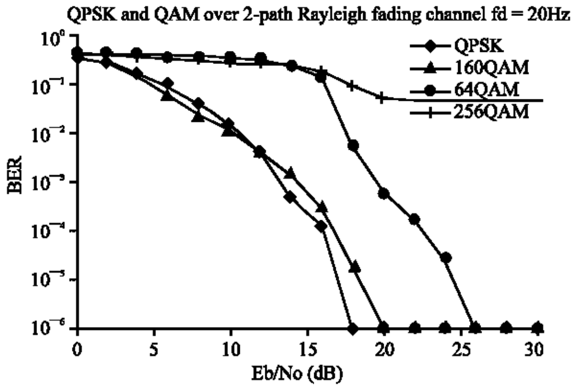

Fig. 10: Performance of modulation over 2-path Rayliegh channel fd = 20

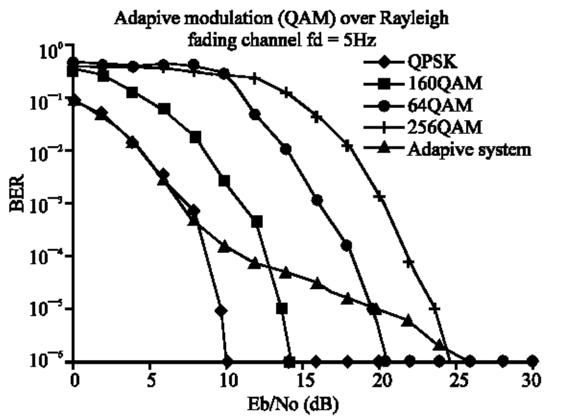

Fig. 11: Performance of adaptive modulation over Rayliegh channel fd = 5Hz

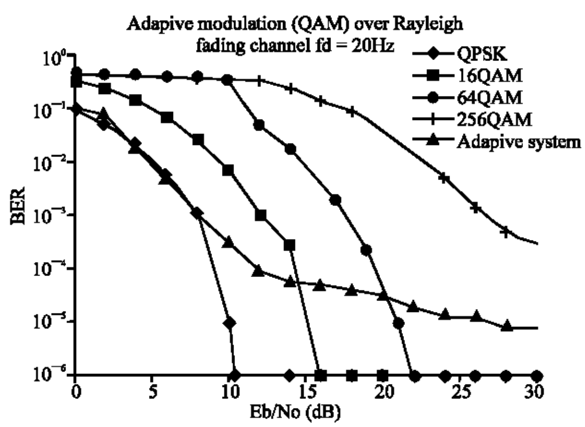

Fig. 12: Performance of adaptive modulation over Rayliegh channel fd = 20Hz

The length of the packet was adapted according to the channel state in order to maximize the user data

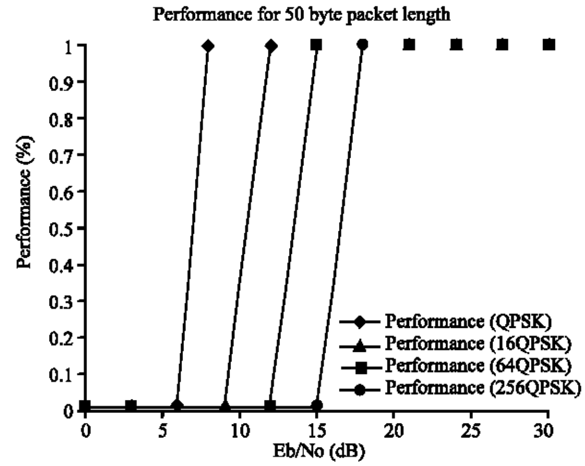

Fig. 13: Packet loss performance (50 byte length)

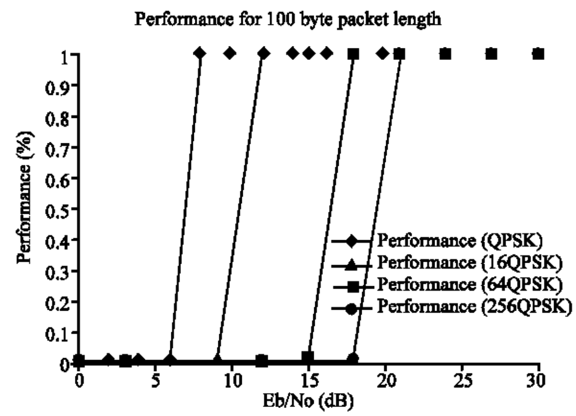

Fig. 14: Packet loss performance (100 byte length)

throughput. The payload throughput is depending upon the packet overhead ratio. The simulation was done using different modulation techniques with different packet lengths over AWGN channel, the received packet was declared lost if it was erroneously received through CRC check. Figure 13 and 14 show the packet loss performance with different packet length.

CONCLUSION

The selection of different modulation schemes based on the channel SNR estimation for a pre-defined BER of 10^{-4} made the possibility of maintaining error free transmission with the highest possible data rate. The system considered is designed to select an appropriate coding and modulation technique mode. The channel SNR and target BER were translated to an allowed transmission mode. When the channel SNR estimation failed, the proposed pointer of the number of attempts the link layer should try to transmit the data to obtain an error free reception. It is worthy to note that completely error free reception may require an unlimited number of retransmission; hence the retransmission is limited depending on the type of application. The BER performance of the adaptive modulation scheme was better than that for fixed modulation scheme, by maintaining bandwidth efficiency of 6 bits/symbol when coded 256QAM modulation is adopted, hence increased data rate achieved over fading channel. The Rate Compatible Puncture Convolutional Codes derived from a mother code rate ½ , suggested the use of different code rates with the same physically realizable encoder decoder pair. The use of different packet length in conjunction with different modulation and coding schemes gave a third dimension for adaptivity. When using ARQ over a link where the probability of packet losses was related to the packet size there should be an optimal frame size for any specific target BER.

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