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Adaptive Techniques with Cross-Layer Design for Multimedia Transmission

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Adaptive Techniques with Cross-Layer Design for Multimedia Transmission

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As the candidate's supervisor I have approved this dissertation for submission.

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Date: 14 January 2013

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To my girlfriend, Tarryn, thank you for all your support and love you have shown me, you have been so understanding and always encouraging me. I only hope I can be as supportive and encourage you with your career. Love you always.

To all my friends, thank you for making the years that we have spent together incredible. I hope that our friendships will strengthen and continue for many years to come.

Abstract

Wireless communication is a rapidly growing field with many of its aspects undergoing constant enhancement. The use of cross-layer design (CLD) in current technologies has improved system performance in terms of Quality-of-Services (QoS) guarantees. While multimedia transmission is difficult to achieve, CLD is capable of incorporating techniques to achieve multimedia transmission without high complexity. Many systems have incorporated some form of adaptive transmission when using a cross-layer design approach.

Various challenges must be overcome when transmitting multimedia traffic; the main challenge being that each traffic type, namely voice; image; and data, have their own transmission QoS; delay; Symbol Error Rate (SER); throughput; and jitter requirements. Recently cross-layer design has been proposed to exchange information between different layers to optimize the overall system performance. Current literature has shown that the application layer and physical layer can be used to adequately transmit multimedia over fading channels. Using Reed-Solomon coding at the application layer and Rate Adaption at the physical layer allows each media type to achieve its QoS requirement whilst being able to transmit the different media within a single packet.

The following dissertation therefore strives to improve traffic through-put by introducing an unconventional rate adaption scheme and by using power adaption to achieve Symbol Error Rate (SER) QoS in multimedia transmission.

Firstly, we introduce a system which modulates two separate sets of information with different modulation schemes. These two information sets are then concatenated and transmitted across the fading channel. The receiver uses a technique called Blind Detection to detect the modulation schemes used and then demodulates the information sets accordingly. The system uses an application layer that encodes each media type such that their QoS, in terms of SER, is achieved. Simulated results show an increase in spectral efficiency and the system achieves the required Symbol Error Rate constraint at lower Signal to Noise Ratio (SNR) values.

The second approach involves adapting the input power to the system rather than adapting the modulation scheme. The two power adaptive schemes that are discussed are Water-Filling and Channel Inversion. Channel Inversion allows the SER requirement to be maintained for low SNR values, which is not possible with Rate Adaption. Furthermore, the

system uses an application layer to encode each media type such that their QoS is achieved. Simulated results using this design show an improvement in through-put and the system achieves the SER constraint at lower SNR values.

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List of Acronyms

3G	Third Generation
AMC	Adaptive modulation and coding
AWGN	Additive White Gaussian Noise
BER	Bit error rate
BPSK	Binary phase shift key
CLD	Cross-layer design
CSI	Channel state information
EDGE	Enhanced data for global evolution
FIFO	First-in-first-out
FSMC	Finite state Markov chain
FTP	File transfer protocol
GPRS	General packet radio service
GSM	Global system for mobile
IEEE	Institute of Electrical and Electronics Engineers
ISO	International organization for standards

LAN	Local area network
MAC	Medium access control
PAM	Pulse amplitude modulation
QAM	Quadrature amplitude modulation
QoS	Quality of service
SER	Symbol error rate
SNR	Signal-to-noise ratio
RS	Reed-Solomon

Chapter 1

Introduction

In the last decade wireless communications has evolved to provide resourceful communication, mobile networks shifted from GPRS to EDGE to 3G and more recently, 4G has become available. In wireless networks there are constant amendments being made to the IEEE standards, for example, IEEE 802.16, IEEE 802.11 and IEEE 802.15. These rapid changes stem from the constant increase in the amount of data that is required from the user. Essentially, the system cannot satisfy the demands since the resources are scarce and unreliable channels decrease performance. The transmission of multimedia requires diverse Quality of Service (QoS) and most systems tend to satisfy at least one of these requirements. The use of cross-layer design has opened up various opportunities for systems to achieve QoS requirements whilst simultaneously increasing performance in areas where it was previously impossible. However, these new technologies need constant revision and improvement to ensure that users experience quality services that are robust, adaptable and reliable.

Cross-layer design (CLD) has recently sparked a great deal of interest, particularly using the physical, data-link and application layers of the ISO protocol stack. As a result, various studies on its application have been conducted and several design approaches have emerged from this research. The classifications of these designs are discussed in [9] and [10]. They include:

- **Top-down approach** – In these designs, the higher layer protocols optimize its parameters and consequently, the strategies at the layer below it. For example, this occurs where the application layer informs the MAC parameters and strategies and thereafter the MAC determines the parameters and strategies of the layers below it.
- **Bottom-up approach** – In these designs, the lower layers attempt to protect the higher layers from losses and channel variations. This solution is not always optimal since the resulting delays and throughput variations impact the performance of multimedia transmission.
- **Application-centric approach** – This approach makes use of the application layer to optimize each lower layer parameter consecutively, in either a top-down or

bottom up manner, based on the application requirements. This solution is not always efficient as the application layer operates at slower timescales and coarser data granularities than the lower layers and is not able to instantaneously adapt its performance.

- **MAC-centric approach** – In this design, the higher layers send the traffic information and requirements to the MAC layer, which determine the parameters of the lower layers based on the available channel information.
- **Integrated approach** – The strategies of the various OSI layers are determined jointly in this design. However, trying all possible strategies and parameters in the interacting layers in order to choose a composite strategy is impractical due to the complexities in cross-layer optimizations.

The above cross-layer design approaches each have their own advantages and disadvantages for wireless multimedia transmission. The optimal solution depends on the complexity; power requirements; and the application of the multimedia transmission system. The authors in [9] discuss optimizing the parameters that affect only the layer in which they appear and the optimization of parameters that affect two or more layers. Signaling amongst the various layers is crucial for CLD to be improved. Some of the signaling approaches presented in [9] mention some service that collects the parameters from each layer and makes them available to the other layers in order to perform CLD. Another approach uses packet headers as a form of in-band signaling over the network; where another uses extra packets as out-band signaling over the network. The ultimate purpose of CLD is improving QoS, and the next section discusses some designs where QoS provisioning is performed within the protocol layers.

1.1 Cross-Layer Designs and QoS Requirements for Multimedia Transmission

The cross-layer design models discussed here use various combinations of the application, network, data-link and physical layers. Although research has been done on each of these layers independently, it is necessary for more attention to be given to the coordination of the layers in terms of optimizing specific QoS requirements. Cross-layer designs, in general, define an achievable target requirement that must be met before optimizing other QoS parameters. In this section, a cross-layer design approach focuses on use of the physical layer and its integration with the other protocol layers, this is followed by a discussion on multiple systems that consider multimedia transmission using cross-layer design.

The system model considered in [1] takes into account the data arrival statistics and buffer conditions from the higher protocol layers when making decisions in the physical layer. The model is a single-user system with a limited buffer size and a varying data arrival rate. All packets have the same size and if a packet arrives when the buffer is full, it is dropped and considered lost. Communication is done over a discrete-time block-fading channel with Additive White Gaussian Noise (AWGN) and the fading process is represented by a finite state Markov chain (FSMC). The optimal strategies proposed improve some QoS whilst relaxing others. In this model, throughput, which is dependent on an average transmit power constraint, is maximized whilst the Bit Error Rate is relaxed. The disadvantage of this system is that it only takes into account one type of general traffic class.

The following systems all consider multimedia transmission however each vary in their approach and consider different QoS requirements. The cross-layer scheduler design proposed in [6] and [7], considers a system where the scheduler depends on both the queue state at the data link layer and the channel state at the physical layer when reserving bandwidth to users. In this system, multiple users are connected to the gateway over wireless channels where the gateway is the transmitter and the user is the receiver, in this system the focus is placed on the downlink operation. The gateway implements a finite-length buffer for each user and each buffer operates in a first-in-first-out (FIFO) mode. If a packet arrives when the buffer is full, the packet is then considered lost. Communication is carried out over a frequency flat fading channel which is modeled as an FSMC and it only varies from frame to frame. The authors propose a multi-user scheduler at the medium access control (MAC) sub layer of the data link layer adopting an adaptive modulation and coding (AMC) at the physical layer. A cross-layer scheduler design is developed which accounts for channel variations and status of users' queues, and includes admission control and scheduling policies with different QoS requirements. In this system, the multimedia applications are classified into two categories: QoS-guaranteed traffic (which includes voice, video/audio streaming and conferencing), and Best-Effort traffic which includes applications such as web-browsing, email and file transfer protocol (FTP). The scheduler's aim is to guarantee QoS per user and utilize bandwidth efficiently. This is done by classifying the users by the type of multimedia application they are using. The difference between the users is that the users that are QoS-guaranteed reserve a certain amount of bandwidth while the best-effort users do not. The advantage of this system is that the scheduler is compatible with separate layer designs since the scheduler can be implemented by simply adding the corresponding functions for cross-layer information exchange. The disadvantage of this model is that it groups voice and video under the same category when they do not always have the same QoS requirements.

The work in [11] considers a system which separates information into two categories: real time traffic and non-real time traffic. The application layer classes this traffic into high priority and low priority respectively, with strict priority levels. By solving the steady state probabilities of a discrete Markov modulated Poisson process, it enables the investigation of some QoS performance metrics. These QoS metrics include: packet error rate due to transmission errors; packet drop rate due to buffer flow; and network impairments. The physical layer implements AMC to handle the time -varying nature of fading channels and considers the data link layer’s queuing effects. The disadvantage of this system is that it concentrates on delay as the main constraint while the error rate is not optimized.

The system model proposed by [3] has multiple users each connected to a central unit. The assumption is made that the uplink would be similar to the downlink and thus only the downlink is considered. Communication is made over a block fading model where the channel between users is frequency flat and invariant during each frame transmission. Channel state information (CSI) is available at the receiver and channel feedback is assumed to be error free and instantaneous. In the system model, an AMC module follows and precedes the buffer at the transmitter and the receiver respectively. The AMC module provides some error protection in the system. An interesting CLD implementation is presented here whereby a physical layer and application layer adaptation mechanism are used to overcome previous limitations. One such limitation is the inability to insert more than one class of traffic in the physical layer frame. The objective of this mechanism is to enable transmission of multimedia within a single frame and while still achieving specific QoS requirements. This is done at the application layer since it controls what information gets placed into the packet. Using feedback information on the channel gain, certain parameters are adjusted to improve overall system performance. Spectral efficiency is improved with the assistance of rate adaption in the physical layer. However, the disadvantages of this system are that QoS requirements can only be met when the channel conditions are favorable; and only an Additive White Gaussian Noise faded channel is considered.

1.2 Motivation

Multimedia transmission requires cross-layer design frameworks to focus on optimizing services within the protocol layers. The above-mentioned designs apply several different adaptive techniques in order for CLD to be achieved. These adaptive techniques provide significant improvement on the QoS performance and therefore motivate systems that aim to enhance the service process. In [3] a variant of Rate Adaption is used in the physical layer with the aim of maximizing the spectral efficiency whilst maintaining a target BER. In the application layer [3] applies a coding technique, with parameters for each media type, which enables the system to transmit multimedia on the identical channel. To the best of the author's knowledge, there have been no publications to date reporting the extension of this proposed scheme by incorporating power adaption in the physical layer. The first contribution of this dissertation is to adapt the Rate Adaption used in [3] for a Rayleigh fading channel and improve the overall spectral efficiency using a partial packet technique. However, in this dissertation the error rate constraints are measured in symbols and thus the system will be subject to SER.

The Power Adaption techniques discussed in [4] maximize spectral efficiency while satisfying the target SER constraint. Integrating these techniques to the system used in [3] allow for the system to achieve greater spectral efficiency at highly faded areas. The second contribution of this dissertation is to integrate Rate Adaption, Power Adaption and an application layer coding to allow the system to transmit multimedia traffic. The QoS metric of interest in this dissertation is SER, given that this is the only QoS that has no delay restrictions when transmitting multimedia. To contextualize the improvement of each adaption technique, a comparison is made without the adaption. Comparisons are also made of the integrated system with the individual adaption schemes.

1.3 Outline of dissertation

The remainder of this dissertation is organized as follows:

Chapter 2 introduces the cross-layer design system model, which exploits the relationship between the physical and application layer. This is followed by a detailed description of the system's adaption methods within the physical layer (namely, power and rate adaption); and a description of application layer coding. A Rayleigh fading channel approximation is then derived which will be used throughout this dissertation.

Chapter 3 discusses the conventional method in which rate adaption is used. Calculations are performed on the channel approximation using numerical analysis and simulated results are used to validate this approach. The method used in [21], which aims to improve throughput of the system whilst maintaining QoS constraints, is discussed. Thereafter a new method is proposed which aims to achieve a similar performance to [21] with less complexity. The chapter is then concluded with simulation results and a discussion.

Chapter 4 begins with discussing two techniques of adapting power; the Channel inversion technique; and the Water-Filling technique. Each technique is discussed thoroughly and simulated results are presented with comparisons in error rate performance as well as in transmit power.

Chapter 5 introduces the cross-layer design approach in which an application layer coding and its integration with the previous chapters' adaption techniques are discussed. Each technique is discussed and implemented individually and performance results are presented. First Power Adaption is added to each of the two techniques discussed; and then Rate Adaption is added. The chapter is then concluded with a discussion of multimedia transmission and the implementation of these adaption techniques.

Chapter 6 concludes this dissertation and discusses possible future work on this topic.

Chapter 2

Background

2.1 Introduction

This chapter will be used to introduce the system model which implements cross-layer design, and provide a detailed discussion of the integrated layers and their role in providing QoS.

This chapter is outlined as follows: in Section 2.2 the system model is presented showing a cross-layer design where different layers in the OSI Protocol stack are used. Section 2.3 and 2.4 discuss the identification and implementation of cross-layer design. Section 2.3 elaborates on the physical layer, while Section 2.4 discusses the application layer. In Section 2.5 a Rayleigh fading channel approximation is derived that will used throughout the rest of this dissertation.

2.2 System Model

The system model that will be used throughout this dissertation is shown in Figure 2-1.

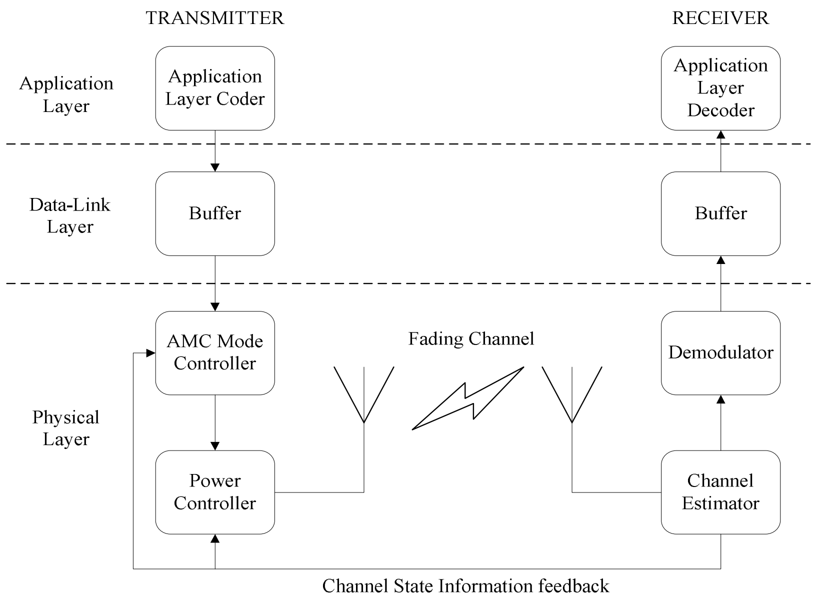

Figure 2-1 Block diagram of the system model used

The system modeled illustrates nodes in a wireless LAN, the central command station can be represented as the transmitter and the mobile node as the receiver. In this downlink transfer operation error correction coding is performed on the application layer data. These coded blocks are sent to the data link layer at a constant arrival rate where they are divided into packets. The packets are then stored in the infinite, transmitter buffer. There after the frames are converted into bits which are streamed into the physical layer. In the physical layer the adaptive modulation module is used to choose the optimal transmission mode and the power controller chooses a transmit power level to help improve the Symbol Error Rate performance and to reduce power consumption.

At the receiver side the reverse operation occurs. Information received is demodulated at the physical, and is fed to the data link layer and then sent to the application layer to be decoded. In addition, at the receiver side, the channel estimator is used to estimate the channel and feedback the estimated CSI to the transmitter for adaptive modulation. Using the CSI, the adaptive modulation module adjusts its parameters appropriately to determine the best transmission mode. The CSI is also sent to the power controller where it adjusts the power level according to the implemented power adaptive policy.

The rest of this chapter discusses the physical layer and the application layer in terms of their responsibilities and adaptive methods used for improvement. A Rayleigh fading channel approximation is then derived which will be used throughout this dissertation.

2.3 Physical Layer

The physical layer is responsible for low level transmission of data between nodes. This layer allows for optimization in amplifier efficiency, packet size, rate control and energy per bit (power control) of the system [8]. This section describes Adaptive modulation and Power adaptive policies.

2.3.1 Adaptive Modulation

Understanding adaptive modulation requires the knowledge of data modulation and how the adaption occurs. A modulation scheme modulates information bits into a single symbol. Depending on the modulation scheme the number of information bits per symbol varies.

Adapting the data rate of the system can be done using two possible methods. The first method is to adapt the number of symbols per frame, this is very difficult practically because varying the signal bandwidth is impractical [8], [4]. The second method is to keep the symbol rate constant but vary the modulation scheme which is used in current systems today such as EDGE (Enhanced data for global evolution) and GPRS (General packet radio service) which are used in cellular systems. The main types of modulation schemes are BPSK (Binary Phase Shift Key), PAM (Pulse Amplitude Modulation), QAM (Quadtrature Amplitude Modulation) which comprises of 4-QAM, 8-QAM, 16-QAM, 32-QAM and 64-QAM and can be extended further and is usually denoted M-QAM. Each of these modulation schemes has a different spectral efficiency which is defined as the number of information bits per symbol.

One of the performance metrics when discussing a modulation scheme is its Bit Error Rate (BER) in terms of Signal-to-Noise Ratio (SNR). A high SNR value provides a low BER value. Using channel feedback an estimation of the channel gain is found. This estimation is used to determine which modulation scheme should be used. There are many considerations when choosing a modulation scheme, according to [8] these are:

- High spectral efficiency
- High data rate
- High power efficiency
- Robustness to channel impairments
- Low cost

While these are conflicting requirements the trade off for adaptive modulation technique used in [3] is spectral efficiency vs. bit error rate (robustness to channel impairments).

2.3.2 Power Adaptive Modulation

Adaption in terms of power can effectively take advantage of favorable channel conditions [4]. The selection of the transmit power level of the system is vital as the rest of the system adapts according to the channel conditions and the transmit power level. Usually the transmit power is selected according to some policy and the channel conditions but the main objective is to obtain a constant received SNR or to improve certain QoS constraints such as BER.

The work proposed by [1] adapts the transmit power and rate so that the system throughput is maximized; subject to an average transmit power constraint. They propose a transmission policy which selects the power and rate subject to a fixed BER requirement. They compare this policy to one where the transmission rate is kept constant where it calculates the necessary power to achieve the required BER given the channel gain. A comparison is also made with a policy that maximizes the transmission rate under a certain power constraint.

They make an interesting observation that at a high range of SNR, if power is only adapted to the channel, the performance is worse than not doing any rate adaption at all.

The work in [2] adapts both power and rate, aiming to maximize throughput subject to a given delay QoS constraint. Similar to [4] and [5] they discuss three adaptive power policies, the first being the optimal power policy (Water-Filling scheme) which assigns more power when the channel is in a good condition and less power when the channel is in a worse condition. In this case, as soon as the channel is below a certain threshold no information is transmitted. The second policy is the total channel inversion policy which is opposite to that of the Water-Filling policy since it assigns more power when the channel is in a poor condition and less power when the channel is in a good state. This is done to maintain a constant SNR which then allows the system to have a constant service rate. The third policy is the truncated inversion policy which maintains the concept of the total channel inversion policy but combines the idea of having a channel quality threshold which is used by the Water-Filling policy. The Water-Filling structure used in [4] and [5] offers the system a higher spectral efficiency than the total inversion policy but does this offer a greater QoS, specifically in terms of BER?

2.4 Application Layer

Understanding the reasoning behind multimedia transmission and the reason behind its relevance for QoS guarantees requires some background information. When the term multimedia is mentioned it refers to the three different types of traffic classes, these being voice, video and data. The work proposed in [6], [7] and [11] uses the application layer to classify the different multimedia into high priority (QoS guaranteed) or low priority (best-effort) traffic. This information is then sent to the data-link layer or MAC layer such that the QoS requirements are met. The work done in [22] provides some insight into using block coding within an adaptive system, which is used in [3] at the application layer to allow for improved overall system performance.

Each of these types of traffic classes each has its own QoS requirement. Usually QoS guarantees are in terms of delay, BER or throughput. When trying to achieve certain QoS requirements the system provides these requirements only for the overall system therefore the requirements can only be met for each individual packet. This then only allows for one type of media class to be transmitted within a single packet.

Figure 2-2 shows a packet that contains data, voice and video data types. The overall system may have a SER requirement of 10^{-3} which is applied to the packet, this is sufficient for voice but not for data or video. With the use of some form of error correcting coding on the data block the SER is reduced to 10^{-7} and similarly for the video block. Therefore, allowing the system to transmit multimedia traffic whilst satisfying the BER constraint for each data traffic.

DATA	VOICE	VIDEO

Figure 2-2 Data Packet

2.4.1 Application Layer Coding

The type of coding that was done in [3] is the Reed-Solomon (RS) Coding and is a type of error correcting coding that can detect τ number of errors and correct $\tau/2$ errors. The general formula for RS coding is RS(n, k) where n is the number of symbols and k being the design parameter. The method in which they implement the coding is to first evaluate the frame error rates for RS$(127, k)$ and RS$(63, k)$ codes using τ = 1,2,3 and 4 over an AWGN channel. In [3] the channel gain information is passed to the application layer coder and this is where the value of k is chosen. The k is selected depending on which type of traffic is being transmitted.

2.4.2 Received Signal

The system model proposed above provides some insight into the overall operation of the system although this system model is a high-level illustration it is necessary to show the low-level operation of the model. Figure 2-3 represents the low-level signal model for the system receiving information that is coded in the application layer as well as modulated in the physical layer.

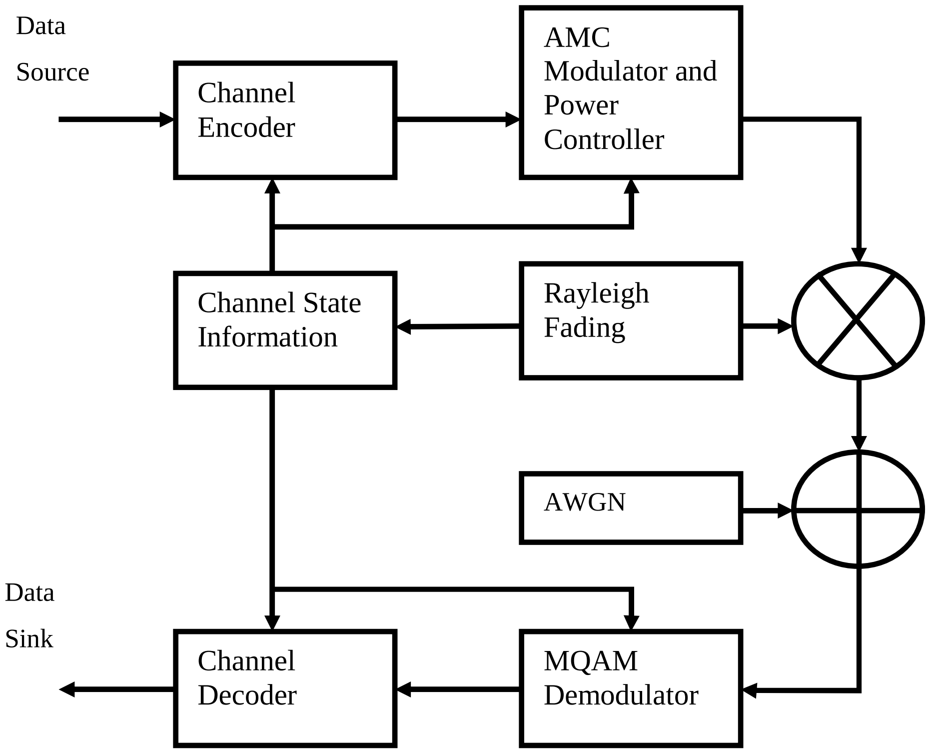

Figure 2-3 Signal System Model

The channel encoder receives the CSI and determines which parameters must be used in the application layer. The AMC modulator decides which constellation size to apply and the Power controller decides the power gain to apply. Attenuation to the signal follows the Rayleigh fading distribution and the distortion is due to the AWGN. These disturbances can be expressed as follows:

$$\gamma = \alpha x + n$$

where γ is the received signal, x is the transmitted signal, α is the attenuation due to fading and n is the Additive White Gaussian Noise. The signal is then demodulated and decoded.

2.5 Rayleigh fading channel approximation

The discussions in the previous sections provide a general understanding of the system model and the different layers that will be used in the cross-layer design, in order to validate these adaptive techniques an expression of the fading channel is required. To obtain a closed-form expression for a Rayleigh fading channel is not a simple task and in this section an exact approximation is introduced which will be used within this dissertation to validate the simulations results found for each of the adaptive techniques. This approximation is similar to the Nakagami channel approximation found in [3].

The general expression for SER coherent M-QAM with two-dimensional Gray coding over the AWGN channel is given by [8, eqn 6.23]

$$P_{AWGN}(\gamma) = 4\left(1-\frac{1}{\sqrt{M}}\right)Q\left(\sqrt{\frac{3\gamma}{(M-1)}}\right) - 4\left(1-\frac{1}{\sqrt{M}}\right)^2 Q^2\left(\sqrt{\frac{3\gamma}{(M-1)}}\right), \qquad (2.1)$$

where P_{AWGN} is the symbol error probability in an AWGN channel, M is the size of M-QAM and γ is the SNR. The $Q(x)$ and $Q^2(x)$functions are defined as [13]:

$$Q(x) = \frac{1}{\pi}\int_0^{\pi/2} exp(\frac{-x^2}{2sin^2\theta})d\theta \qquad (2.2)$$

$$Q^2(x) = \frac{1}{\pi}\int_0^{\pi/4} exp(\frac{-x^2}{2sin^2\theta})d\theta \qquad (2.3)$$

(2.2) or (2.3) cannot be evaluated in a closed-form, however the integration can be computed using a numerical integration. The trapezoidal rule for numerical integration from is given as follows:

$$\int_a^b f(x)dx \approx \frac{b-a}{p}\left[\frac{f(a)+f(b)}{2} + \sum_{k=1}^{p-1} f\left(a + k\frac{b-a}{p}\right)\right]$$

where p is the number of summations. Applying the trapezoidal rule to equation (2.2) the following expression is derived [14]:

$$Q_p(x) = \frac{exp\left(\frac{-x^2}{2}\right)}{4p} + \frac{1}{4p}\sum_{i=1}^{p-1} exp\left(\frac{-x^2}{2sin^2\theta_i}\right) \qquad (2.4)$$

where $\theta_i = \frac{i\pi}{2p}$

$Q^2(x)$ can also be derived using a similar process and is given by [14]:

$$Q_p{}^2(x) = \frac{exp(-x^2)}{8p} + \frac{1}{4p}\sum_{i=1}^{p-1} exp\left(\frac{-x^2}{2sin^2\theta_i}\right) \qquad (2.5)$$

where $\theta_i = \frac{i\pi}{4p}$

It is shown in [14] that applying a p larger than 6 results in a perfect match between the exact simulation and the numerical computation for (2.1). Applying (2.4) and (2.5) into (2.1), and after some simplification, the SER for M-QAM in AWGN is given by:

$$P_{AWGN}(\gamma) = \frac{a}{p}\left\{\frac{exp\left(\frac{-b\gamma}{2}\right)}{2} - \frac{a \times exp(-b\gamma)}{2} + (1-a)\sum_{i=1}^{p-1} exp\left(\frac{-b\gamma}{S_i}\right) + \sum_{i=p}^{2p-1} exp\left(\frac{-b\gamma}{S_i}\right)\right\} \tag{2.6}$$

where $a = \left(1 - \frac{1}{\sqrt{M}}\right)$; $b = \frac{3}{(M-1)}$; $S_i = 2sin^2\left(\frac{i\pi}{4p}\right)$ and $\gamma = \frac{E_s}{N_0}$

Using this expression, a Rayleigh fading approximation can be calculated as

$$\begin{aligned} P_s(\gamma) &= \int_0^\infty P_{AWGN}(\gamma) \times p_R(\gamma) d\gamma \\ &= \int_0^\infty P_{AWGN}(\gamma) \times \frac{1}{\bar{\gamma}} exp^{-\frac{\gamma}{\bar{\gamma}}} d\gamma \end{aligned} \tag{2.7}$$

Where $\bar{\gamma}$ is the average SNR and p_R is the probability density function for a Rayleigh fading channel. However this expression has no closed from solution.

By substituting (2.6) into (2.7) produces

$$P_s(\gamma) = \int_0^\infty \frac{a}{p}\left\{\frac{exp\left(\frac{-b\gamma}{2}\right)}{2} - \frac{a \times exp(-b\gamma)}{2} + (1-a)\sum_{i=1}^{p-1} exp\left(\frac{-b\gamma}{S_i}\right) + \sum_{i=p}^{2p-1} exp\left(\frac{-b\gamma}{S_i}\right)\right\}\frac{1}{\bar{\gamma}} exp^{-\frac{\gamma}{\bar{\gamma}}} d\gamma \tag{2.8}$$

For a Rayleigh fading channel we assume the fading coefficient is α, and thus

$$\gamma = \alpha^2 \frac{E}{N_0};\ \bar{\gamma} = E[\gamma] = E\left[\alpha^2 \frac{E_s}{N_0}\right] = E[\alpha^2]\frac{E_s}{N_0} = \Omega\frac{E_s}{N_0} = \frac{E_s}{N_0}$$

The SER is given as

$$P_s(\bar{\gamma}) = \frac{a}{p}\left\{\frac{1}{b\bar{\gamma}+2} - \frac{a}{2} \times \frac{1}{b\bar{\gamma}+1} + (1-a)\sum_{i=1}^{p-1}\frac{S_i}{b\bar{\gamma}+S_i} + \sum_{i=p}^{2p-1}\frac{S_i}{b\bar{\gamma}+S_i}\right\} \tag{2.9}$$

To confirm the close match of this theoretical approximation, Figure 2-4 compares 4-QAM, 16-QAM and 64-QAM simulations in a Rayleigh fading channel with the theoretical approximation for each modulation constellation.

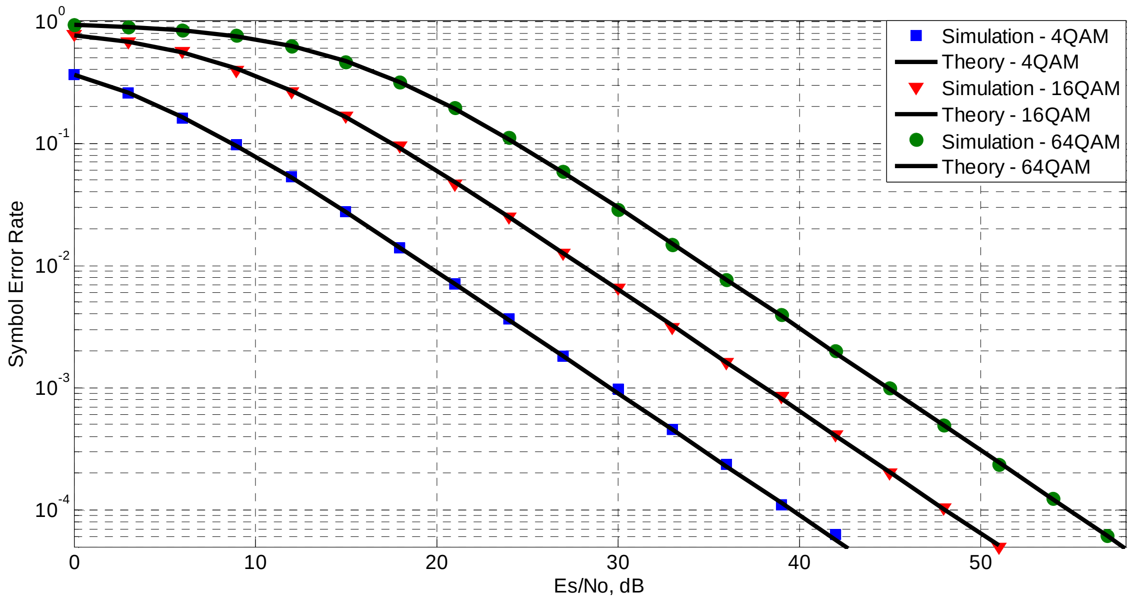

Figure 2-4 showing the theoretical expression derived compared to simulations for 4-QAM, 16-QAM and 64-QAM in a Rayleigh fading channel

2.6 Chapter summary

In this chapter, the adaptive system model is presented and a detailed description of the interaction between the transmitter and receiver are discussed. In this interaction the particular OSI protocol layers that will be used in this dissertation are highlighted. This is followed by a discussion on the physical layer, where a literature survey is presented on rate adaptive modulation and power adaptive modulation techniques. The application layer is then discussed with a mention on previous work that has been done in this area as well as application layer coding. Finally a theoretical approximation of a Rayleigh fading channel is derived and validated to ensure that the approximation is a close match to the simulated results. In the next chapter, the discussion continues with rate adaptive modulation with more attention given to the implementation within the physical layer.

Chapter 3

Rate Adaptive Modulation

3.1 Introduction

Modern systems are designed to achieve certain Quality of Service (QoS) specifications such as delay, Symbol Error Rate (SER), throughput and jitter. The system proposed in this dissertation is designed to achieve a target SER requirement throughout the communication period, although this is sometimes difficult to achieve because these QoS are highly dependent on the conditions of the wireless channel. The objective of this system is to achieve a pre-defined SER and concurrently optimize the data rate, power consumption or bandwidth-usage. One of the solutions to improving the data rate of the system is to utilize a concept called rate adaption. The previous chapter introduced the different protocol layers within the adaptive system model, this chapter begins with the introduction of rate adaptive modulation and a discussion on related work in the area of rate adaptive modulation. This is followed by a revision of the system model with the attention being placed on the Adaptive Mode Controller in the physical layer. This leads to a discussion on conventional rate adaptive modulation followed by a new proposed technique called the Partial Packet scheme which takes advantage of transmitting packets with two different modulation types and blind-detection to improve throughput. Simulation results are presented for both schemes with a discussion on the comparisons made. The chapter draws to a close with a conclusion of the work proposed.

3.2 Related Work

Conventional rate adaption has been researched rigorously since the 1980's and there has been a great deal of investigation dedicated to this topic. Current cellular systems such as GSM implement rate adaption in EDGE and GPRS data transmission. An informal definition of rate adaption is that the system changes the transmission data rates as the channel conditions change. Thus as the channel conditions become more favorable the data rate increases. The channel information is gained from the system feedback which allows the system to make a decision and adapt parameters accordingly.

In general, systems implement rate adaptive modulation to maintain a constant predetermined error rate by either varying the constellation size, coding rate/scheme or symbol transmission rate [4]. In [2-4] use the approach of varying the constellation size to provide guaranteed error rates. The system in [2] uses rate adaptive modulation to maximize throughput subject to a given QoS constraint where as the system proposed in [3] uses this technique to allow for multimedia transmission. Varying the constellation size is also used in [4] where it combines this technique with a variable-power scheme to achieve high speed data transmissions. The system proposed in this dissertation aims to use rate adaptive modulation to maximize the throughput while guarantying a predetermined error rate.

3.3 System Model

The system model used in this chapter is similar to the system proposed in Chapter 2, where a general operation of the model was discussed. This system model, shown in Figure 3-1, illustrates the downlink of a node in a wireless LAN where the central command station can be represented as the transmitter and the mobile node as the receiver. A typical transmission begins at the application layer of the transmitter, the data then moves down to the physical layer where it is modulated and sent across the fading channel. The data then arrives at the receiver side, the physical layer demodulates the data and sends it to the higher layers to be processed. In this chapter the focus is placed exclusively on using the physical layer, more specifically the AMC mode controller. The application layer is assumed to operate without any error correcting coding and the power controller is considered inactive. This provides an opportunity to analyze the system performance with a single adaptive component active, this component being rate adaptive modulation.

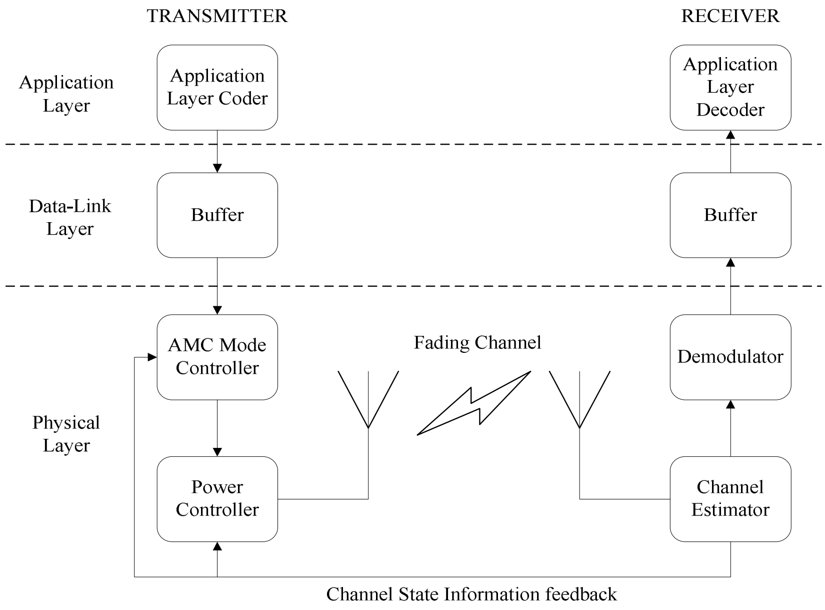

Figure 3-1 A representation of the system model used in this chapter.

The channel model assumed for this system is a block fading model where the channel is frequency flat and varies from frame to frame, but is invariant for the duration of a single frame. This model is suitable for slowly varying wireless channels [7]. The adaptive schemes at the different protocol layers are adjusted on a frame-by-frame basis. There is perfect CSI available at the receiver and the feedback channel is assumed to be error free and instantaneous, therefore the determined SNR value is fed back to the transmitter without error and latency [3].

3.4 Conventional Rate Adaption

In conventional rate adaptive modulation the priority is to maintain a signal quality of a specific target SER thereafter it is to increase spectral efficiency. In future this target SER will be referred to as P_e. Rate adaption is achieved by changing the modulation scheme or constellation size depending on the channel condition. As the channel conditions improve, the system can then increase the constellation size which allows for more data to be transmitted whilst maintaining the P_e requirement set by the system.

In order to switch from one constellation size to the other the system first requires the SNR values at which each of the various constellations achieves P_e. Using numerical analysis of the expression derived in Chapter 2 the SNR values that achieve a P_e can be calculated for each M-ary Constellation. For convenience, we restate equation (2.9),

$$P_s(\bar{\gamma}) = \frac{a}{p}\left\{\frac{1}{b\bar{\gamma}+2} - \frac{a}{2}\times\frac{1}{b\bar{\gamma}+1} + (1-a)\sum_{i=1}^{p-1}\frac{S_i}{b\bar{\gamma}+S_i} + \sum_{i=p}^{2p-1}\frac{S_i}{b\bar{\gamma}+S_i}\right\} \quad (3.1)$$

Table 3-1 shows the results of the numerical analysis for the target P_e. Using this information the system now knows at which SNR value the modulation must adapt. After anaylzing this information it was found that there are several areas in which the system exceeds the P_e requirement. In the next section a new scheme is proposed that takes advantage of these areas.

Table 3-1 Numerical results of each M-QAM achieving an SER requirement of 10^{-3} for a Rayleigh fading channel

Modulation(M)	BPSK	4-QAM	8-QAM	16-QAM	32-QAM	64-QAM
SNR(dB)	23.95	29.57	34.24	38.11	41.59	44.89

3.5 Partial Packet Scheme

The conventional rate adaptive modulation scheme, discussed in the last section, allows for the P_e requirement to be achieved whilst improving spectral efficiency. Although the P_e is always met, there are SNR ranges where this scheme uses a constellation size which exceeds the performance requirement due to the next greater constellation size not being able to meet the P_e requirement. In the Partial Packet scheme the aim is to first meet the target P_e and then to increase spectral efficiency specifically in these areas.

An approach used in [21] uses a set of optimum switching levels, which are derived based a closed-form expression of the average BER, to achieve a BER requirement with the aim to maximize spectral efficiency. By rewriting the average BER expression in terms of the average throughput and equating it to the target BER they were able to derive a set of optimum switching formulae using the Langrangian multiplier for the optimization. Finally the Adaptive mode and channel parameters are substituted in these formulae the optimum switching levels were calculated. The system proposed in this section uses a different approach to achieve the constant P_e performance required, using a packet structured technique that adapts instantaneously instead of optimizing the switching levels as [21] showed.

Conventionally the system would make a full transition from one M-ary constellation to the next. Thus each packet would only contain data that is M-ary modulated. Figure 3-2 represents a simplified illustration of the Partial Packet scheme. The packet is first split into two parts, modulated with different M-ary constellations and concatenated before being transmitted across the fading channel.

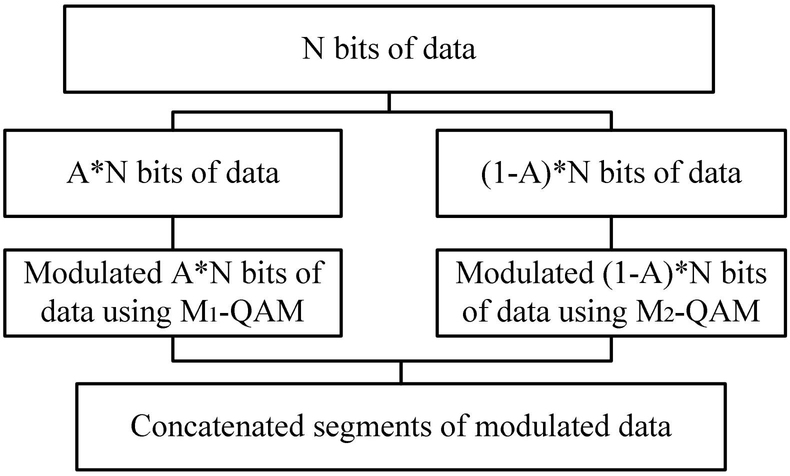

Figure 3-2 Block diagram showing how data is modulated separately

In order to locate areas where to apply the Partial Packet scheme the modulations boundary points for each constellation found in Table 3-1 are required. These boundary points are used to calculate the ratio in which the packet must be split into. This ratio is dependent on the SNR value and the SER values of both constellations. Using (3.1) we derive the expression to find this ratio.

We introduce a variable A that determines what portion of the packet will be modulated using the M_k constellation size, the remaining portion will be modulated with M_{k+1} constellation.

$$P_s(\bar{\gamma}) = A\frac{a_1}{p}\left\{\frac{1}{b_1\bar{\gamma}+2} - \frac{a_1}{2}\times\frac{1}{b_1\bar{\gamma}+1} + (1-a_1)\sum_{i=1}^{p-1}\frac{S_i}{b_1\bar{\gamma}+S_i} + \sum_{i=p}^{2p-1}\frac{S_i}{b_1\bar{\gamma}+S_i}\right\} + (1-A)\frac{a_2}{p}\left\{\frac{1}{b_2\bar{\gamma}+2} - \frac{a_2}{2}\times\frac{1}{b_2\bar{\gamma}+1} + (1-a_2)\sum_{i=1}^{p-1}\frac{S_i}{b_2\bar{\gamma}+S_i} + \sum_{i=p}^{2p-1}\frac{S_i}{b_2\bar{\gamma}+S_i}\right\} \quad (3.2)$$

where $a_k = \left(1-\frac{1}{\sqrt{M_k}}\right)$, $b_k = \frac{3}{(M_k-1)}$ and A is the ratio of modulation.

Solving numerically the ratio for each SNR value is calculated and thus the amount of bits that is modulated with the M_{k+1} constellation can be calculated. The number of information bits per symbol transmitted is determined by the modulation constellation size. Once the system achieves the target P_e the system throughput improvement is based on the number of bits that are modulated using M_{k+1} constellation. Table 3-2 and Table 3-3 show the values of A required to meet a SER target of 10^{-3} for each of the modulation combinations.

Table 3-2 showing the ratios (A) indicating how the data should be split for BPSK with 4QAM and 4-QAM with 8QAM for a target SER of 10^{-3}

BPSK – 4-QAM							4-QAM – 8-QAM					
SNR (dB)	24	25	26	27	28	29	30	31	32	33	34	35
A	1	0.9	0.77	0.62	0.42	0.17	0.96	0.86	0.71	0.57	0.36	0.08

Table 3-3 showing the ratios (A) indicating how the data should be split for 8QAM with 16QAM, 16-QAM with 32QAM and 32-QAM with 64QAM for a target SER of 10^{-3}

8-QAM – 16-QAM				16-QAM – 32-QAM			32-QAM – 64-QAM		
SNR(dB)	36	37	38	39	40	41	42	43	44
A	0.79	0.48	0.05	0.82	0.6	0.22	0.94	0.66	0.37

On the receiver side a technique called Blind detection [16] is used. Blind detection detects which constellation size is used by the system and for which data sets. The order in which the process occurs is as follows; types of modulation are detected, the packet is then split accordingly and demodulated. Once the sections have been demodulated the sections are concatenated and then sent to the higher protocol layers. Figure 3-3 is a simplified illustration of this process.

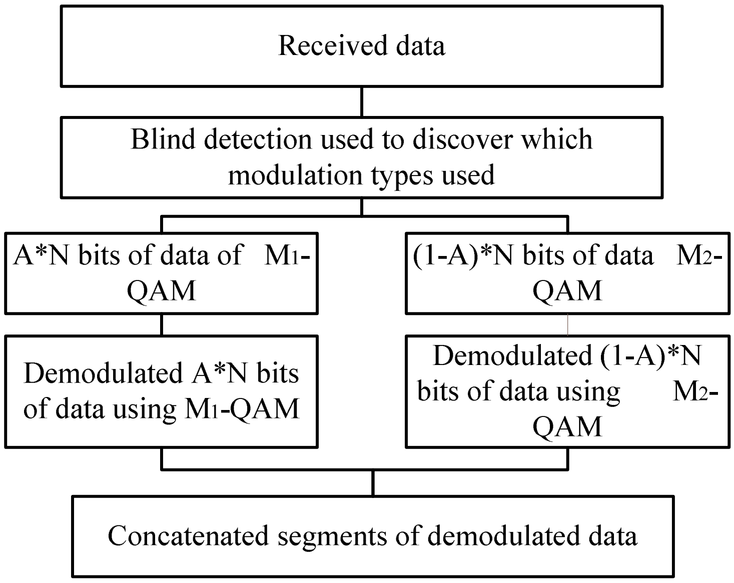

Figure 3-3 Block diagram showing detection and demodulation of data

3.6 Simulation Results

The conventional rate adaptive modulation and Partial Packet schemes were simulated in order to verify the theoretical expressions discussed for each modulation scheme. The simulator used was MATLAB v7, with M-QAM modulation and a Rayleigh fading channel model. The packet size for both the conventional rate adaptive scheme and Partial Packet scheme contained 200 symbols each and the channel and noise parameters used were as described in Section 2.4.2. The channel state information was assumed to be perfect with no delay or errors. The number of summations p performed in expression (3.1) was 20. The SNR values used refer to the ratio between symbol and noise energies. The performance target P_e set for the following simulations was a SER of 10^{-3}.

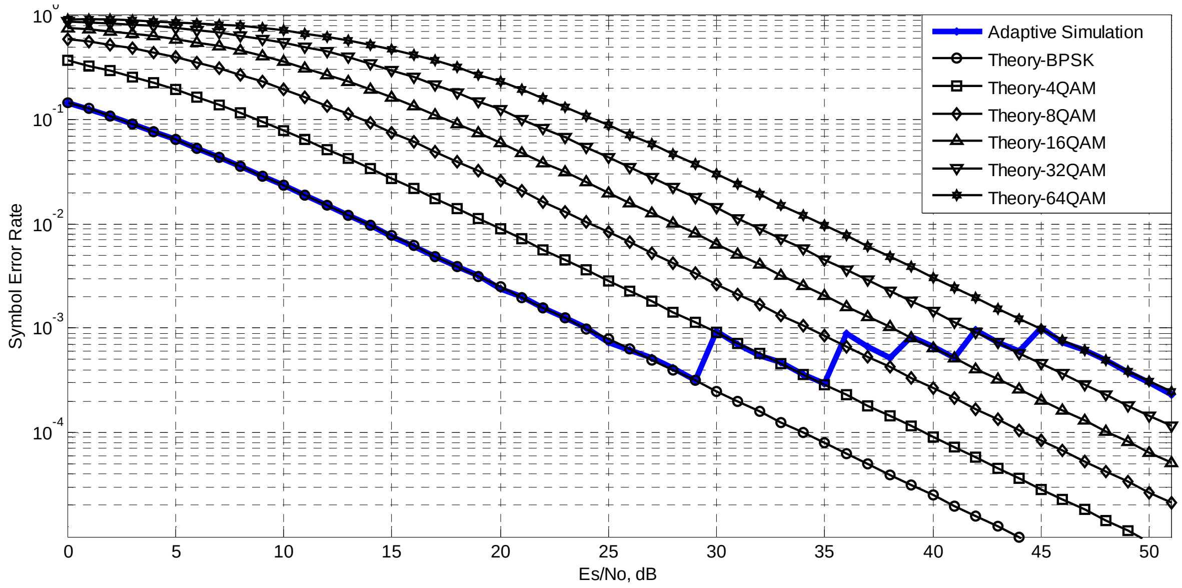

Figure 3-4: Average SER of adaptive M-QAM over a Rayleigh fading channel

Figure 3-4 shows the conventional rate adaptive modulation scheme as the fading conditions improve. Simulated results confirm that the numerical analysis was correct and show how the system adapts the constellation size to achieve the system performance requirement where possible.

Figure 3-5 shows the areas, indicated by red circles, in which each of the constellation sizes performs greater than the P_e required since the next greater constellation cannot meet this requirement.

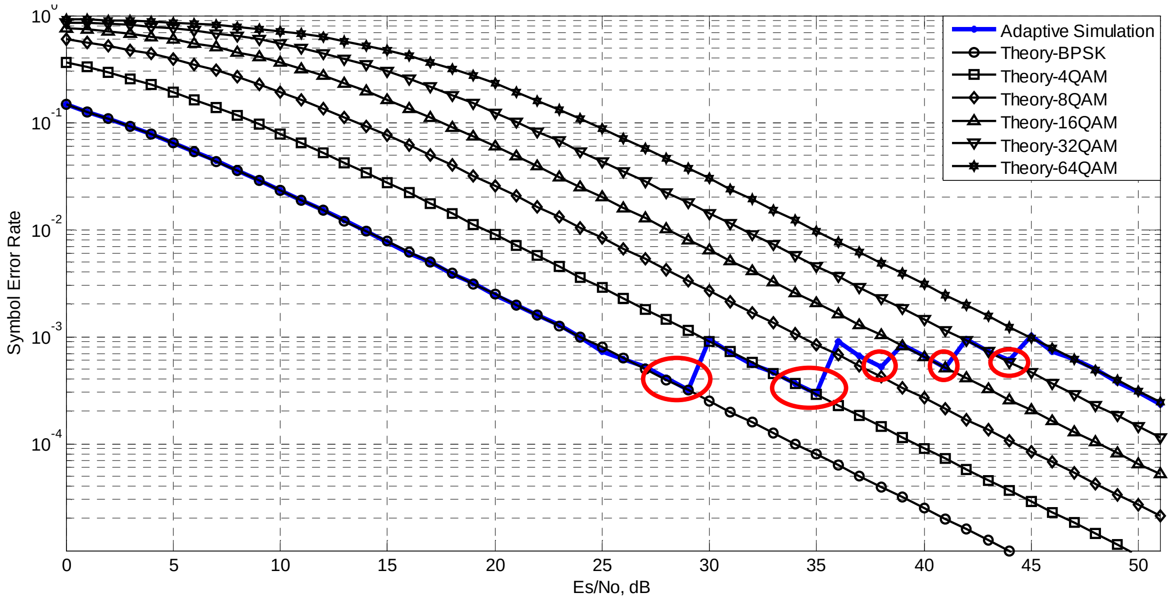

Figure 3-5 Average SER with adaption showing areas where improvement is possible

The aim of Partial Packet scheme is to increase spectral efficiency by introducing a scheme that modulates a packet of data with two different constellation sizes. The constellation size determines the amount of information that is transmitted per symbol, the lower the number of information bits per symbol the better the system performs. Therefore as the system uses two different constellation sizes the amount of information bits per packet increases, although the system performance worsens the target P_e is achieved. Figure 3-6 shows the system using the Partial Packet scheme compared to the conventional system.

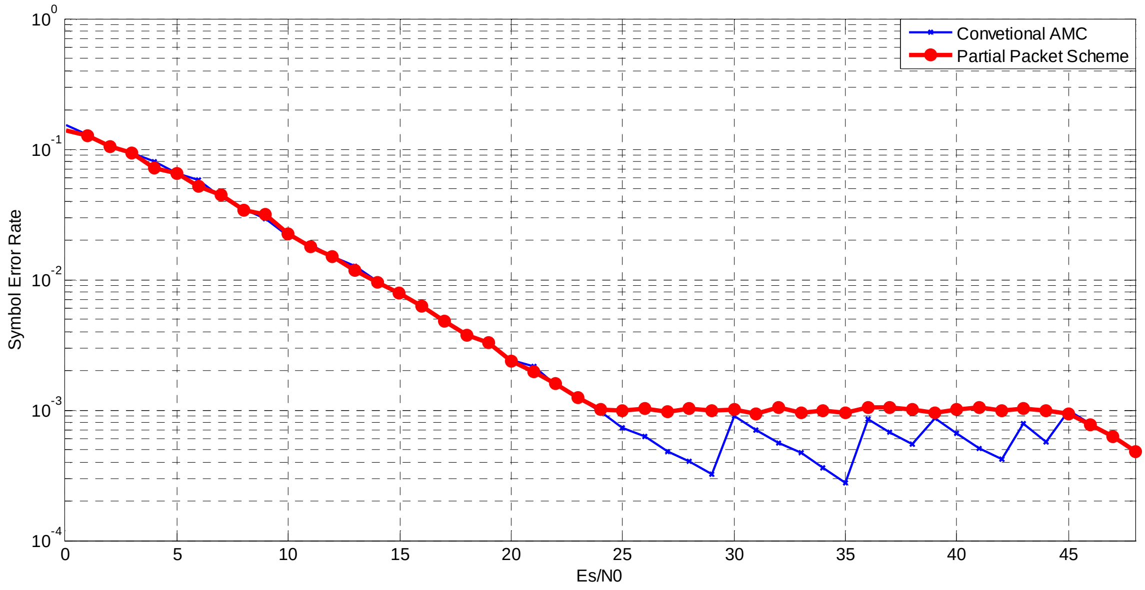

Figure 3-6 Average SER using Partial Packet Scheme in Rayleigh fading channel

Now that the SER performance improvement has been shown in the simulations, it is important to calculate the throughput of the Partial Packet scheme and compare it to the conventional rate adaptive modulation.

The equation to determine the data rate of the system from [4] is

$$R(\bar{\gamma}) = \mathrm{B}\log_2 M(\bar{\gamma}), \tag{3.3}$$

where B is the number of received symbols. In order to calculate the entire throughput of the Partial Packet scheme, the throughput for each constellation size is required. Using the information given from Figure 3-3 and equation (3.2) it is noted that a portion of the received symbols will be a certain constellation size and the other portion will be a different constellation size. This portion is defined as above by A, therefore the throughput of the Partial Packet scheme is defined as

$$R(\bar{\gamma}) = A\mathrm{B}\log_2 M_k(\bar{\gamma}) + (1 - A)\mathrm{B}\log_2 M_{k+1}(\bar{\gamma}) \tag{3.4}$$

Using Table 3-2 and Table 3-3 for the values of the constellation size and A. Throughput here is measured in bits per symbol. Figure 3-7 shows throughput improvement compared to conventional rate adaption.

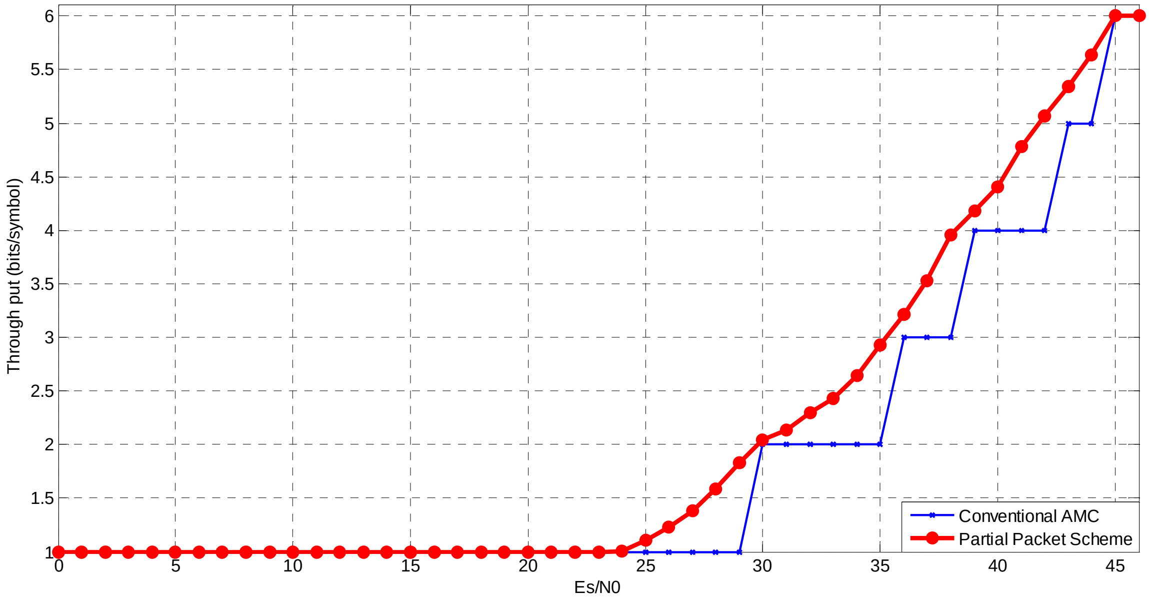

Figure 3-7 Through-put using Partial Packet Scheme in Rayleigh fading channel

Figure 3-7 shows the increased number of information bits per symbol per packet using the Partial Packet scheme when compared to the conventional adaptive modulation.

3.7 Chapter Summary

In this chapter, rate adaptive modulation was introduced with a look at some related work, this lead to a discussion on conventional rate adaption which highlighted areas in which improvement was possible. The proposed method used in [21] was examined. This method for rate adaption calculates the optimal switching levels between constellations to achieve a constant symbol error rate. A system was then proposed, which instead of using the optimal switching levels, used a technique that combines two different constellations within a single packet and requires lower computation. This technique together with a method called blind detection on the receiver side, provides improvement on the overall spectral efficiency of the system compared to conventional rate adaption. Simulation results were presented showing the conventional rate adaptive modulation as well as the Partial Packet scheme. A comparison was made to show that both schemes met the required performance target of SER of 10^{-3}. Spectral efficiency of the system was discussed and an equation was derived to determine the entire throughput of the system. The improvement of the Partial Packet scheme was shown when compared to the throughput of the conventional rate adaption. The following chapter continues the focus on the physical layer and discusses the use of constant rate - variable power techniques to achieve a required SER.

Chapter 4

Power Adaptive Modulation

4.1 Introduction

In modern technological devices, power efficient systems are a necessity to combat high processing requirements in day to day usage. In the previous chapter, rate adaptive modulation within the physical layer was described with an emphasis on spectral efficiency, the focus remains on the physical layer however in this chapter power adaptive modulation is discussed with the aim of varying the SER performance by providing variable power. This discussion begins with a look at related work regarding power control in the physical layer which is then followed by a discussion on the system model that will be used in this section. The Rayleigh fading channel is presented as well as the implementation of power adaptive modulation within this fading channel is presented, which is followed by a discussion on the different power adaptive techniques with specific principles discussed for each technique. The simulation results are presented and discussed, the chapter is then concluded with a chapter summary.

4.2 Related Work

Power adaptive modulation can be described as adapting the transmit power of the system in order to achieve a specific performance target P_e. The method that this adaption occurs is dependent on the adaption policy or scheme. In the work proposed in [4] two power adaptive schemes are discussed, these being the Channel Inversion and Water-Filling schemes, each have their own benefits and shortfalls. Channel Inversion counteracts severe fading by applying more power to the signal, this provides better performance in high fading levels. Water-Filling takes advantage of low fading areas and applies more power to further improve performance and disregards severely faded areas.

The work presented in [2] is a QoS driven system that uses rate and power adaptive schemes to maximize throughput subject to a given delay QoS constraint. The analysis done on this system provide an interesting insight to the tradeoff between throughput and QoS provisioning: when the QoS constraint becomes loose their optimal power control strategy converges to the Water-Filling scheme where on the other hand when the QoS constraints are gets stringent the optimal policy converges to the total channel inversion scheme. In this section these two power adaptive schemes are investigated and are used to obtain the main objective of our system, which is to maintain an overall target SER (P_e).

4.3 System Model

The system model used in this chapter is similar to the system used in Section 3.3. In the previous system the AMC in the physical layer improves the system performance using rate adaptive modulation, Figure 4-1 represents this system model. In this chapter the focus is once again placed exclusively on using the physical layer, with attention placed on the Power controller. The application layer is assumed to operate without error correction and the adaptive mode controller is treated as being inactive.

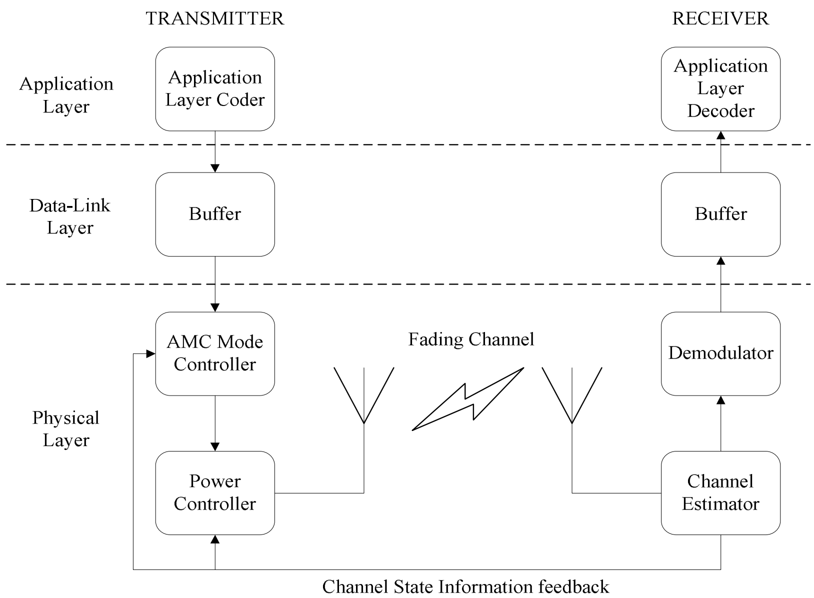

Figure 4-1 A representation of the system model used in this chapter

The channel model used in this chapter is the same as the model presented in Section 3.3. A theoretical expression for a Rayleigh fading channel is discussed in the next section.

4.4 Fading Channel

In this section the theoretical expression is introduced for the implementation of power adaptive modulation in a Rayleigh fading channel, this expression will be referenced in the rest of this chapter. For convenience the SER equation in a Rayleigh fading channel that was presented in Chapter 2 is restated,

$$P_s(\bar{\gamma}) = \frac{a}{p}\left\{\frac{1}{b\bar{\gamma}+2} - \frac{a}{2}\times\frac{1}{b\bar{\gamma}+1} + (1-a)\sum_{i=1}^{p-1}\frac{S_i}{b\bar{\gamma}+S_i} + \sum_{i=p}^{2p-1}\frac{S_i}{b\bar{\gamma}+S_i}\right\} \tag{4.1}$$

The expression (4.1) is used to describe a constant-power system, in order to allow for variable power the transmit SNR $\bar{\gamma}$ becomes $P(\bar{\gamma})\bar{\gamma}$ from [4], where $P(\bar{\gamma})$ is the transmitted power of the signal. Therefore the variable-power equation is

$$P_s(\bar{\gamma}) = \frac{a}{p}\left\{\frac{1}{bP(\bar{\gamma})\bar{\gamma}+2} - \frac{a}{2}\times\frac{1}{bP(\bar{\gamma})\bar{\gamma}+1} + (1-a)\sum_{i=1}^{p-1}\frac{S_i}{bP(\bar{\gamma})\bar{\gamma}+S_i} + \sum_{i=p}^{2p-1}\frac{S_i}{bP(\bar{\gamma})\bar{\gamma}+S_i}\right\} \tag{4.2}$$

4.5 Channel Inversion Power Adaption

The objective of Channel Inversion power adaption is to supply increased power when the channel conditions are severe and less power when the channel conditions are favorable. This allows for a constant Symbol Error Rate (SER) to be achieved. Using the equation (9.1) from [8]

$$\frac{P(\bar{\gamma})}{\bar{P}} = \frac{\sigma}{\bar{\gamma}} \tag{4.3}$$

where $P(\bar{\gamma})$ is the transmit power according to the received SNR $\bar{\gamma}$ value, $\bar{P}$ is the average transmit power and σ is the constant received power required to satisfy the SER requirement. In order to implement this power adaptive scheme it is first necessary to calculate the required constant received power required to meet the target SER, it is then required to calculate the Peak and Average power to ensure that there is an upper bound to the maximum amount of power transmittable.

4.5.1 Constant Received Power

To calculate the transmit power $P(\bar{\gamma})$ it first necessary to calculate the constant received power σ. This discussion begins with a look at how this calculation would be performed in an AWGN fading channel. Since equation (2.1) is not easily inversed an approximation is used to perform the calculations. Using the approximations found in Table 6.1 in [8], the constant received SNR is the SNR value that achieves our required target SER. In this case the approximation for 4QAM is used.

$$P_e \approx 2Q(\sqrt{\gamma}) \tag{4.4}$$

Using numerical analysis on equation (4.4) it was found that for a target SER of $P_e = 10^{-3}$ it was found that $\bar{\gamma} = 10.8dB$. Therefore our constant received power required for 4QAM is $\sigma = 10.8dB$. In [4] the average power used was $\bar{P} = 1$, using this information it now possible to calculate the required transmit power $P(\bar{\gamma})$ using (4.3).

Table 4-1 Constant received power σ values for the different modulation types for an AWGN faded channel given a target SER of 10^{-3}

Modulation	Constant Received SNR σ (dB)
BPSK	6.7
4QAM	10.8
16QAM	17.1
64QAM	23.4

Similarly to the AWGN fading channel, numerical analysis was used on equation (4.1) to determine the constant received power σ in a Rayleigh fading channel. Table 4-2 shows the constant received power σ for the different modulation types.

Table 4-2 Constant received power σ values for the different modulation types for a Rayleigh fading channel given a target SER of 10^{-3}

Modulation	Constant Received SNR σ (dB)
BPSK	23.9
4QAM	29.5
16QAM	30.0
64QAM	38.0

4.5.2 Peak Power and Average Power

The transmit power P is constrained by equation (4.5), the average power constraint [4]. The reason for this constraint is to prevent P from reaching impractical values. To satisfy this average power constraint the maximum allowable transmit power is

$$\int_0^\infty P(\gamma)\rho(\gamma)d\gamma = \bar{P} \tag{4.5}$$

where the power allocation is

$$P(\gamma) = \begin{Bmatrix} \frac{\sigma}{\gamma}, \gamma > \gamma_1 \\ P_{max,}\gamma \leq \gamma_1 \end{Bmatrix} \tag{4.6}$$

The integral for a Rayleigh Fading channel thus becomes

$$\int_0^{\gamma_1} P_{max}\frac{1}{\bar{\gamma}}e^{\frac{-\gamma}{\bar{\gamma}}}d\gamma + \int_{\gamma_1}^{\infty}\frac{\sigma}{\gamma}\frac{1}{\bar{\gamma}}e^{\frac{-\gamma}{\bar{\gamma}}}d\gamma = \bar{P}$$

$$\frac{P_{max}}{\bar{\gamma}}\left(-\bar{\gamma}e^{\frac{-\gamma}{\bar{\gamma}}}\right)_0^{\gamma_1} + \frac{\sigma}{\bar{\gamma}}Expint\left(\frac{-\gamma}{\bar{\gamma}}\right) = \bar{P} \tag{4.7}$$

where $Expint(x) = \int_x^\infty \frac{e^{-t}}{t}dt$ and $\gamma_1 = \frac{\sigma\bar{P}}{P_{max}}$.

Table 4-3 shows respective P_{max} values for each modulation type, using $\bar{P} = 1$ for the average transmit power [4] and $\bar{\gamma} = 7dB$ for the average SNR [8] in a Rayleigh fading channel.

Table 4-3 showing the maximum power P_{max} for each modulation in a Rayleigh fading channel

Modulation Scheme	P_{max} (dB)
BPSK	23.51
4QAM	28.98
16 QAM	37.56
64 QAM	44.35

These calculations as well as the information that is provided by the CSI in the system model are vital in allowing the Channel Inversion scheme can adapt as channel conditions change. In the next section the Water-Filling scheme and the implementation is discussed.

4.6 Water-Filling Power Adaption

Channel Inversion discussed previously utilizes more power when the channel conditions are severely faded while the main property the of Water-filling scheme is to supply less power to the system when the channel is severely faded and supply more power when the channel is favorable. This scheme is defined by following equation [4].

$$\frac{P(\gamma)}{\bar{P}} = \frac{1}{\gamma_0} - \frac{1}{\gamma} \quad \gamma \geq \gamma_0 \tag{4.8}$$

where γ_0 is the cut-off value, if the received SNR value is less than γ_0 then the channel is too severely faded to transmit data hence no data is transmitted. In [4] they have optimized this equation further by introducing a value K such that the optimum cutoff fade depth is now γ_0/K . Therefore the scheme now becomes

$$\frac{P(\gamma)}{\bar{P}} = \frac{1}{\gamma_0} - \frac{1}{\gamma K} \quad \gamma \geq \gamma_0/K \tag{4.9}$$

where $K = \frac{-1.5}{\ln{(5P_e)}}$ and P_e is the target SER required [4].

In order to implement this power adaptive scheme it is first required to calculate γ_0 after which it is possible to calculate the transmit power. The next section discusses each of these calculations which are later confirmed with simulation results in a Rayleigh fading channel.

4.6.1 Cut-Off Value

To calculate the cut-off value the transmit power P policy for Water-filling must be substituted into (4.5) and subsequently using numerical analysis to solve for γ_0 [4].

$$\int_{\gamma_0}^{\infty} \left(\frac{1}{\gamma_0} - \frac{1}{\gamma}\right) p_R(\gamma) d\gamma = 1 \tag{4.10}$$

For a Rayleigh fading channel the distribution $p_R(\gamma)$ is:

$$p_R(\gamma) = \frac{1}{\bar{\gamma}} e^{\frac{-\gamma}{\bar{\gamma}}}$$

$$\int_{\gamma_0}^{\infty} \left(\frac{1}{\gamma_0} - \frac{1}{\gamma}\right) \frac{1}{\bar{\gamma}} e^{\frac{-\gamma}{\bar{\gamma}}} d\gamma = 1$$

$$\int_{\gamma_0}^{\infty} \frac{1}{\gamma_0} \frac{1}{\bar{\gamma}} e^{\frac{-\gamma}{\bar{\gamma}}} d\gamma - \int_{\gamma_0}^{\infty} \frac{1}{\gamma} \frac{1}{\bar{\gamma}} e^{\frac{-\gamma}{\bar{\gamma}}} d\gamma = 1$$

Which finally reduces to:

$$\frac{1}{\gamma_0} e^{\frac{-\gamma_0}{\bar{\gamma}}} - \frac{1}{\bar{\gamma}} Expint\left(\frac{\gamma_0}{\bar{\gamma}}\right) = 1 \tag{4.11}$$

Using the same parameters as in the previous section with $\bar{\gamma} = 7dB$ for the average power [8] and after numerically solving for γ_0 in equation (4.11) the solution found was $\gamma_0 = 0.66$. The integral changes when solving for the optimized cutoff value thus by using a target SER required of $P_e = 10^{-3}$, the value of K from (4.9) was calculated and similarly the new cutoff value γ_0 was found.

Table 4-4 showing the cutoff value γ_0 and optimal cutoff value K in a Rayleigh fading channel

Fading	γ_0 (dB)	γ_0/K (dB)
Rayleigh	-1.7607	1.7199

4.6.2 Transmit Power

The transmit power varies depending on the condition of the channel (SNR), the cut-off value as well as the average transmit power. In the previous section the cut-off value was determined, in this section the transmit power is calculated by using (4.9) which is shown restated for convenience.

$$\frac{P(\gamma)}{\bar{P}} = \frac{1}{\gamma_0} - \frac{1}{\gamma K} \quad \gamma \geq \gamma_0/K \tag{4.9}$$

Solving for the transmit power $P(\gamma)$ the equation becomes

$$P(\gamma) = \bar{P}\left(\frac{1}{\gamma_0} - \frac{1}{\gamma K}\right) \tag{4.12}$$

Using the values of γ_0 and K which was calculated in the previous section, it is possible to calculate the transmit power as γ varies.

4.7 Simulation Results

The power adaptive policies were simulated in order to verify the theoretical expressions discussed for each power adaptive scheme. The simulator used was MATLAB v7, with M-QAM modulation and a Rayleigh fading channel model. The packet size for the both power policies contained 200 symbols each and the channel and noise parameters used were as described from Section 2.4.2. The channel state information was assumed to be perfect with no delay or errors. The number of summations p performed in expression (4.2) was 20. The SNR values used refer to the ratio between symbol and noise energies. The performance target P_e set for the following simulations was a SER of 10^{-3}.

The Channel Inversion discussed above supplies increased power to the signal when channel conditions are not favorable. Using the theoretical equation (4.12), Figure 4-2 shows how the transmit power reduces as the channel conditions become favorable.

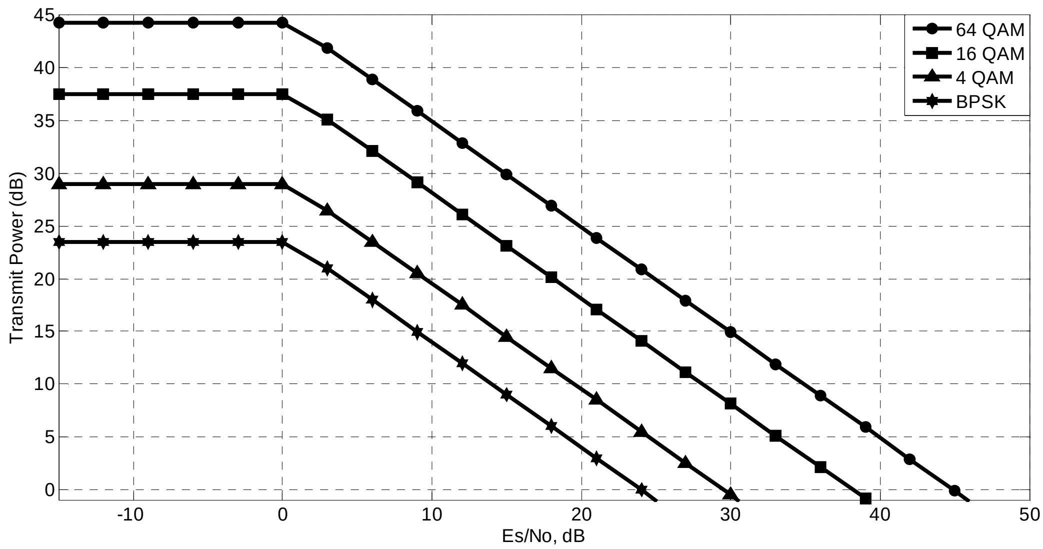

Figure 4-2 Transmit Power versus SNR in a Rayleigh fading channel for BPSK, 4QAM, 16QAM and 64QAM

Figures 4-3 to 4-6 show simulations using the calculated constant received power from Table 4.2 and the P_{max} values found in Table 4.3 in a Rayleigh fading channel using BPSK, 4QAM, 16QAM and 64QAM, respectively. Each of the figures shows the comparison of using the Channel Inversion power scheme versus no adaption.

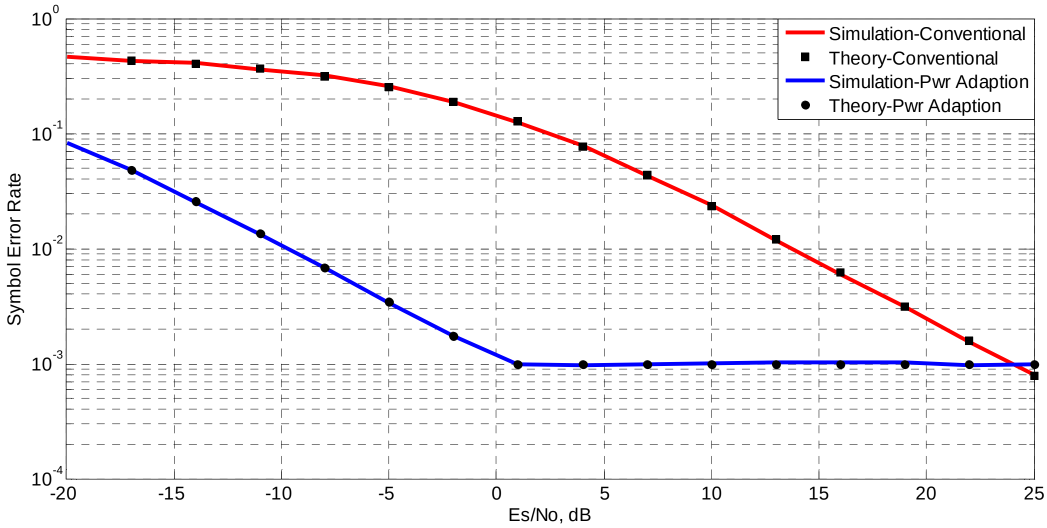

Figure 4-3 Channel Inversion adaption in a Rayleigh fading channel with BPSK modulation with target SER of 10^{-3}

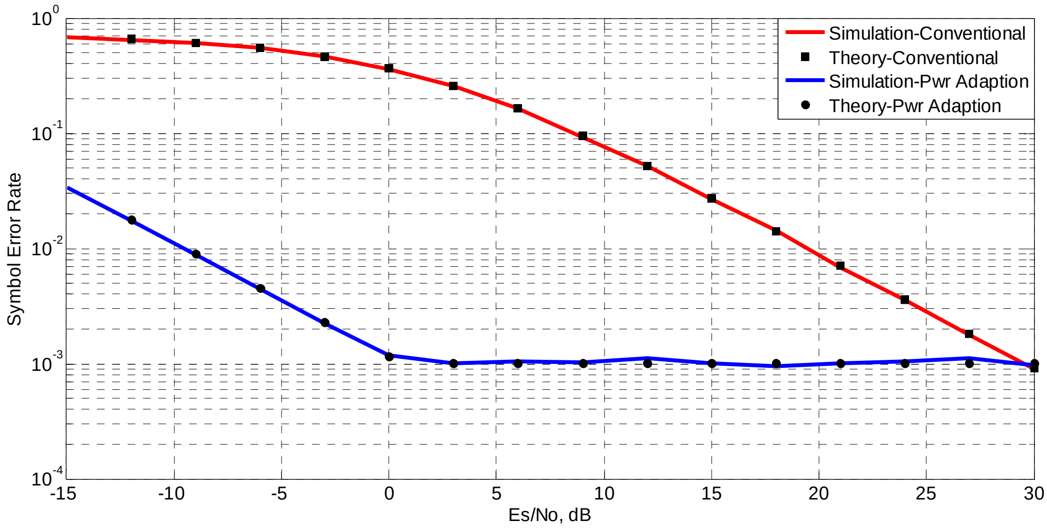

Figure 4-4 Channel Inversion adaption in a Rayleigh fading channel with 4QAM modulation with target SER of 10^{-3}

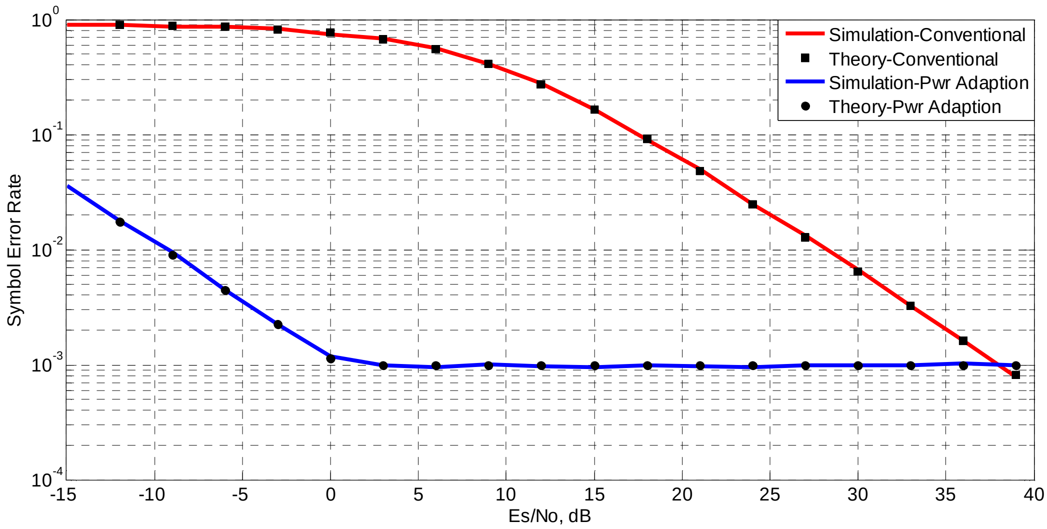

Figure 4-5 Channel Inversion adaption in a Rayleigh fading channel with 16QAM modulation with target SER of 10^{-3}

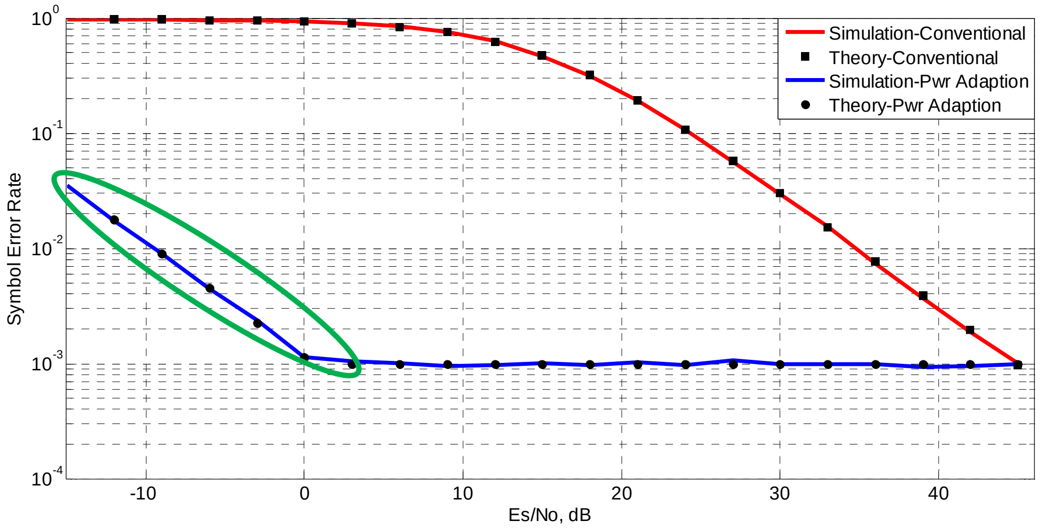

Figure 4-6 Channel Inversion adaption in a Rayleigh fading channel with 64QAM modulation with target SER of 10^{-3}

Each of these simulations show the Peak Power P_{max} impacting the performance of the system at SNR values below 3dB. For values lower that 3dB the transmit power P required to achieve the SER requirement is too high. Figure 4-6 highlights this area with a green oval. These simulations confirm the theoretical calculations made and also confirm that the Channel Inversion power scheme utilizes the most power in severely faded channels and least power when the channel is favorable, this is shown in Figure 4-7.

Although each modulation type is able to achieve the target SER, the system must be able to supply sufficient power to the power controller. Therefore obtaining the different levels of spectral efficiency depends on the system's ability to allocate enough power to the power controller.

Water-Filling power scheme takes advantage of favorable channel conditions by increasing the transmit power. Figure 4-7 shows the Transmit Power $P(\gamma)$ using the calculation results from Table 4-4 and expression (4.12), with $\bar{P} = 7,\ K = 0.2831$ as γ varies with the channel feedback.

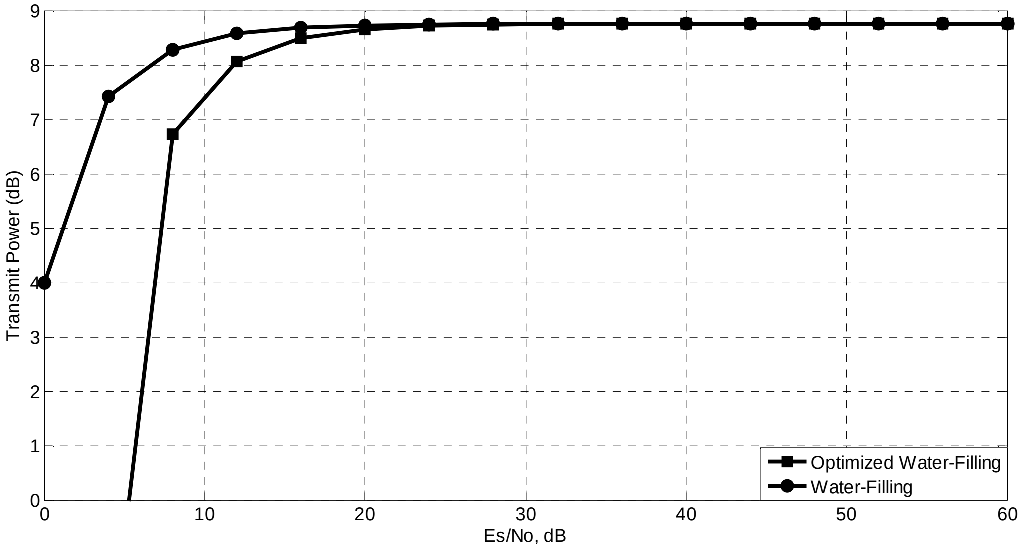

Figure 4-7 Transmit Power versus SNR for a Water-Filling Power scheme in a Rayleigh fading channel

The optimized Water-Filling scheme uses less overall power since its cut-off point is at a higher SNR value than the non-optimized Water-Filling scheme.

The Figures 4-8 to 4-11 are simulations using a Rayleigh fading channel using BPSK, 4QAM, 16QAM and 64QAM respectively. Each figure shows the comparisons of using the Water-Filling power scheme, Optimized Water-Filling power scheme and no adaption.

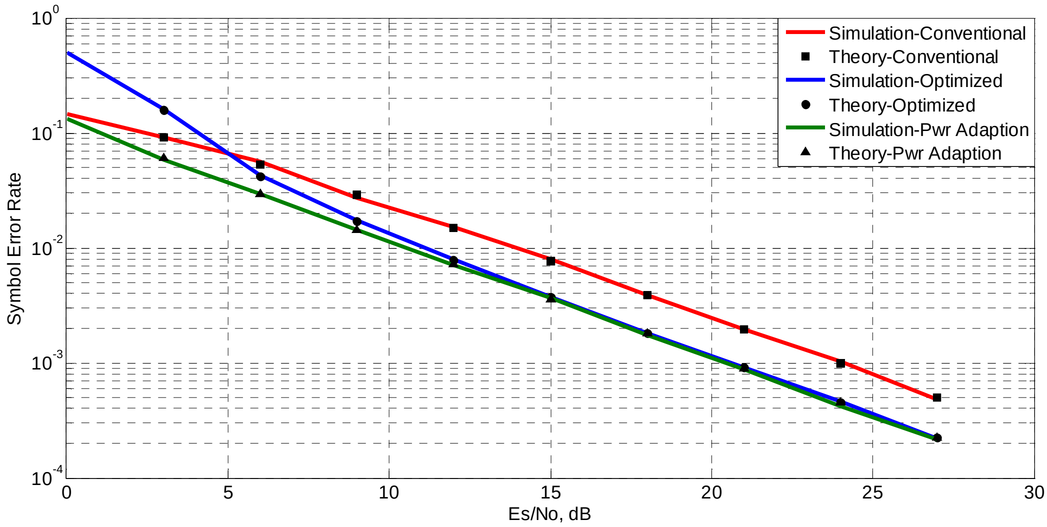

Figure 4-8 Water-Filling adaption and Optimized Water-Filling adaption in a Rayleigh fading channel with BPSK modulation

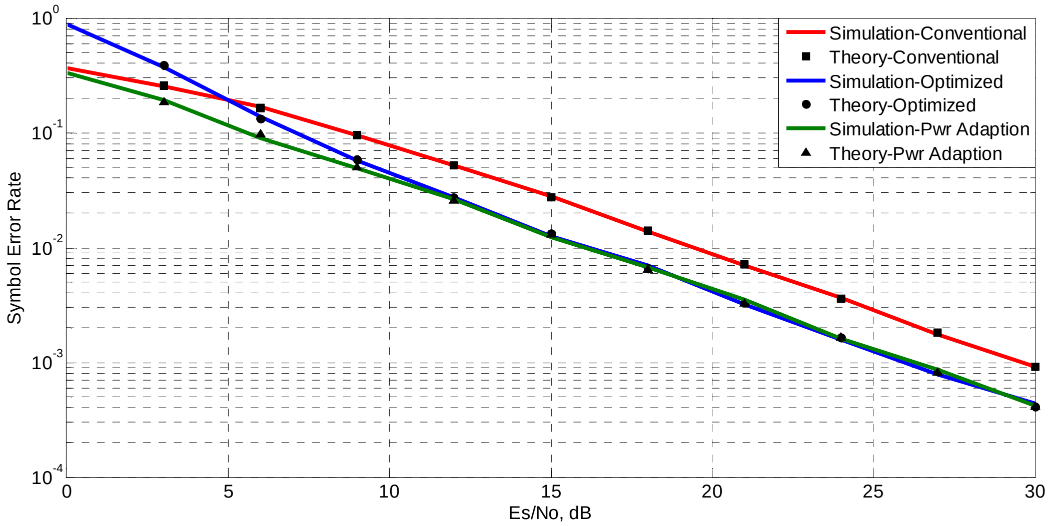

Figure 4-9 Water-Filling adaption and Optimized Water-Filling adaption in a Rayleigh fading channel with 4QAM modulation

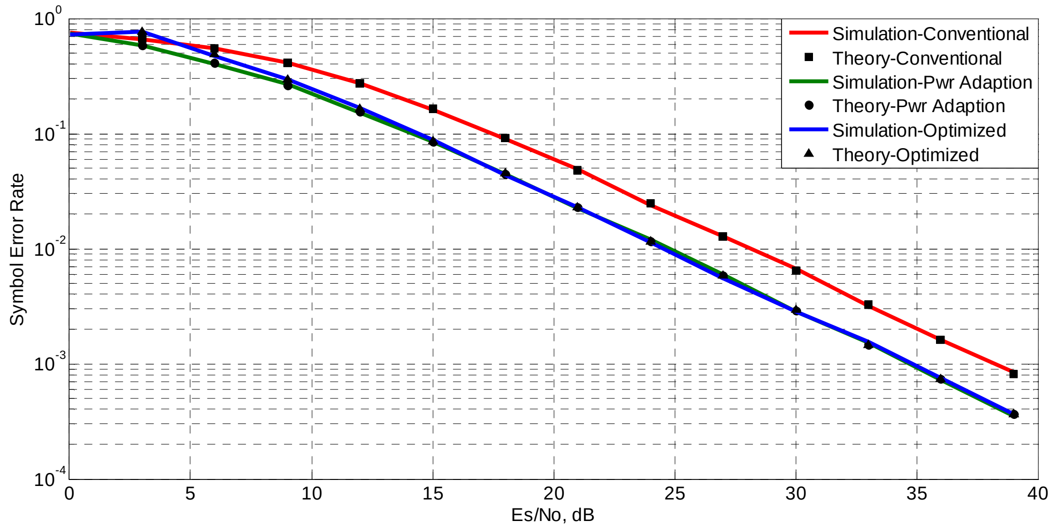

Figure 4-10 Water-Filling adaption and Optimized Water-Filling adaption in a Rayleigh fading channel with 16QAM modulation

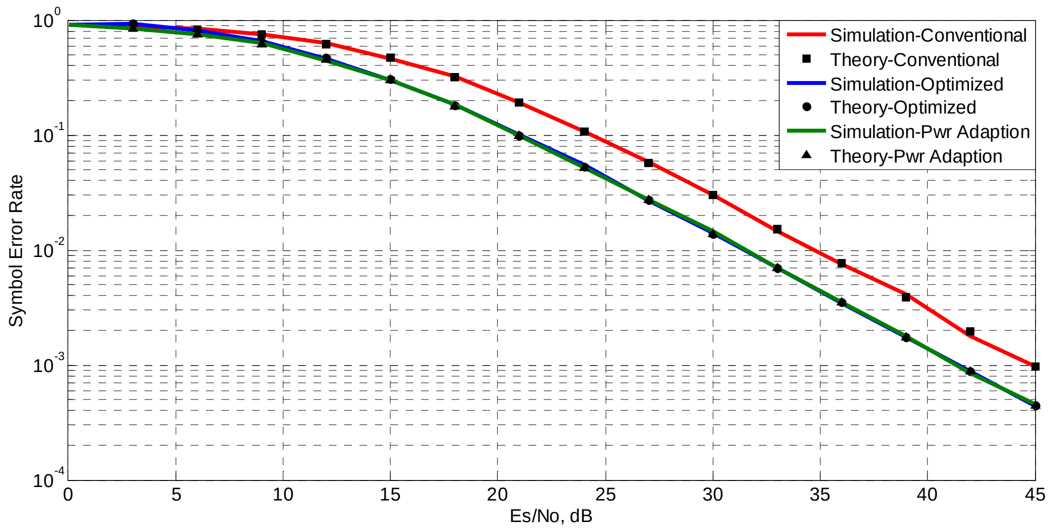

Figure 4-11 Water-Filling adaption and Optimized Water-Filling adaption in a Rayleigh fading channel with 64QAM modulation

Each of the simulations shows the performance of the Optimized Water-Filling scheme compared to the non-optimized Water-Filling scheme as well as non-adaptive transmissions. At high SNR there is no performance improvement between the two Water-Filling schemes but at low SNR the cut off value is clearly shown. The SER improvement when comparing the conventional non adaptive performance with the Water-Filling adaptive modulation is significant, at some points there is a 4dB improvement. The target SER is not constantly achieved using this power scheme although at certain SNR values the target can be met.

4.8 Chapter Summary

This chapter investigates the use of constant-rate variable-power schemes to provide constant SER rates. Channel Inversion attempts to inverse the fading effect on the channel by increasing the power applied to the system, whereas the Water-Filling scheme applies increased power when the channel conditions are favorable. Derivations of these two techniques are calculated for a Rayleigh fading channel, with the simulations confirming these theoretical calculations made. A comparison of the two systems shows that the Channel Inversion scheme achieves the required SER of 10^{-3} at a much lower SNR value than the Water-Filling scheme. However, Channel Inversion requires higher power to achieve this. The optimized cut off values, derived in the Water-Filling scheme, improves the power usage at low SNR but the amount of improvement varies depending on the constellation size used. In the next chapter, a cross-layer design approach is presented that applies an application layer coding technique to allow for multimedia transmission using the information obtained from this chapter and in the previous chapters.

Chapter 5

Cross-Layer Design for Multimedia Transmission

5.1 Introduction

The adaptive techniques discussed in Chapters 3 and 4 improve the system performance, in terms of SER and throughput, but are still only sufficient for the transmission of a single type of data. In this chapter the system combines these adaptive schemes used in the physical layer with an error correcting code performed in the application layer to transmit multiple types of data. The discussion begins with a cross-layer design approach that will be applied, along with an overview of the requirements for multimedia transmission. Thereafter related work of systems that use application layer coding is discussed. This is followed by a discussion on the system model that will be used in this chapter which utilizes the physical layer as well as the application layer. An introduction to a block code technique in the application layer is presented with theoretical expressions that will be used to validate simulations results. The combination between the block coding in the application layer and the power adaptive modulation in the physical layer is implemented with simulations to show the improvement in the system. This is followed by the addition of rate adaptive modulation to the system in the physical layer and this is where the complete cross-layer design is presented, simulation results are shown with SNR ranges in which multimedia transmission occur. The chapter is then concluded with a discussion on the performance of the system.

5.2 Specifications of Multimedia Transmission

Cross-layer design attempts to utilize different layers in the protocol stack to achieve better performance which conventional usage of the protocol layers is not able to achieve. Research has shown that cross-layer design has the potential to improve various QoS however there exists a fundamental trade-off between QoS deliverables and throughput [2]. The ability to use the protocol layers inter-dependently lessens the impact due to this trade-off whilst still increasing overall performance and allowing each layer to obtain their maximum potential.

With the inter-dependent protocol layer approach in mind, the current system design objective is for the system to have the ability to transmit different types of media within a single packet of information. However a problem arises when attempting to simply transmit a packet containing different media types. Each media has a different degree of performance required (SER constraint). Usually systems state their overall QoS per packet, the performance target for the approaches in Chapter 3 and 4 was a SER of 10^{-3}. This error rate is only sufficient for the transmission of a single type of media, for example voice (P_{vo}). Video and data require a greater system performance of $P_{vi} = 10^{-6}$ and $P_d = 10^{-7}$ respectively.

The work done in [9] discusses the adaptable parameters for each protocol layer, the physical layer adapts the signal modulation, the MAC layer uses ARQ and FEC to deliver QoS requirements and the application layer uses coding techniques to encoding parameters to achieve SER improvement. The work done in [11] applies a strict priority approach to classify real-time and non-real-time traffic and provisions QoS deliverables appropriately, specifically delay. The work presented in [3] applies an adaptive mode controller in the physical layer and a block coding technique at the application layer which adapts according to the channel conditions as well as according to the media type transmitted, this approach provides a system performance based, in terms of symbol error rate, on the media type. Similarly in Chapters 3 and 4, the focus has been on achieving the target SER performance set, in order to provide for multimedia transmission the system will be required to adapt block coding parameters in the application layer depending on the media type. The authors in [3] implement a CLD system using Reed-Solomon block coding to provide system improvement in terms of SER. The authors in [22] recommend Reed-Solomon coding as it is low in complexity and is useful in practical applications. In the next section the system model is presented where the multimedia transmission is considered.

5.3 System Model

The system models used in Section 3.2 and Section 4.2 make partial use of the model discussed in Chapter 2, in Section 3.2 the system model focuses on rate adaptive modulation where as the system model in Section 4.2 focuses on power adaptive modulation. Both systems apply the adaptive schemes in physical layer and assume that the application layer operates without error correction codes. In the first half of this chapter the system model concentrates on the application layer with no adaptive schemes applied in the physical layer. The second half of the chapter uses cross-layer design by combining the application layer and physical layer to enable the system to transmit multimedia. A transmission from this cross-layered approach begins at the application layer of the transmitter, the data is then coded using the application layer coder, and the coding parameters depend on the type of media the data belongs to. This data is passed down to the physical layer where the AMC modulates the data depending on the channel conditions provided by the CSI. The power controller applies the power adaptive policy and the data is sent across the fading channel. The data then arrives at the receiver’s side, the physical layer demodulates the information and sends it to the higher layers where the data is decoded and processed. Figure 5-1 is a block diagram representing the system model.

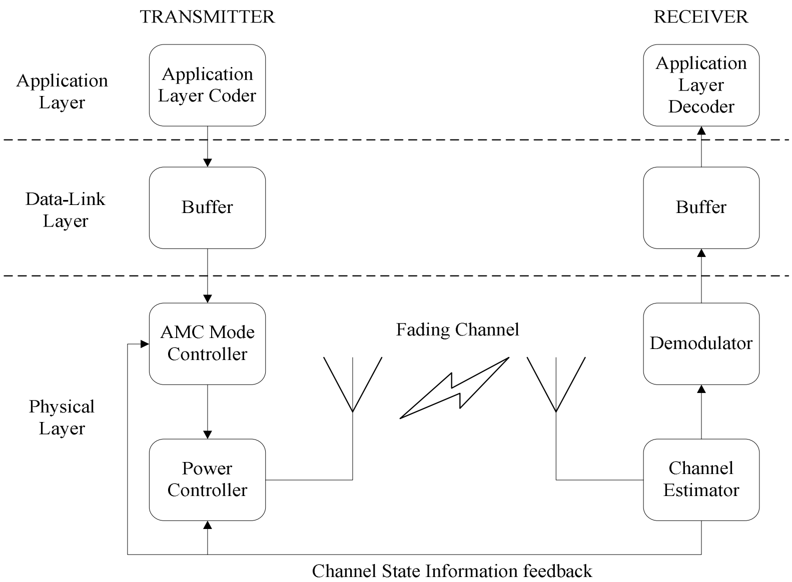

Figure 5-1 Block diagram representing the system model used in this chapter.

The channel model used in this chapter is the same as the model presented in Section 3.3. An application layer coding technique is discussed in the next section.

5.4 System Design

5.4.1 Reed-Solomon Coding

Reed-Solomon (RS) coding is a form of block coding which uses parity symbols within the transmitted message to detect erroneous symbols at the receiver. The Figure 5-2 illustrates an example of a coded message using RS coding.

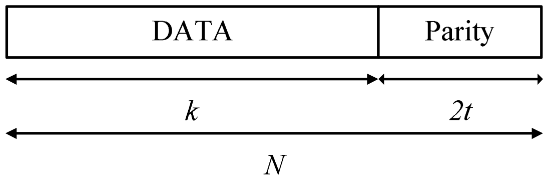

Figure 5-2 Data information concatenated with the parity makes up a Reed-Solomon code word

A message of length k symbols is encoded and $N-k$ parity symbols are applied to the end to form a packet containing N symbols. The correcting potential of this type of block coding is given by $t = \frac{N-k}{2}$. The message error probability is defined as [3],

$$P_H = \sum_{k=t+1}^{N} \binom{N}{k} (1-P_s)^{N-k} P_s^k \tag{5.1}$$

where N is the number of code symbols per message, t the number of code symbols that the code can correct, P_s the symbol error probability and k the number of data symbols. Channel Symbol Error Rate is P_H. Then, P_s can be expressed as

$$P_s = 1-(1-P_b)^L \tag{5.2}$$

where P_b is the bit error rate and L is the number of bits per code symbol.

The system model applied in this section is the model that concentrates on the application layer coding only, the physical layer though using MQAM is non adaptive in this model. The aim of this section is to calculate the performance improvement from using Reed-Solomon coding, the equation to calculate the channel SER can be written as follows:

$$P_H = \frac{1}{2^m-1} \sum_{k=t+1}^{2^m-1} \binom{2^m-1}{k} (1-P_s)^{2^m-1-k} P_s^k \tag{5.3}$$

where 2^m is the number of bits in each code symbol. By substituting equation (2.9) for P_s, into (5.3) the Channel Symbol Error Rate P_H for a Rayleigh fading channel can be found. The number of correctable code symbols t is directional proportional to the encoding and decoding complexity of Reed-Solomon [17] hence using low t values allows for sufficient performance increase with a marginal increase in system complexity.

The simulations shown in Figures 5-4 to 5-6 show the implementation of RS(127, k) with no use of adaptive techniques. The correcting capabilities simulated were t = 1, 2, 3 and 4. The packet size used was 127 code symbols and channel fading model used is as described in Section 2.3. At low SNR values the performance of RS coding worsens, this is due to the intense fading that causes errors not only in the symbols but in the parity bits as well which in turn causes more decoding errors. Figure 5-3 shows a flow diagram of the simulation process:

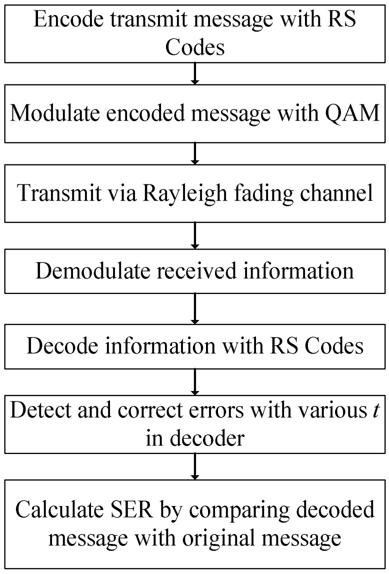

Figure 5-3 Block diagram showing the simulation process

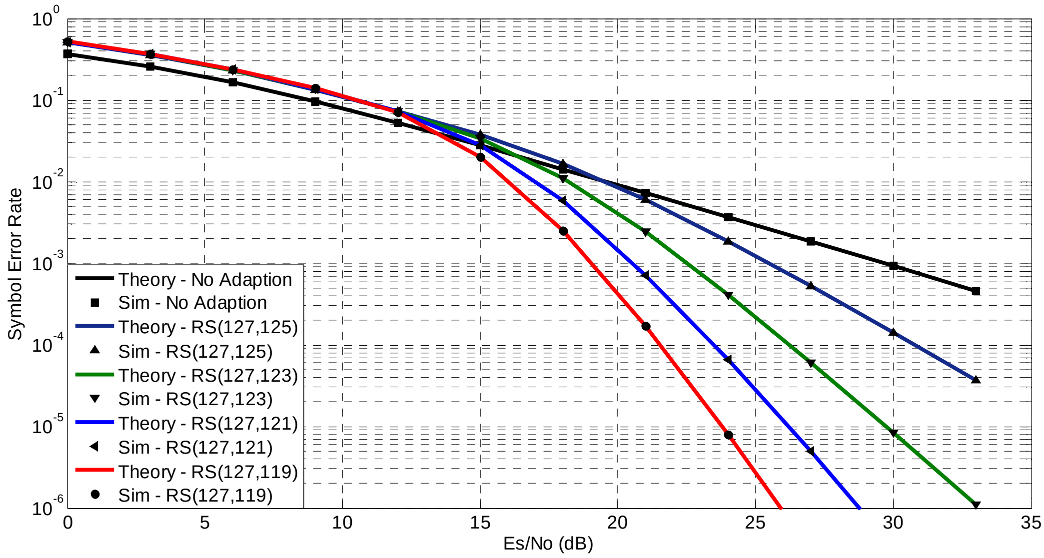

Figure 5-4 Symbol Error Rate for 4QAM in a Rayleigh fading channel

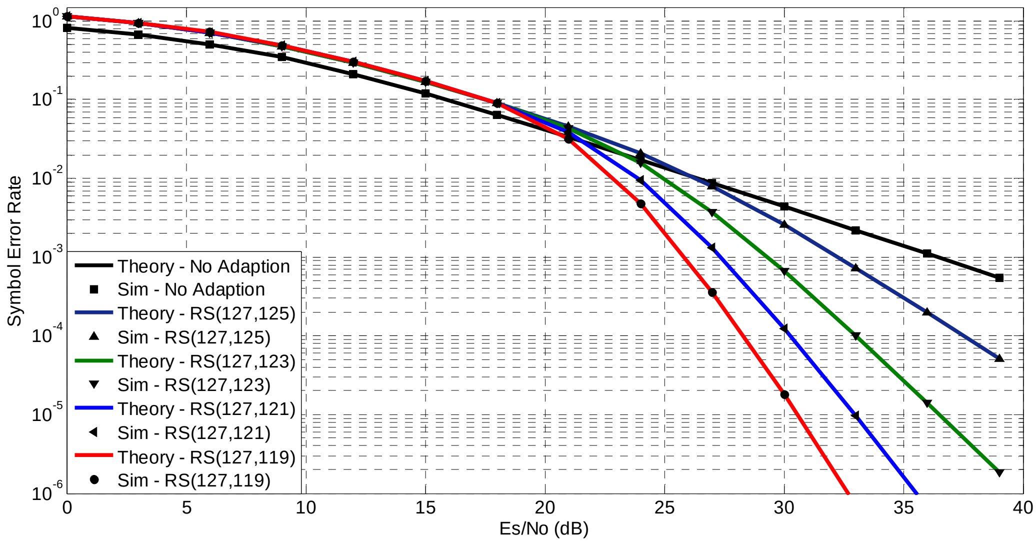

Figure 5-5 Symbol Error Rate for 16QAM in a Rayleigh fading channel

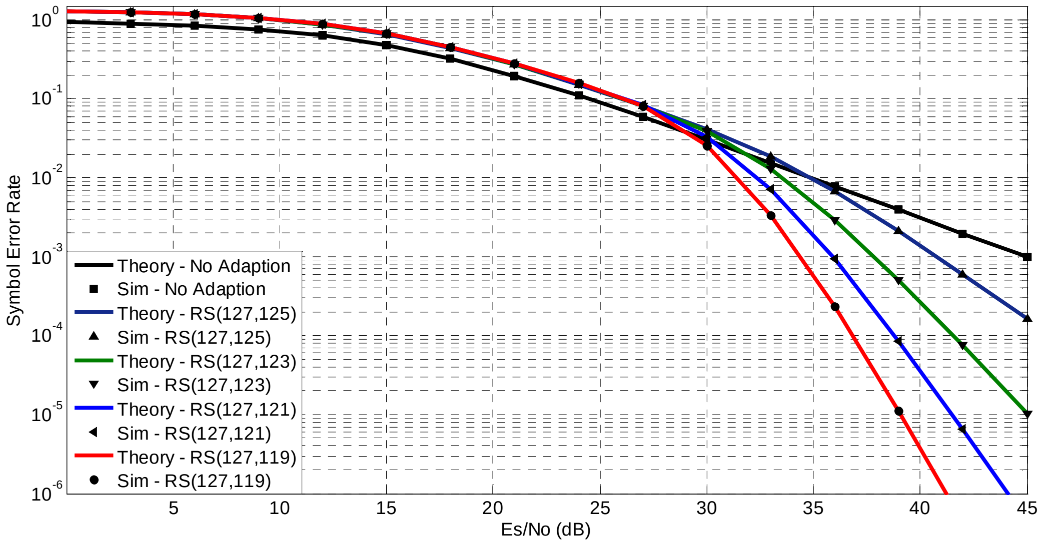

Figure 5-6 Symbol Error Rate for 64QAM in a Rayleigh fading channel

The simulations presented in Figures 5-4 – 5-6 represent RS coding with t = 1, 2, 3 and 4 in 4-QAM, 16-QAM and 64QAM respectively. The SER for each modulation size reaches the targets for $P_{vo} = 10^{-6}$ and $P_{vi} = 10^{-7}$ at very high SNR values (above 26dB). Using the adaptive techniques discussed in the previous chapters the system will be able to achieve these performance criteria at lower SNR values due to the SER improvements they provide.

5.4.2 Reed-Solomon Code with Power Adaptive Modulation

Using the Power adaption schemes discussed in Chapter 4 to increase performance over all channel conditions enables the system to successful transmit different media types by varying the number of code symbol that can be corrected. In this section the Power adaptive techniques discussed previously, namely Channel Inversion and Water-Filling, are implemented in the physical layer whilst at the application layer the information is encoded using Reed-Solomon coding.

Using the derived equation for Power adaption (4.2) and substituting it into equation (5.3) the general SER performance of the system can be expressed as

$$P_H = \frac{1}{2^m-1}\sum_{k=t+1}^{2^m-1}\binom{2^m-1}{k} \text{x}$$
$$\left(1-\left\{\frac{a}{p}\left\{\frac{1}{bP(\overline{\gamma})\overline{\gamma}+2} - \frac{a}{2}\frac{1}{bP(\overline{\gamma})\overline{\gamma}+1} + (1-a)\sum_{i=1}^{p-1}\frac{S_i}{bP(\overline{\gamma})\overline{\gamma}+S_i} + \sum_{i=p}^{2p-1}\frac{S_i}{bP(\overline{\gamma})\overline{\gamma}+S_i}\right\}\right\}\right)^{2^m-1-k} \text{x} \quad (5.4)$$
$$\left\{\frac{a}{p}\left\{\frac{1}{bP(\overline{\gamma})\overline{\gamma}+2} - \frac{a}{2}\times\frac{1}{bP(\overline{\gamma})\overline{\gamma}+1} + (1-a)\sum_{i=1}^{p-1}\frac{S_i}{bP(\overline{\gamma})\overline{\gamma}+S_i} + \sum_{i=p}^{2p-1}\frac{S_i}{bP(\overline{\gamma})\overline{\gamma}+S_i}\right\}\right\}^{k}$$

where the symbols for equation (4.2) can be found in Chapter 4 and the symbols used in to describe the Rayleigh fading channel can be found in Chapter 2.

The following discussions will use equation (5.4) as a theoretical expression to represent the adaptive system.

5.4.2.1 Channel Inversion

In Chapter 4, this adaptive technique successfully allowed the system to transmit information at the target P_E, which is equal to P_{vo}, and was able to achieve this for values above a SNR of 3dB in a Rayleigh fading channel, this can be seen in Figures 4-3 to 4-6. In this section the effect of the combining RS coding with Channel Inversion is discussed. Now that the SER requirement for P_{vo} can be met without error correcting coding, the idea is to change the t such that the different target SER requirements, namely P_{vi} and P_d, can be met.

Appling the same P_{max} calculated in Table 4-1 and substituting it into equation (5.4) the SER performance can be determined for Channel Inversion. The $P(\gamma)$ for Channel Inversion is defined by (4.3) and discussed in Chapter 4. The simulations using Reed Solomon coding on its own reached the required SER targets, P_{vo}, P_{vi} and P_d, by varying the correcting capabilities of the code. These simulations were simulated in a Rayleigh fading channel using 4-QAM, 16-QAM and 64 QAM modulations. The implementation of RS(127, k) with correcting capabilities of t = 1, 2, 3 and 4 in the application layer.

Using the theoretical expression for RS coding and using the Channel Inversion power adaptive policy, the SER values for each coding parameter t can be determined. The Table 5-1 shows the SER achieved for each value of t with a base SER of 10^{-3}. From this information, using t = 3 will satisfy the performance requirements for P_{vi} and using t = 4 will satisfy the performance requirements for P_d. These simulations are limited to an SER of 10^{-6}.

Table 5-1 Showing the Performance improvements from Reed-Solomon Coding

RS Coding Parameter (t)	No RS	1	2	3	4
SER	10^{-3}	10^{-4}	$0.7\ x\ 10^{-5}$	$0.3\ x\ 10^{-6}$	$0.9\ x\ 10^{-8}$

In the Channel Inversion simulations presented in Section 4.7, each modulation type used achieves 10^{-3}. In this section the application layer is completely independent from the physical layer, thus the performance increase due to Reed-Solomon coding is completely independent on the modulation type used.

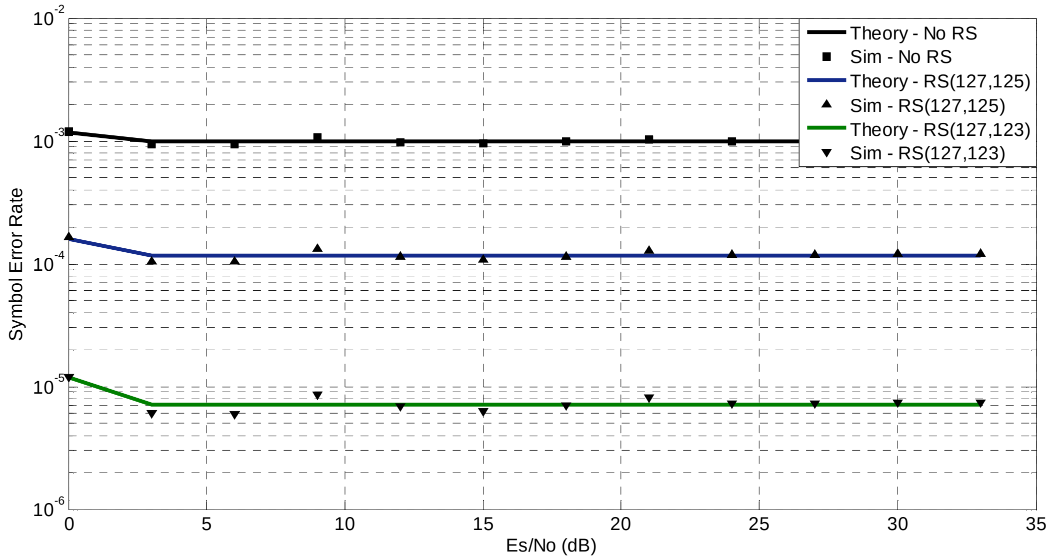

Figure 5-7 Symbol Error Rate for 4QAM in a Rayleigh fading channel using Channel Inversion power adaption

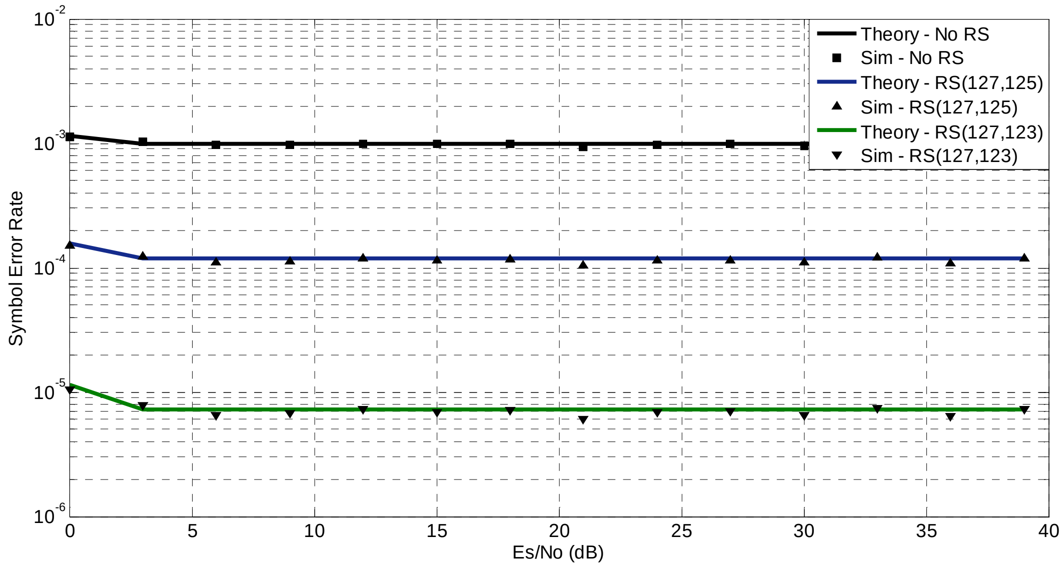

Figure 5-8 Symbol Error Rate for 16QAM in a Rayleigh fading channel using Channel Inversion power adaption

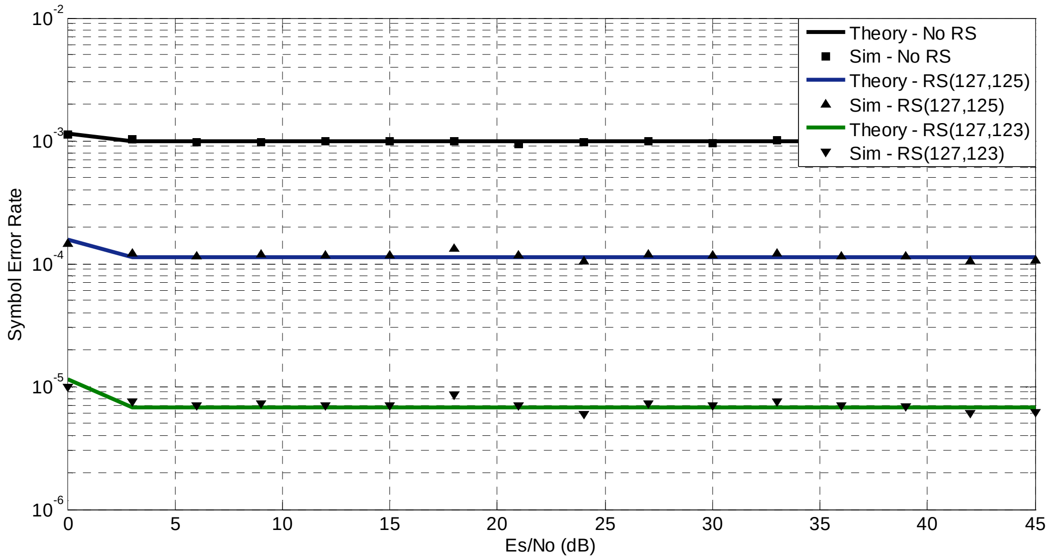

Figure 5-9 Symbol Error Rate for 64QAM in a Rayleigh fading channel using Channel Inversion power adaption

The Figures 5-7 to 5-9 show the performance improvement of using RS coding within a Rayleigh Fading channel. For 4, 16 and 64QAM the RS coding improves system performance from a SER of 10^{-3} to 10^{-4} for $t = 1$, a SER of 10^{-5} for $t = 2$, from Table 5-1 the SER improves to a value of 10^{-6} for $t = 3$ and 10^{-8} for $t = 4$.

Using Channel Inversion power adaption in the physical layer and RS coding in the application layer allows the system to maintain the initial SER of 10^{-3} and improve performance to 10^{-6} for video and 10^{-8} for data when required to.

5.4.2.2 Water-Filling

When channel conditions are favorable the Water-Filling adaption scheme transmits the information with the most power possible thus in these areas RS coding will be able to improve performance even further. The system SER performance can be determined by using the information for the cut off value found in Table 4-4 and substituting it into (5.4). The $P(\gamma)$ for Water-Filling is defined by (4.8) and discussed in Chapter 4. Using the Optimized cut off value the system will prevent using unnecessary power at low SNR since the SER requirements for voice, video and data cannot be achieved.

The results shown if Figures 5-10 to 5-12 are performed using a CLD approach with RS(127, k), with correcting capabilities of t = 1, 2, 3 and 4 in the application layer and 4-QAM, 16-QAM and 64 QAM modulation over a Rayleigh fading channel in the physical layer. The simulations are limited to an SER of 10^{-6}.

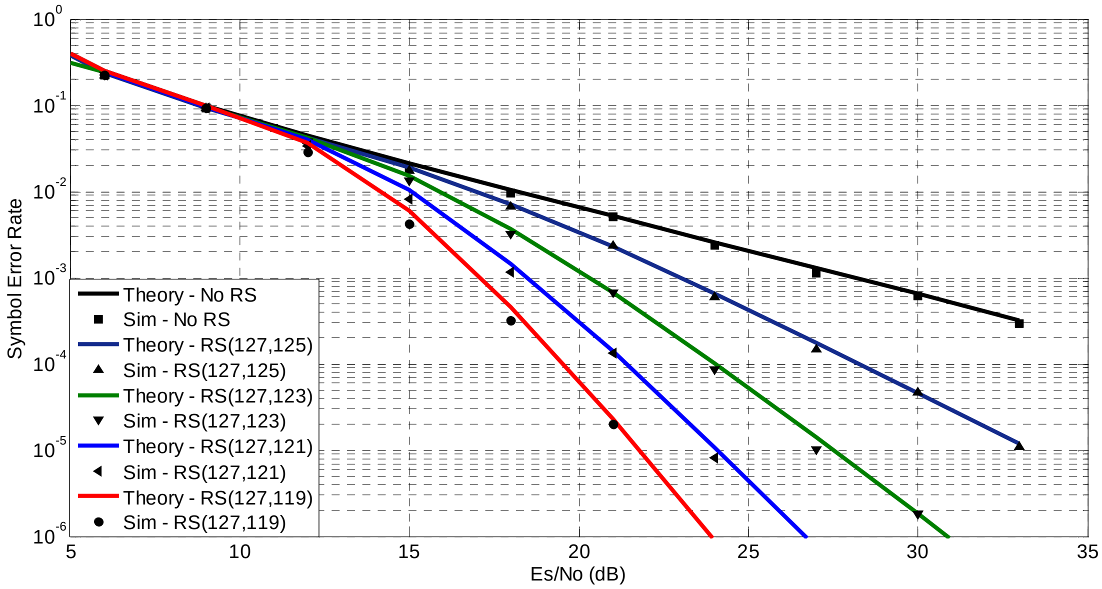

Figure 5-10 Symbol Error Rate for 4QAM in a Rayleigh fading channel using Water-Filling power adaption

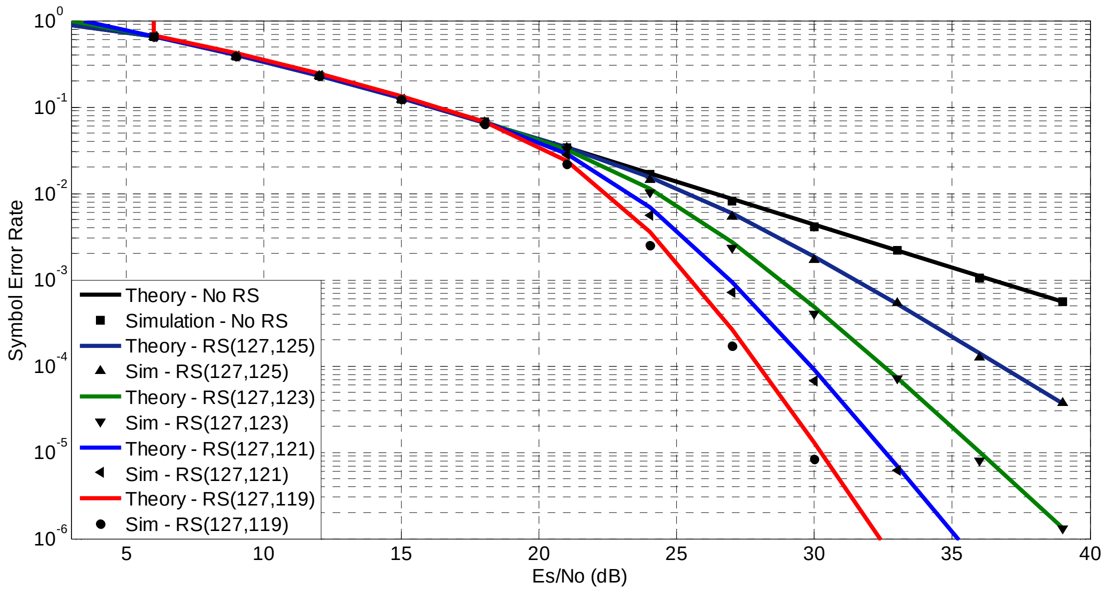

Figure 5-11 Symbol Error Rate for 16QAM in a Rayleigh fading channel using Water-Filling power adaption

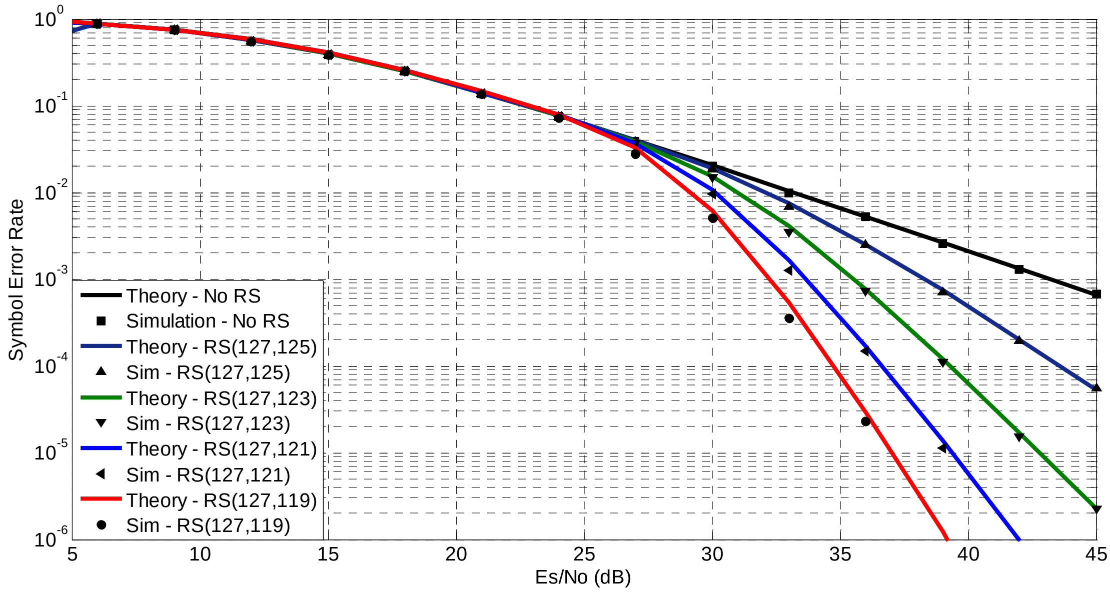

Figure 5-12 Symbol Error Rate for 64QAM in a Rayleigh fading channel using Water-Filling power adaption

The Figures 5-10 to 5-12 show the system performance using RS coding with Water-Filling power scheme, although the simulations were limit to 10^{-6} there is a clear indication that the more favorable the fading channel is the lower the correcting capability needs to be in order to meet the performance targets. However, when utilizing Water-Filling power adaption the more favorable the channel conditions are the higher the constellation size (modulation type) can be whilst still satisfying the system requirements for multimedia transmission. The simulations shown in Figures 5-10 to 5-12 confirm that it is possible to transmit the different media types using this Water-Filling power adaption scheme and RS coding combination.

In the next section rate adaptive modulation is added to the system with power adaptive modulation and Reed-Solomon coding. Using Water-Filling scheme it is possible to adapt the rate modulation and thus improve the throughput of the system.

5.4.3 Rate Adaptive Modulation, Power Adaptive Modulation and Reed-Solomon Coding

Having satisfied the SER criteria for each media type in the previous sections using Power adaption and RS coding, this section will include Rate Adaption and attempt to improve spectral efficiency (throughput) of the system. Since Channel Inversion cannot be adapted by rate, the Water-Filling power adaption will be used. The boundary points in Figures 5-13 to 5-15 represent the different media's requirements and indicate in which areas the system is able to adapt the rate.

In order to calculate the points where the system will make the transition from one modulation type to the other, numerical analysis must be performed on (5.4). Tables 5-2 to 5-4 show the boundary points calculated for each media type and the SER criteria that need to be satisfied.

Table 5-2 Showing SNR values that satisfy SER for voice which is 10^{-3}

Modulation	4QAM	16QAM	64QAM
SNR (dB)	17.10	25.46	32.24

Table 5-3 Showing SNR values that satisfy SER for video which is 10^{-6}

Modulation	4QAM	16QAM	64QAM
SNR (dB)	23.90	32.39	39.18

Table 5-4 Showing SNR values that satisfy SER for data which is 10^{-7}

Modulation	4QAM	16QAM	64QAM
SNR (dB)	25.97	34.48	41.26

The Reed-Solomon code used in the Tables 5-2 – 5-4 all used RS(127,119) since the idea is to adapt the rate to improve spectral efficiency (throughput) not to lower complexity.

5.5 System Performance

The simulated results confirm the numerical analysis and calculated results in Tables 5-2 to 5-4. The Figures 5-13 – 5-15 show the transition from one modulation to the next and each satisfy the SER for the specific media type. The program used was MATLAB v7, with M-QAM (M = 4, 16 and 64) modulation and a Rayleigh fading channel model. The packet size for the all the simulations in this chapter was 127 symbols and the channel and noise parameters used were as described from Section 2.4.2. The channel state information was assumed to be perfect with no delay or errors. The number of summations p performed in expression (5.4) was 20.

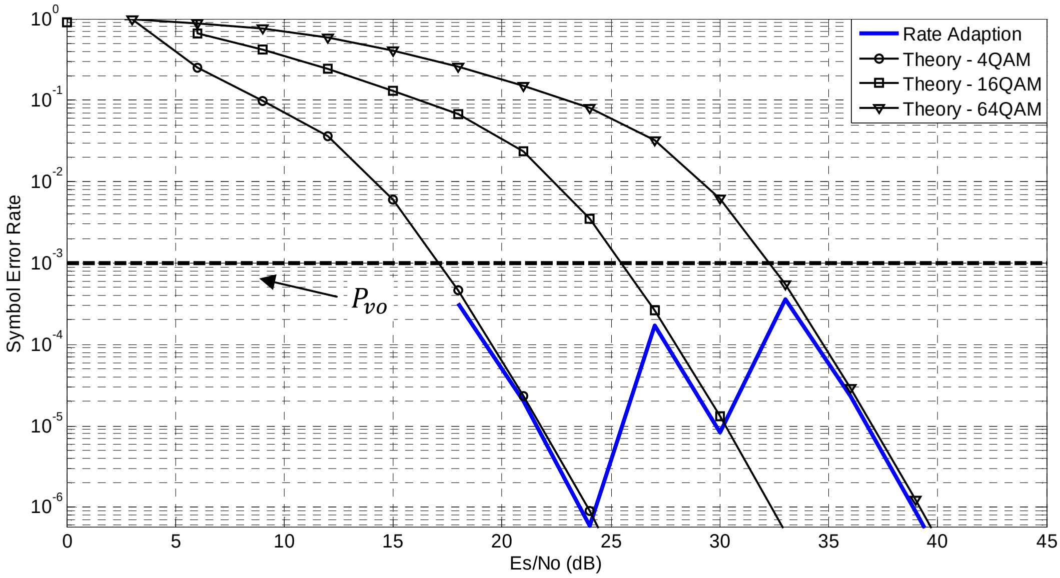

Figure 5-13 showing Rate adaption for voice media in a Rayleigh fading channel using Water-Filling power adaption and RS(127,119)

Figure 5-13 shows the simulated rate adaptive modulation for media requiring the performance target of voice media (P_{vo}), shown in blue. Figure 5-14 and Figure 5-15 show the theoretical rate adaptive modulation, shown in red, for performance targets of video media P_{vi} and data media P_d respectively. The simulations shown in this chapter are limited to a symbol error probability of 10^{-6} thus the theoretical rate adaptive modulation was shown to provide a visual representation of the rate adaptive modulation for media that requires SER performance lower than 10^{-6}. Furthermore the simulations confirm that the performance targets shown in Table 5-3 and Table 5-4 are attainable when using RS coding in the application layer combined with rate adaptive modulation in the physical layer.

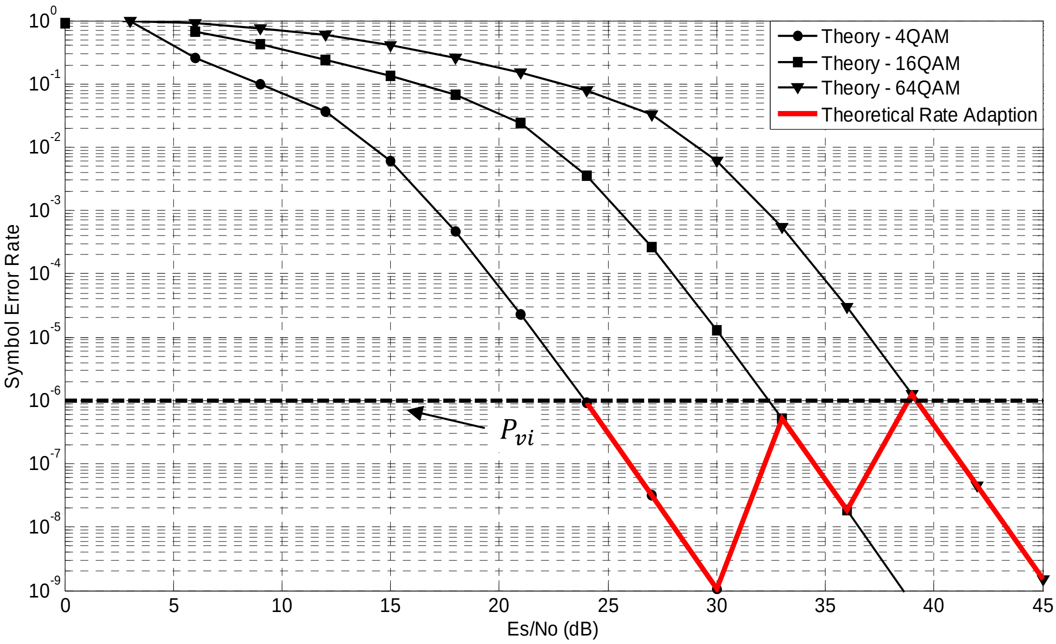

Figure 5-14 showing theoretical Rate adaption for video media in a Rayleigh fading channel using Water-Filling power adaption and RS(127,119)

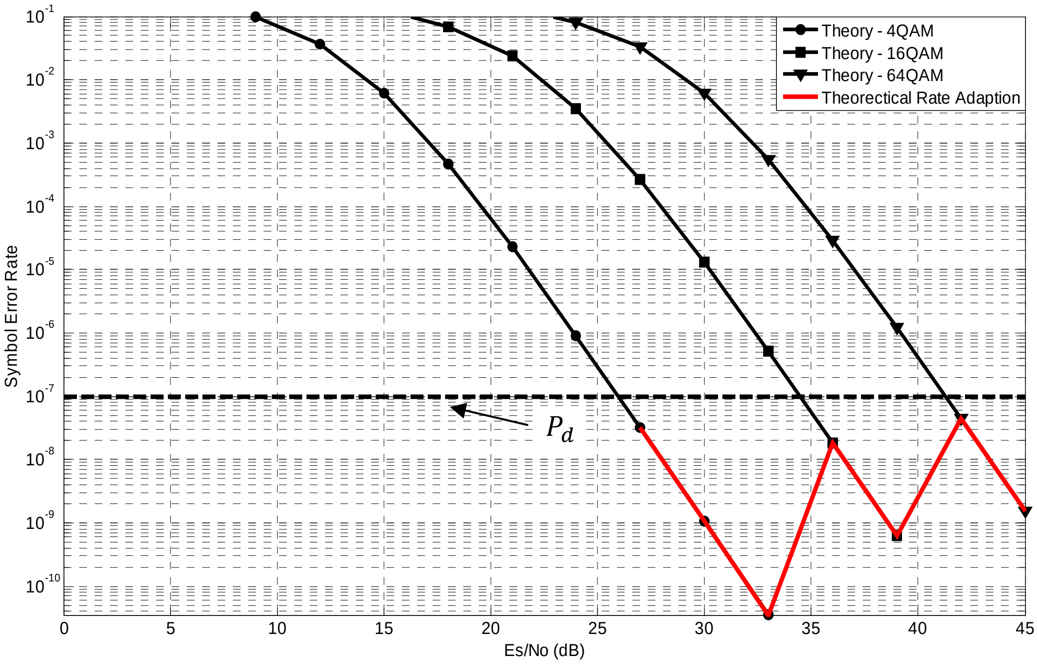

Figure 5-15 showing theoretical Rate adaption for data media in a Rayleigh fading channel using Water-Filling power adaption and RS(127,119)

Combining the rate adaption with the Water-Filling power adaptive policy in the physical layer and Reed-Solomon coding in the application layer reveals the great potential that cross-layer design system have. These adaptive techniques allow the system to transmit different types of media whilst achieving each of their respective performance targets by constantly adapting their parameters depending on the channel conditions.

5.6 Chapter Summary

In this chapter, Reed-Solomon coding was investigated at the application layer and introduced to the system model presented in Chapter 2. The first section in this chapter dealt with the implementation of RS at the application layer without any adaption in the physical layer. The SER performance expression was derived using the work done in [3], [17] and [18]; and simulated results show the SER improvement of the system, specifically at high SNR. The second section investigated a CLD approach by adding power adaption at the physical layer. The aim was to utilize the physical layer and the application layer interdependently to increase system performance in terms of SER. Using the Channel Inversion and Water-Filling schemes, simulation results showed that both adaption techniques were able to transmit multimedia. In addition, it was found that it was possible to adapt the modulation rate whilst using the Water-Filling power adaption and RS coding of RS(127,119). The performance targets for each media were set using the boundary points calculated by means of numerical analysis, these performance targets were used in the simulations to provide a comparative reference for the system performance. Simulations confirmed the numerical analysis and provided graphical confirmation that the QoS were achieved for each media type.

Chapter 6

Conclusion and Future Work

One of the criteria in determining the success of a wireless communication is how well the quality of services is satisfied. Multimedia transmission requires certain Quality of Service requirements if performance is to be considered satisfactory. For voice, video and data the quality of service requirements differ. For voice and video, delay is a more important factor to consider than for data. Furthermore, error rate is lower for data and video than for voice. Thus it is essential for the system to constantly adapt its parameters, which depend on the traffic type, channel conditions, and network impairments in order to achieve satisfactory performance. cross-layer design utilizes different layers in the protocol stack to optimize parameters that impact performance, which the conventional protocol structure is not able to. Different cross-layer design approaches provide different advantages and disadvantages and the more integrated the layers are the more complex the system becomes, examples of these approaches were discussed with specific attention given to the approaches that took into account both the physical and application layers. This investigation began with an examination of the physical layer and discussions of the types of adaption were considered. Rate adaption and power adaption were then concentrated on and the different techniques and schemes were analyzed. This was followed by a discussion considering the application layer and multimedia transmission in general.

A closed-form solution for a Rayleigh fading channel is difficult to obtain, in Chapter 2 an expression of the Symbol Error Rate in a Rayleigh fading channel was derived and used throughout this investigation to prove that the system simulations performed match the theoretical expressions. Rate adaption was then discussed and simulations showed the improvement of spectral efficiency. This was further advanced with a technique that split a packet of information in to two parts and modulated each part with different constellation sizes. The idea was to improve the spectral efficiency in the SNR regions in which the system over satisfies the quality of service requirements in terms of SER. This was confirmed with simulations using the values calculated from the expression describing the system performance. Power adaption was discussed thereafter highlighting the two main schemes used in current systems, namely the Water-Filling scheme and the Channel Inversion Power scheme. Derivations of the system implementation were shown and calculations were performed with the results shown in the various tables. Simulations were then provided to confirm the theory expressions.

A cross-layer design approach was then implemented using the application layer and physical layer. Firstly, the application layer is discussed with the idea that block coding will ensure that each multimedia traffic type is able to satisfy their own quality of service requirements in terms of SER. Reed-Solomon block coding was implemented and matching theoretical expressions were used for confirmation. The cross-layer approach was then implemented using power adaption in the physical layer and Reed-Solomon coding in the application layer. Results show that with the different Reed-Solomon parameter settings , each traffic type is able to be transmitted well within their quality-of-service requirements. This is further extended using Rate adaption when the system implemented the Water-Filling scheme in the power adaption. Results show that each multimedia traffic type is able to meet quality-of-service requirements at operable signal-to-noise values. The ability of transmitting different types of media when the system utilizes the Water-Filling power adaptive policy with Reed-Solomon coding shows the true power of using cross-layer designed systems. With the capability to constantly adapting the system parameters depending on the channel conditions permits the system to perform powerfully, even in less favorable conditions.

The aim of future work should be to design a system that uses its resources more efficiently. The optimal use of power can be researched such that the quality-of-service requirements are not over satisfied. In addition, spatial diversity can be implemented on this system to further improve the error rates.

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