Doctoral Thesis
博士論文

Dependable Medical Network Using Super External Channel Code with Existing Cellular Networks According to Various Medical QoS Levels
医療情報の QoS レベルに応じた既存セルラーネットワークに外部通信路符号を用いた超高信頼医療用ネットワーク

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13SD191
Emtithal Ahmed Talha Mohamed
イミテサル・アハメド・タルハ・モハメド

Supervisor: Professor Ryuji KOHNO
指導教官: 河野隆二　教授

Department of Physics, Electrical and Computer Engineering
Graduate School of Engineering
Yokohama National University
Kohno Laboratory
横浜国立大学大学院 工学府 物理情報工学科専攻 河野研究室

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Notation

The notation that adopted in this thesis is listed in the following table.

AM	Acknowledged Mode
AM	Amplitude Modulation
ARQ	Adaptive Repeat Request
AWGN	Additive White Gaussian Noise
BCH	Bose Chaudhuri Hochquenghem
BCH	Broadcast Channel
BER	Bit Error Rate
BM	Branch Metric
BPSK	Binary Phase Shift Keying
BN	Burst Noise
CC	Concatenated Codes
CPCH	Common Packet Channel
DCH	Dedicated Channel
D_{free}	Free distance
DL	Downlink
DSCH	Downlink Shared Channel
E	Trellis Paths
ECC	Error Correction Codes
ECG	Electrocardiogram
E_b/N_o	Bit Energy to Interference
EEG	Electroencephalography
EMG	Electromyography
EU	European Union
EUTRA	Evolved Universal Terrestrial Radio Access
ETSI	European Telecommunication Standard Institute
FACH	Forward Access Channel

FDD	Frequency Division Duplex
FEC	Forward Error Correction
G	Guard Space
G	Generator Polynomial
GSM	Global System of Mobile communication
H-QoS	Higher QoS
ICT	Information and Communication Technology
I/P	Input
K	Constraint Length
LCM	Least Common Multiple
L-QoS	Lower QoS
LTE	Long Term Evolution
MAC	Media Access Control
MAP	Maximum a Posteriori
MICT	Medical Information Communication Technology
MLSE	Maximum Likelihood Sequence Estimator
MNC	Medical Network Channel
M-QoS	Medium QoS
NB	Narrow Band
O/P	Output
PCH	Paging Channel
PDF	Probability Density Function
PER	Packet Error Rate
PHY	Physical Layer
PM	Path Metric
PoE	Probability of Error
QAM	Quadrature Amplitude Modulation
QoS	Quality of Services
QPSK	Quadra Phase Shift Keying
R	Coding Rate
RACH	Radio Access Channel

RF	Rayleigh Fading
RLC	Radio Link Control
RS	Reed Solomon
RSC	Recursive Systematic Convolutional
SDVA	Soft Decision Viterbi Algorithm
SISO	Soft Input Soft Output
SNR	Signal to Noise Ratio
SOVA	Soft Output Viterbi Algorithm
SPO_2	Pulse Oximetry
T	Error
T	Throughput
TDD	Time Division Duplex
TM	Transparent Mode
TrCH	Traffic Channel
UL	Uplink
UM	Unacknowledged Mode
UMTS	Universal Mobile Telecommunication System
UTRA	UMTS Terrestrial Radio Access
UWB	Ultra Wide Band
VA	Viterbi Algorithm
WBANs	Wireless Body Area Networks
WCDMA	Wide Code Division Multiply Access
W_d	Wight Spectrum
WLANs	Wireless Local Area Networks

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Dedication

To My Parents

Abstract

Cellular networks play an important role in the daily life of communications. Global System of Mobile communication (GSM), Universal Mobile Telecommunication System (UMTS) and Long Term Evolution (LTE) system are the main generations of current cellular networks. In order to integrate wide variety of wireless multimedia services, these cellular networks are upgraded from generation to generation to provide much more services than basic voice calls. In general aspects, since GSM upgraded to LTE, the enhancements have been found in the whole mobile services such as: transmission way, transmission speed, data rate, channel capacity, error correction techniques, and Quality of Services (QoS).

In deeply considerations, the cellular network design phases are not well done for the medical applications such as: medical data transmission, hospital networks or even emergency healthcare units. The medical applications need stronger reliable and dependable telecommunication network systems, these are important requirements for a critical health information. Therefore, a new network system was proposed in this dissertation, it was designed as a wireless medical network focusing on the economical demand of reliable medical infrastructure networks, and to establish strong dependable medical networks. The dissertation work is focusing on the detecting and correcting channel errors in order to obtain reliability, which is required for the various medical data QoS. The proposed system uses the existing mobile cellular networks with a sophisticated channel coding techniques. The proposed system is called as Medical Network Channel (MNC) system. The thesis proposes a new highly reliable

communication channel for medical uses via Physical Layer (PHY). MNC is serving the transmission of medical data from the Wireless Body Area Networks (WBANs), to the cellular networks such as, UMTS and LTE networks.

In general, the target is to design MNC system that transmits WBANs medical data through the cellular networks with approximately error-free as much as possible. In order to carry out this target, the dissertation proposed a new method by the use of coding theory techniques. The dissertation designed extra channel codes and decodes for MNC, which can be consider as a concatenated error detection and correction technique. In order to protect medical data more robust against channel errors than other daily life communication data via the existing cellular networks, the new extra channel has been introduced.

The MNC has been designed by adding new outer code with exists inner UMTS or LTE standard codes, which make together special concatenated channel codes. The design of an extra channel code depends on two matters. Firstly, depend on the medical QoS classes. Secondly, depend on remain errors from the inner cellular codes, such as: UMTS inner decoders when MNC is using UMTS channel or LTE inner decoder when MNC is using LTE channel. Regarding to use Uplink (UL) / Downlink (DL) channels based on the inner channel code of MNC. The UL/DL channels code via the cellular UMTS channels and the UL channel code via the cellular LTE channel are proposed in dissertation. The outer channel code has been optimized to use convolution code techniques as a main error correction code. The convolution codes, has good performances in compare to the other Forward Error Correction (FEC) codes, and it's easy to control the performance results by the numbers of redundancy bits on the design.

The technical parameters of the extra channel such as: code rate and constraint length are an only way to optimize and design adaptive MNC for various medical data QoS priority levels. That is because, the inner channel code is fixed related to the international standards of mobile communications.

The WBANs has eight priority levels of medical data QoS. The design of MNC proposed system is considering all WBANs priority levels. MNC proposes to categorize the eight priority levels in three main sets for priority levels such as: lower QoS priority level, medium QoS priority level and higher QoS priority level. In order to demonstrate the feasibility of using the PHY channel design of MNC over UMTS technology or LTE technology, the accomplishment of QoS for medical data has been investigated in this dissertation. On the other hand, the dissertation optimizes the theoretical derivation of the Probability of Error (PoE) bounds and also computer simulation calculation as well, for MNC system. The numerical performances results such as: Bit Error Rate (BER) and throughput results have been provided under different assumed noisy channel conditions such as, Additive White Gaussian Noise (AWGN), Rayleigh fading, and burst noise channel. Moreover, in MNC proposed system design, when the channel is affected by burst noise; the extra outer code is uses burst error correcting convolution code, which uses block interleaver between the inner cellular codes and the extra optimized outer code.

According to MNC proposed system and its results that provided in this dissertation, it can be say without any other reliable network infrastructure, the cellular networks such as: UMTS and LTE could be apply for the applications of medical data transmission from the WBANs, where high mobility and low cost are necessary.

Chapter 1

Introduction

1.1 Background

Medical tele-monitoring systems are a part of tele-communication techniques that access delivery to healthcare services, and are the main applications for Medical Information Communication Technology (MICT). Recently, Information and Communication Technology (ICT) for medical and healthcare applications have drawn substantial attention, which makes an important role to support dependable and effective medical technologies to solve significant problems in any society especially in developing countries, such as regional variation in medical services, ever-increasing medical expenses and lack of physician. Furthermore, MICT provides a new pattern to research and development areas due to innovative integration between medicine and engineering. Although MICT has been widely recognized as an evolving area in a biomedical engineering research field, the dependable communication technologies for dependable and reliable medical services have still not been realized and developed so far; therefore, it is quite necessary to establish an essential research field for MICT.

Newly the WBANs technology is proved in the latest standardization as IEEE 802.15.6 [1]. WBANs standard aims to provide an international standard for short range, low power and extremely reliable wireless communication within the surrounding area of the human body, supporting an enormous range of data rates from 75.9 Kbps Narrow

Band (NB) up to 15.6 Mbps Ultra Wide Band (UWB); for various sets of applications [2]. WBANs technology is growing as a key technology for MICT to transfigure the future of healthcare, therefore, WBANs has been attracting a great treaty of attentions from researchers both in academia and industry in the last few years. The applications of WBANs are covered huge areas such as ubiquitous health care, military, entertainment, sport and other various areas. Concerning to use the WBANs technology for medical is a key for MICT, and resulting to that WBANs are expected to cause a dramatic shift in how people manage and think about their health [3]. A QoS is a major concern for of WBANs medical application. Therefore, the researcher concerning QoS issues in WBANs should handle all of that very seriously by effective way, such as, real time data transmission system, data rate, end to end data transmission services, data transmission accuracy rate, latency, delay time, low power data transmission, data availability, minimum data loss, data security, network coverage, frequency, bandwidth, throughput and reliability matters [4].

The cellular standards have been adopted by the European Union (EU) as a mandatory standard for member states and are spreading throughout much of the world. As a comparison from one standard to other, we can find enhancement in the all aspects such as; transmission speed, transmission way, data rate, error correction capabilities, channel capacity and QoS as general. UMTS is the main standard of Third Generation (3G) with Wide Code Division Multiply Access (WCDMA) air interface and LTE is a main standard of Fourth Generation (4G). The bandwidth of a WCDMA is 5 MHz, and it is enough to provide data rates of 144 and 384 Kbps, and even 2 Mbps in good conditions. On the other hand, LTE provides UL peak rates of 75 Mb/s and QoS facilities permitting a transfer latency of less than 5 ms in the radio access network and supports accessible carrier bandwidths, from 1.4 MHz to 20 MHz. UMTS and LTE are used to cover both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) operations and integrate a wide variety of wireless multimedia services with high data transmission rates, capable of providing much more than basic voice calls [5]-[7].

The way to connect WBANs technology network with other networks such as cellular networks UMTS or LTE is a key point for this thesis work, as is shown in Figure 1.1. The thesis is focusing to build novel way of the combination between WBANs and cellular networks for medical uses adopted as Medical Network Channel (MNC) to serve the WBANs medical data transmission through the ready existing cellular networks. Therefore, the thesis concept is to use the error controlling coding and decoding base on the concatenated channel codes with the cellular ready existing codes to design the MNC proposed system.

The related works in this area have been considering different ways such as; "iterative decoding of parallel and serial concatenated codes performance and analysis", which use the concatenated codes for the consumer electronics networks with no application to medical networks [8]. "Performances analysis of multiplexed medical data transmission for mobile emergency care over the UMTS Channel", which use UMTS cellular network for the emergency medical uses without focusing on the dependability matters [9]-[10]. "Power-aware wireless communication system design for body area networks" and "the impact of source and channel coding in the communication efficiency of wireless body area networks", these apply change of ready existing channel code inside the WBANs without thinking on the connection to the other networks such cellular networks [11]-

[12]. "Wireless body area networks: a survey" and "QoS taxonomy towards wireless body area network solutions", which is a kind survey for WBANs and QoS needed by introducing the number of researches in the medical area with no modify the existing problems [3]-[4]. All of these related works are introduced to show the originality of the thesis policies and concepts.

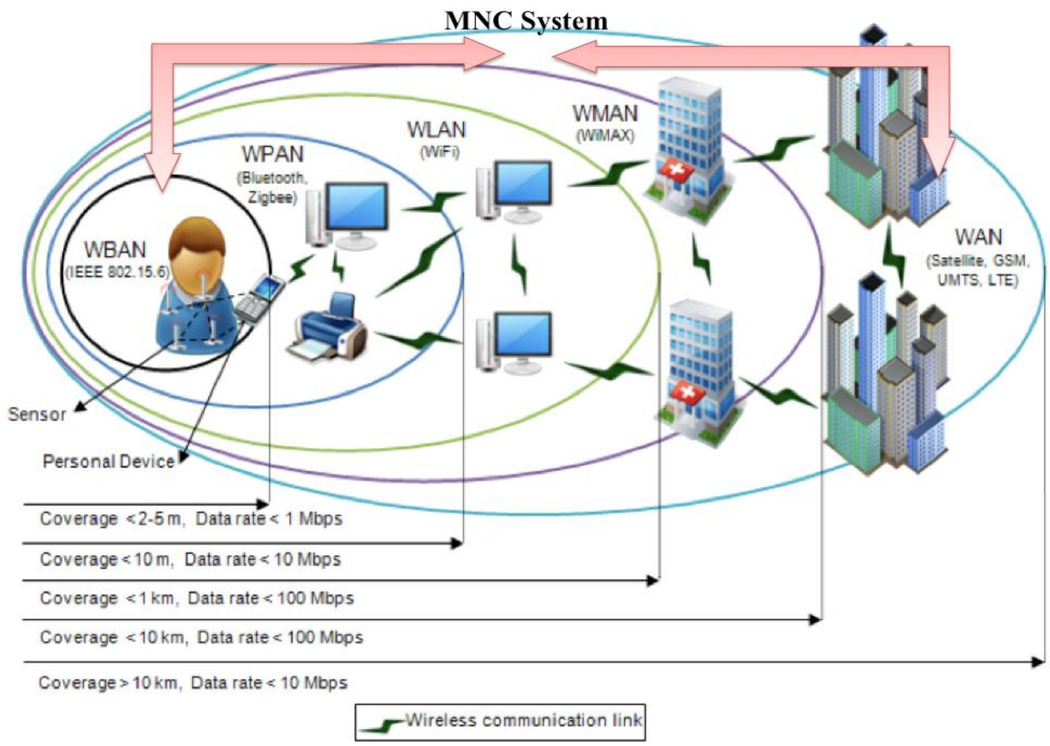

Figure 1.1 Main Key-Point of the Thesis Work

1.2 Rational; Motivation and Aims

The combination of WBANs and cellular networks technologies is necessary, since it can increase the demands of reliable medical networks infrastructure economically by providing faraway medical data transmission that can achieve the medical QoS requirements. Correspondingly, the combination can be very unique novel way to establish dependable medical networks from the ready existing networks for most of the developing countries. Reliable transmission of medical data is critical and essential since is related to diagnosis and treatments human body diseases. In ICT field, the reliable transmission procedures must guarantee detection and correction of erroneous transmissions. However, the transmission channel is often subject to various disturbances and interferences from the external environment conditions (noise) [13].

The thesis focuses on the dependability of medical tele-monitoring system from WBANs through UMTS and LTE via MNC system at this point. Reliability of medical data transmission via MNC is defines as the probability of the MNC system to operate successfully, which mean transmitted medical data are reach their destination completely uncorrupted and guarantee the minimum performances with lower error rate as much as possible under different environment conditions. There are different methods can be employed to overcome the channel impairments, such as increasing transmission power or the use of error control coding schemes in information theory field.

Meanwhile the current cellular standards have not been designed for the medical reliable networks, however has designed for more daily life communications. According to that, the thesis proposes reliable and dependable MNC via UMTS and LTE ready existing networks by focusing on using the error control coding techniques to build MNC system. The MNC end to end services should satisfy the minimum performances according to the different environment channel conditions and also QoS of medical data. The reliabilities issues of medical data transmission supporting transmission of the various QoS medical data is need to be solving when we introduce the new MNC system by this thesis work. A high level of reliability can be obtained by introducing redundancy bits in the signal transmission (encoding). The system of the thesis, when develop and implement, will improve exchange of medical information easily from the WBANs via cellular networks. It will enable better utilization of limited healthcare resources, early diagnosis and treatment in certain events and reduce visits to healthcare facilities with a major reduction in cost for any society.

1.3 Problem Statement and Assumptions

The WBANs medical data is sensitive and any type of noise can corrupt it during transmission. Although, the cellular standards including significant amounts of error detection and correction techniques, which are designed for daily life communications mainly, however, some errors may still be present in the received data, and these transmission errors are not serious for the daily communication but when we considered for medical uses it can have fatal outcomes. For the reason that UMTS and LTE codes are designed for a certain levels of channel condition and if the error becomes more than estimated condition then the error become more seriously and the cellular networks standards perform worse using the preexisting error detection and correction capability.

The reliability problems through the MNC system need to solve by covering all the QoS medical data from WBANs an also the different channel environment such AWGN, easy and hard Rayleigh fading and burst noise channels. The QoS levels has different reliability required based on the BER for various medical data and other constrains [14]. The error control coding play an important role in modifying the reliability issues. The concatenated codes are one of the error control coding techniques that have been widely adopted due to its simplicity and effectiveness [15]-[18]. Therefore, the thesis proposes a novel way of conducting error control encoding and decoding with QoS constraints by using the concatenated codes techniques to build MNC system. Consequently, the thesis works intend to add extra channel code in order to combine the WBANs and the cellular networks and optimize the technical parameters for this extra channel depending on the reliability required for the medical data QoS levels and channel conditions as well. Therefore, the adaptive external channel codes choice has six pairs of encoding and decoding, three for QoS levels (high, medium and low) then two for the channel condition (normal such AWGN or simple Rayleigh fading and worse such as hard Rayleigh fading or burst noise).

The restrictions of UMTS and LTE channel codes are a standard, which is fixed by the European Telecommunication Standard Institute (ETSI) [5]-[7]. The technical parameters cannot be changed in order to provide good system performance. The only way is to design and optimize good extra outer channel codes with strong decoding capabilities resulting in better performance for MNC to transmit the WBANs medical data robustly.

1.4 Thesis Objectives and Contributions

The objective of the thesis is to design a reliable and dependable MNC system through the cellular networks to provide reliable transmission for all QoS of medical data coming from WBANs. The structure design of MNC is based on channel coding that using concatenated channel codes technique in the serial manner which adds extra channel codes to the cellular UMTS or LTE codes. The inner channel codes in MNC are a cellular network standard UMTS or LTE error correction codes that it can’t be changeable in order to enhance the error performance, regarding to the international standard. On the other hand, the extra outer channel code in MNC is changeable parameters for achieving different QoS constraints of medical data, which used the convolution code as a main error correction technique. Then, it will add WBANs connection end to end to this MNC system using WBANs standard error correction techniques itself. According to QoS of WBANs Output (O/P), we decide whether MNC can be with or without extra code. The thesis thinks about categorize the 8^{th} level QoS of WBANs to three different QoS (lower, medium and higher) set levels. To achieve the chosen set, there is a need for external code with limited or strong error correcting capability with high/medium/low coding rate and redundancy. By that techniques the MNC system is adaptive to varying propagation conditions and also adaptive to various QoS constraints. The UMTS and LTE has limited capabilities for correcting the hard PHY errors such as hard Rayleigh fading and burst noise. Therefore, the work here focusing to overcome different PHY errors that may occurs during the transmission in unpredictable way, making the channel situation time to time change. The thesis need to realize medical data transmission with different assumed three QoS levels under a condition where BER ranges between 10^{-3}~10^{-7}. The MNC here could be adaptively applied to such different kind of physical assumed errors giving acceptable MNC system, which reliable for medical transmission.

The thesis finds to investigate the characteristics and the performance of the MNC system under various conditions may occur during the transmission such as AWGN as single-path, Rayleigh and burst noise as a multi-path distortion. Although this thesis works contributions is to serve transmission of medical data by high level of reliability required for such QoS of medical data by introducing MNCs. The multi-user's environment and the higher digital communication layers such as Media Access Control (MAC), network layers and application layers are remaining problems for the future works. However, the current contributions are as in different parts. Firstly, study and simulate the UMTS, LTE and WBANs data channels code modules under different noise conditions to investigate and test the error correction performance on those ready existing technology. Secondly, design the newly MNC proposed system with adaptive external channel codes, and calculate the PoE theoretically and also by computer simulations for different chosen technical parameters of external outer code to evaluate and compare their BER performances and throughput as well. Investigate the performance of the MNC under different noise channel that may occur during the transmission such as AWGN, easy and hard Rayleigh fading and also burst noise channels by calculating the error performances for MNC system. Finally, we have been solved and completed PHY layer task of this thesis by building our MNC system, which is reliable and dependable for various QoS of WBANs medical data via different environments' transmission channel.

1.5 Thesis Organization

The thesis is organized as follows, which cleared in Figure 1.2. In Chapter 1 Introduction, the background about the medical reliable and dependable proposed system networks is addressed, and in addition, the explanation about rational, problems need to be solve, objectives and contribution of the thesis are given. In chapter 2 the ready existing technologies and the primary data used in the thesis works are introduced such as; medical ICT that based on WBANs, Also error correction codes which may be used later in this thesis work and the PHY layer transmission channel environments are addressed carefully. The investigation of cellular UMTS and LTE channel codes standards and their capability for transmitting medical data are addressed as well. In Chapter 3 the concept and the diagrams of the MNC proposed system via cellular network are proposed. The effectiveness of the adaptive selection of the external channel codes to design a MNC base on the QoS and the channel condition is introduced in chapter 4. In chapter 5, all the theoretical performances and numerical evaluations of the MNC proposed system has been analyzed and detailed for AWGN and Rayleigh fading channels. The system optimizations and all the related simulation performance results are introduced in chapter 6. Finally, a conclusions and future works are given in chapter 7.

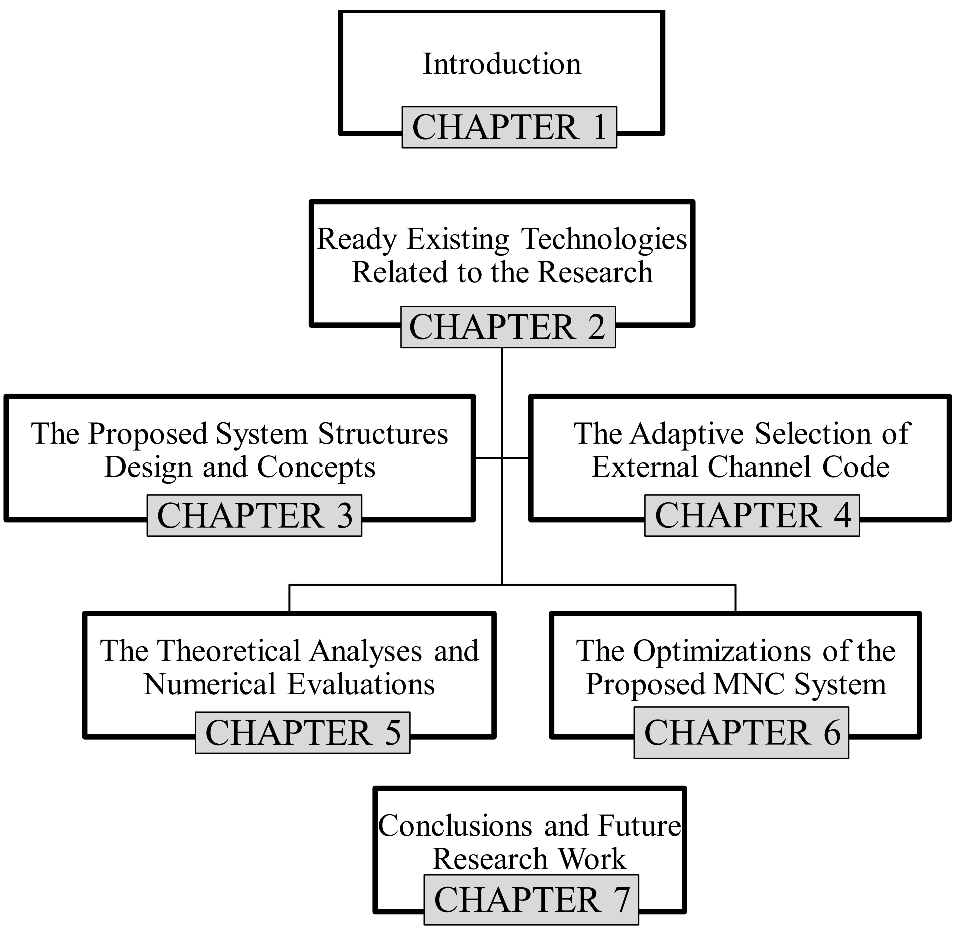

Figure 1.2 Illustrates the Outlines of the Thesis Work

Chapter 2

Ready Existing Technologies Related to the Research

2.1 Reliability in Digital Communications Systems

In digital communication systems including MICT networks, errors can occurs from time to time in data transmissions systems. These errors can come from different sources such as, random noise, channel fading, interference, or physical defects. These channel errors must be reduced to an acceptable level to ensure the quality of data transmission and to have system more reliable. Reliability can be done by the use of errors detection and errors correction techniques and it can test and analyze by calculating the BER or throughput [19-22]. The reliability of each medical or non-medical data can be analyze theoretically by calculating Error Interval (EI) that is a time between errors as in (2-1)

$$EI = L_{data} \big/ \left(E_{data} \times R_{data} \right) \qquad (2\text{-}1)$$

Where L_{data} is the data length (bit) and R_{data} is the data rate [bit/sec] and E_{data} is the error rate that depends on the data coding method [23].

2.1.1 Types of Errors [Physical Transmission Radio Channels]

The Path between the transmitter and the receiver called transmission channel, this channel being random in nature that is the most uncontrollable parameter in an end-to-end communication system. A number of effects introduced by the channel cause distortion in the transmitted information and the making of correct estimation for the data bits at the receiver are difficult. These effects collectively called noise vary in nature based on the type of channel.

The noise or errors can affects each transmitted symbol independently on memory-less channels, and not independently in the channels with memory. On the channel without memory, each transmitted bit has a probability p of being received incorrectly and probability $1- p$ of being received correctly. Thus transmission errors occur randomly in the received sequence the memory-less channels called random-error channel, and the codes devised for correction called random-error-correcting codes. On the other hand, in the channel with memory there are two states for this kind of channel, a "good state" in which transmission errors occur infrequently $p_1 \approx 0$, and a "bad state", in which transmission errors are highly probable, $p_2 \approx 0.5$. The channel is in the good state occasionally can shifts to the bad state due to a change in the transmission characteristics. As a consequence transmission errors occur in clusters or bursts because of the high transition probability in the bad state, and channel called burst-error channels. The codes devised for correcting burst errors are called burst-error-correcting codes. Some channels contain a combination of both random and burst error channels the correction code called burst-and-random- error-correcting codes [15].

2.1.1.1 AWGN Channel

White noise is a noise whose power spectral density is uniform over the entire range of interest frequencies. The term white is used in analogy with white light, which is a superposition of all visible spectral components. The voltage distribution of this noise follows a normal or a Gaussian distribution. Therefore, it is called an Additive White Gaussian Noise (AWGN) channel. The mean of this noise distribution is zero while its variance is a function of the noise spectral density. The spectrum of AWGN noise band-limited between – *fs/2* to *fs/2* where *fs* is the sampling rate of the transmitted signal and *No* is the noise power spectral density. The noise variance is given by

$$\sigma^2 = \frac{N_o f_s}{2} \tag{2-2}$$

Therefore, the normalized Signals to Noise Ratio (SNR) is

$$\frac{E_b}{N_0} = \frac{(+/-)1^2 T_b f_s}{2\sigma^2} \tag{2-3}$$

Where T_b the time period of a bit, $T_b f_s$ is the number of samples per bit and energy per bit is normalized to unity. If 1 sample per bit is used, the variance σ^2 can be represented as

$$\sigma^2 = \frac{1}{2\left(E_b / N_o\right)} \tag{2-4}$$

This formula is used to compute the AWGN noise variance. The AWGN can be found by taking the product of the standard deviation of the noise and a normally distributed random number with unit variance.

2.1.1.2 Rayleigh Fading Channel

The practical radio channel is normally more complex than single path AWGN. The data transmitted over a transmission channel typically encounters various obstructions in its path like buildings, trees and forests. The signal reflects after striking these obstructions and follows multiple paths as it arrives at the receiver at different times, as in Figure 2.1. This time spreading phenomenon of the wireless channel is called fading. A wireless channel is severely limited by the amount of fading present. The small-scale fading occurs because rapid fluctuations in signal strength due to constant change in location of the mobile motion over short distances. Dramatic changes in the signal amplitude and phase can be encountered by small position changes on the order of half a wavelength in the spatial separation between the transmitter and the receiver. Rayleigh fading is one of the small-scale fading. The Properties Density Function (PDF) of Rayleigh distribution is given as

$$p(r) = \begin{cases} \frac{r}{\sigma^2} erp\left(\frac{-r^2}{2\sigma^2}\right) & forr \geq 0 \\ 0 & otherwise \end{cases} \quad (2\text{-}5)$$

Where r the envelope amplitude (voltage) of the received signal and σ is time average power of the received signal before envelope detection.

Figure 2.1 Examples of Channels Fading Propagation

2.1.1.3 Burst Noise Channel

The burst error is the sequence of error bits $e_{l+1}, e_{l+2}, \ldots, e_{l+b}$ is called a burst error of length b relative to a guard space of length g if $e_{l+1} = e_{l+b} = 1$. The g bits preceding e_{l+1} and the g bits following e_{l+b} are all 0's. And the b bits from e_{l+1} through e_{l+b} contain no subsequence of g 0's, or generally the length of a burst is an always determined relative to some guard space. Burst error is the form of the error which is related to the symbols and may be caused due to the first and the lost symbols incurred in the data transmission. The error burst does not have any sort of relation with the number of correct sequence of error, which has been received by the error burst.

2.1.2 Types of Codes [Forward Error Correction Codes]

In information theory field, normally two Error Correction Codes (ECC) techniques are used in digital communication. The first one is Automatic Repeat request (ARQ) and second is Forward Error Correction (FEC). In an ARQ, the errors detected at the receiver, a request is sent for the transmitter to repeat the message, and this continues until the message is received correctly. On the other hand FEC is detected and correct the error without re-transmission, which automatically correct errors detected at the receiver. The major advantages of FEC over ARQ are to avoid the retransmission and save the time and bandwidth and power but somehow has difficulty in implementation [15]. There are two families of FEC codes depending on how redundancy is added, block codes and convolution codes. In both, if the redundancy is implicitly embedded in code word, the code called nonsystematic and if the redundancy is explicitly appended to the message, the code called systematic. Systematic are preferred since message and redundancy is separated then receiver can directly extract the message from the decoded code word.

2.1.2.1 Block Codes

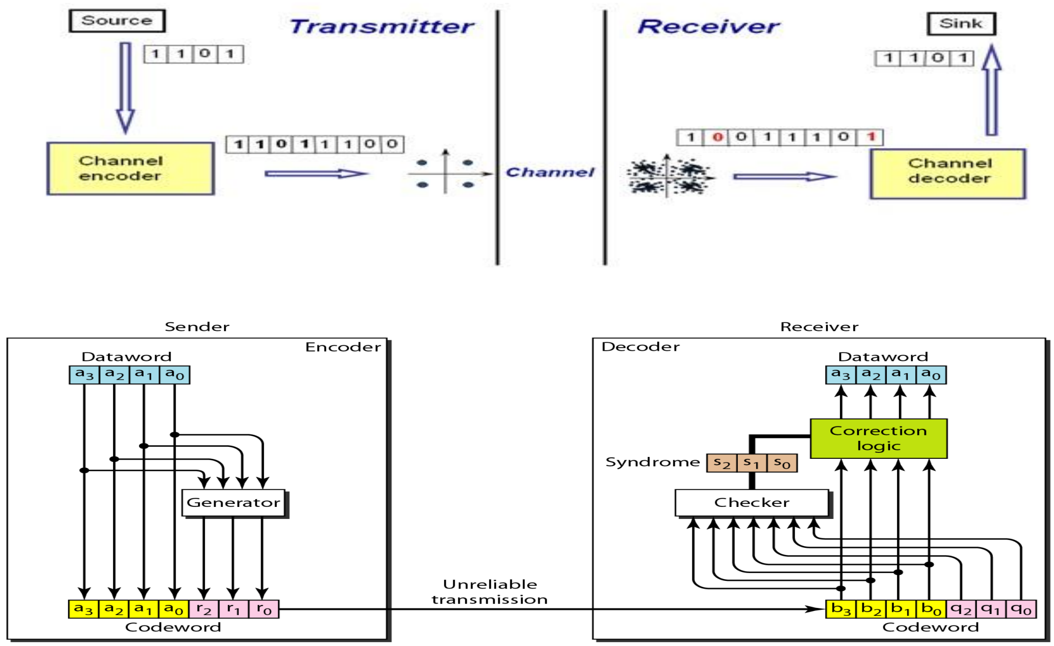

Figure 2.2 General Encoder and Decoder Structure of Block Code

Block coding encode and decode the data on a block-by-block basis each block independent from other. Consequently block coding is a memory less operation and can be implemented using combinational logic. Figure 2.2 shows the block coding scheme that is in the transmitter encode the data by adding redundancy and in the receiver after calculate the syndrome; there are three possibilities, if the syndrome is 0, no error has been detected. If the syndrome contains 1 and only one bit set to 1, then an error has occurred in one of the redundant bits, so no correction is required, if the syndrome contains more than one bit set to 1 then the numerical value of the syndrome indicates the position of the data bit in error, this data bits is inverted for correction [22]. There are two types of block code, binary block code such as Bose-Chaudhuri-Hochquenghem (BCH) codes and non-binary block code such as Reed-Solomon (RS) codes.

2.1.2.2 Convolution Codes

Elias first introduced convolution codes in 1955 [24]. The convolution codes, works on a continuous data stream, and it has encoding and decoding operations depend not only on the current data but also on the previous data. Convolution coding contains memory and it can be implementing using sequential logic. Convolution code is specified by main three parameter *(n,k,m)* which *n* is the code-word, *k* is the data-word, and *m* is the memory length. There is other parameter such as, constraint length (L) that represents the number of bits in encoder memory, which affect the generation of the *n o*utput bits. *L* can be calculated using 2-6. The number of states that equal to 2^L that means the states of a code indicates what a register is in the memory. The selection of which bits are to add to produce the output bit from in the encoder is called the generator polynomial (g) for that output bit.

$$L = K(m-1) \tag{2-6}$$

2.1.2.3 Concatenated Channel Codes

Forney first proposed concatenated Codes (CC) when he tried to find a high performance of FEC codes at low decoding complexity [25]. The excellent performance achieved using CCs with only algebraically increasing of decoding complexity [26]. Classically, CCs consist of two or more component codes. Initially, the development of CCs is motivated only by the interest of the coding community for reasons that low error rate and acceptable decoder complexity. Subsequently, CCs slowly found its way in deep space communication requirement [27]. The fundamental principle of CCs is to employ short component codes to construct complicated codes to achieve desired performance.

There are main two types of CCs used in many applications in telecommunication systems. Serial concatenated code that is a main code used in this thesis work. The other CCs are a Parallel concatenated code that is a main code known as a turbo code. Furthermore, each of the component codes can be decoded individually with the use of component decoder.

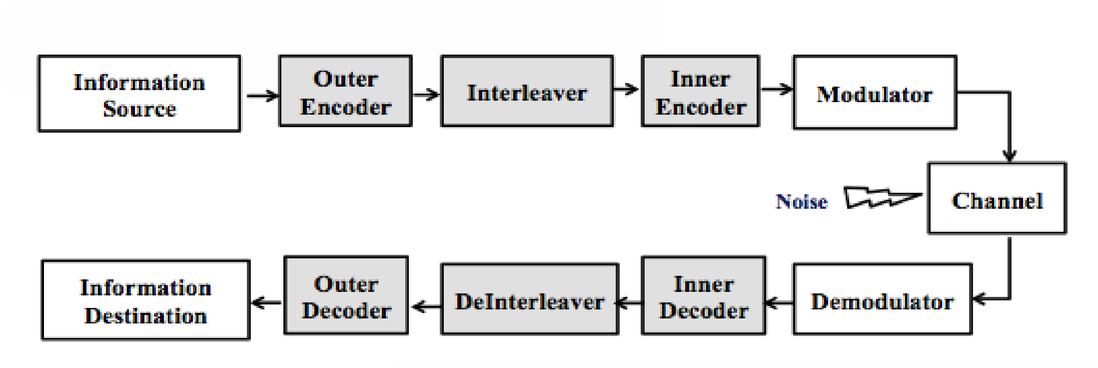

Figure 2.3 Block Diagram of a Concatenated Coding System

In order to generate CCs, two or more encoders are connected in cascade where output code words from the first encoder are fed to the second encoder. In the case of two-level CCs as shown in Figure 2.3, the first encoder is denoted as outer encoder and the second as inner encoder. The interleaver is required between a two encoders to spread error bursts that may appear at the output of the inner coding operation. In general, outer encoder usually operates at higher code rate with lower redundancy added to the information bits. It can reduce the error probability to certain level [28]. In such a case, inner encoder eliminates most of the error bursts with an interleaver between of outer and inner encoders. Decoding of the CCs can be done in several stages depending on the combination of each of the component codes. CCs are decomposed to several shorter codes known as constituent codes. The magnificence of CCs is that each of the components code can be decoded individually before the hard decision are made on the soft decision output to recover the original transmitted symbols. Alternatively, soft decision can be exchanged between component decoders to improve the system performance. As a conclusion, a concatenated code is a good example for burst-and-random- error-correcting codes, while the inner code works as random- error-correcting code, the both inner and outer codes with an interleaver work as burst- error-correcting.

2.1.3 Quality of Digital Communications Systems

The connectivity and the dependability are major factors to measure the quality of the system. The dependability terms can include the reliability, security, safety and other related factors. The error rate performances in the error control coding can be the key-point for all that mentioned. Generally here will introduce the important terms related to measure the quality of the communication system, such as channel capacity, BER and throughput.

2.1.3.1 Channel Capacity

The error control approach in digital communications has started with the innovative work of Shannon [29]. Shannon put down a theory that explained the essential limits on the efficiency of any communications system. The most famous formula from Shannon's work as

$$C = W\log_2\left(1+\frac{S}{N}\right) bits/S \tag{2-7}$$

Where C is the channel capacity, that is, the maximum number of bits can be transmitted through the channel in one second, W is the bandwidth of the channel, and

S/N is the signal-to-noise power ratio at the receiver. Shannon theorem asserts that error probabilities as small as desired can be achieve as long as the transmission rate *R* through the channel is smaller than *C*, using an appropriate encoding and decoding operation can achieve this. However Shannon's theory is silent about the structure of theses encoders and decoders [20].

2.1.3.2 Bit Error Rate

BER is a one important key to measure the quality of any communication system transmits digital data from one location to another. Although there are some differences in the way of these communication systems works and the way in which BER is affected, the basics of BER itself are still the same. BER assesses the full end-to-end performance of a system including the transmitter, receiver and the medium in between. In this way, BER enables the actual performance of a system in operation to be tested, rather than testing the component parts and hoping that they will operate satisfactorily when in place. As the name implies, a BER is defined as the rate at which errors occur in a transmission system. This can be directly translated into the number of errors that occur in a string of a stated number of bits. The definition of bit error rate can be translated into a simple formula

$$BER = {}^{\#\,ofErrors}\!\big/_{Total\,\#\,ofBitsSent} \qquad (2\text{-}8)$$

If the medium between the transmitter and receiver is good and the SNR is high, then the bit error rate will be very small, possibly insignificant and having no noticeable effect on the overall system however if noise can be detected, then there is chance that the BER will need to be considered. The main reasons for the degradation of a data channel and the corresponding BER is noise and changes to the propagation path where radio signal paths are used. Both effects have a random element to them, the noise following a Gaussian probability function while the propagation model follows a Rayleigh model. This means that analysis of the channel characteristics are normally undertaken using statistical analysis techniques.

In terms of that, BER can also be defined in terms of the Probability of Error (PoE). The E_b can be determined by dividing the carrier power by the bit rate and is a measure of energy with the dimensions of Joules. N_o is a power per Hertz and therefore this has the dimensions of power divided by seconds that is joules per second. The different type of modulation has its own value for the error function. This is because each type of modulation performs differently in the presence of noise. In particular, higher order modulation schemes such as, 64QAM are able to carry higher data rates are not as robust in the presence of noise. Lower order modulation formats such as, BPSK or QPSK can offer lower data rates but are more robust. On the other hand, each type of coding techniques, encoders and decoders has own value to the error function as well.

2.1.3.3 Throughput

Throughput (T) is also one important key that measures the quality of the wireless communication links. Throughput is defined as the number of information bits received without error per second, that is successful message delivery and this quantity has to be as high as possible, and usually measured by bits per second (b/s). The T of a communication system may be affected by various factors, including the limitations of underlying analog physical medium, available processing power of the system components, and end-user behavior. When various protocol overheads are taken into account, useful rate of the transferred data can be significantly lower than the maximum achievable throughput; the useful part is usually referred to as good put. Generally T is the number of payload b/s received correctly and given as

$$T = \frac{K}{L} Rf(\gamma) \tag{2-9}$$

Where *(KR/L) b/s* is the payload transmission rate and $f(\gamma)$ is the probability of receiving a data correctly. This probability is a function of SNR ratio and defined as E_b/N_o. T also can be calculated from the BER using the formula (2-10). Subsequently, if the BER equal to zero, the T is equal to the information bit.

$$T = (1 - BER) \times DataBits \tag{2-10}$$

2.2 MICT Based on WBANs Technology

The healthcare scores are increasingly looking for advanced ICT systems to efficiently administer the healthcare delivery for range of services called Medical-ICT. One of the advanced technologies for MICT is the WBANs. WBANs technologies is growing as a key technology to transfigure the future of healthcare, therefore, WBANs has attracted a great treaty of attentions from researchers both in academia and industry in the last few years. WBANs are a special purpose sensor network designed to operate autonomously to connect various medical sensors and appliances, located inside and outside of a human body. WBANs are consisting of a number of tiny sensor nodes and a gateway node used to connect to the external database server. The gateway node could connect the sensor node to a range of telecommunication networks. These communication networks could be either a standard telephone network, mobile phone network, a dedicated medical center, hospital network or using public Wireless Local Area Networks (WLAN) hotspots also known as Wi-Fi. WBANs can also take advantage of widely deployed mobile data networks such as the UMTS/LTE data networks to transmit patient data [30].

2.2.1 WBANs Standard for Medical Applications

Recently, WBANs technology has been verified-out in the latest standardization of IEEE 802.15.6 [1]. IEEE 802.15.6 standard aims to provide an international standard for short range, low power and extremely reliable wireless communication within the surrounding area of the human body, supporting by that huge range of data rates from 75.9 Kbps narrow-band up to 15.6 Mbps Ultra-Wide-Band (UWB); for different applications [3]. The main requirements of IEEE 802.15.6 standard is that WBANs links should support bit rates in ranges of 10 Kb/s to 10 Mb/s. Packet Error Rate (PER) should be less than 10% for a 256 octet payload for a majority 95% of the best performing links based on PER [3]. Moreover, BER from 10^{-3} to 10^{-10} and latency from 10ms to 250ms needs for the QoS support and differentiation [4].

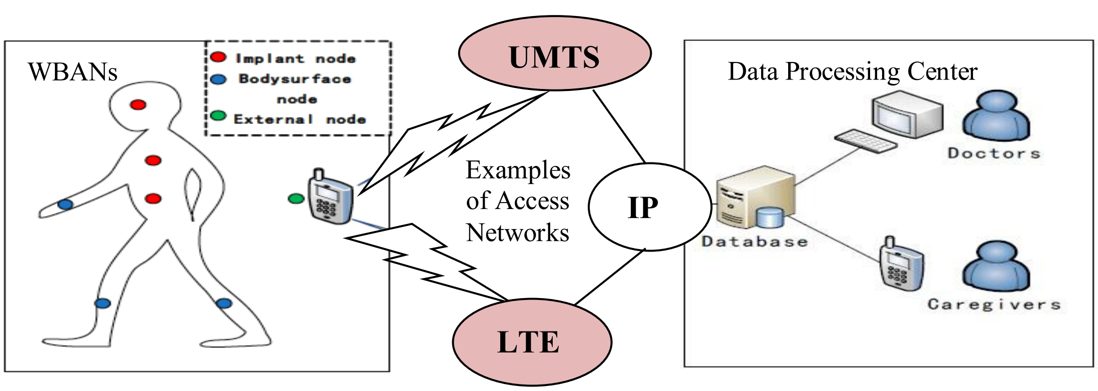

Figure 2.4 WBANs Architecture of Medical Applications

2.2.2 WBANs QoS for Medical Data

WBANs technology is used to continuously monitoring Patients' vital signs. Therefore the key elements for the WBANs that is how these data sets should be handled with special care ensuring reliability and accuracy since a wrong signal could make critical anxiety of the person's life. Electronic systems in WBANs sensors are playing a vital role, by collecting the medical data to the coordinator, such as Electrocardiogram (ECG), Electromyography (EMG), and Electroencephalography (EEG) electrodes, Pulse Oximetry (SpO2), respiration, blood pressure, and temperature sensors etc. [14].

A QoS of WBANs medical application is a major concern. Up to now, many efforts have been made in all WBANs aspects [31]. Therefore, the researcher concerning QoS issues in WBANs should handle all of that very seriously by effective way, such as, real time data transmission system, data rate, end-to-end data transmission, data transmission accuracy rate, latency, delay time, low power data transmission, data availability, minimum data loss, data security, network coverage, frequency, bandwidth, throughput and reliability matters [4].

Table 2.1 QoS Levels Mapping of WBANs Standard

Priority Level	**User Priority**	**Traffic Designation**
1st Lowest Priority Level [Non-Medical]	**0**	Background (BK)
	1	Best Effort (BE)
	2	Excellent Effort (EE)
2nd Medium Priority Level [Medical]	**3**	Video (VI)
	4	Voice (VO)
	5	Medical Data / Network Control
3rd Highest Priority Level [Medical]	**6**	High Priority Medical Data / Network Control
	7	Emergency / Medical Implant Event Report

The analyzing of WBANs medical data QoS is figured out from the standard [1]. The standard itself consider eight levels of QoS as in Table 2.1. The three groups of priority level sets are categorized later for the purpose of the thesis work. The following data in Table 2.2 has shown the commonly used sensors along with their work range. It also notices the wide variation in data rate, BER, delay tolerance, duty cycle, and lifetime, which requires scalable solutions with QoS provisions [4].

Table 2.2 QoS Constraints that Considered in MNC Proposed System

Priority Level	**Types of Medical Applications of WBANs**	**Data rate (kbps), Bit error rate (BER), Setup time, Duty Cycle, Desired Battery Lifetime, Latency**
Lowest Priority	**Audio**	1 Mbps for 3 nodes, **$<10^{-5}$**, <3s, <50%, >24 hours, < 100 ms
	Video	<10 Mb/s for 2 node, **$<10^{-3}$**, <3s, <50%, >12 hours, < 100 ms
Medium Priority	**Respiration**	Low, 0.24; **$<10^{-10}$**, <3s, <1%, >1week, < 250 ms
	Blood Pressure	Low, 0.05, <10 kbps up to 12 nodes, **$<10^{-10}$**, <3s, <1%, >1 week, < 250 ms
	Blood Sugar	Low, **$<10^{-10}$**, <3s, <1%, >1 week, < 250 ms
	Temperature	Very low, 0.0024-0,05; **$<10^{-10}$**, <3s, <1%, >1 week, < 250 ms
Highest Priority	**ECG**	High, 6.0, **$<10^{-10}$**, <3s, <10%, >1 week, < 250 ms
	EMG	High, 1.536 Mbps for up to 6 nodes, **$<10^{-10}$**, <3s, <10%, >1 week, < 250 ms
	EEG	High,3.6,**$<10^{-10}$**,<3s,<10%,>1week,<250ms

2.2.3 Reliability Requirements of WBANs Medical Data

WBANs which could collect critical and non-critical data from different parts of a patient body needs to be designed considering a number of important issues. In-patient monitoring system data transmission reliability and latency is extremely important. Reliability and latency of WBANs will depend on the design of PHY and MAC layers. Design of these layers determines the power consumption profile of WBANs, which is an important design issue. The MAC layer also plays an important role to determine network efficiency and resource utilization issues, which ultimately determine a system and operating, cost of WBANs. At the same time the PHY layer also determines reliability of WBANs. A PHY layer could select appropriate modulation and coding techniques to combat against transmission channel variability. Performance of WBANs can be defined in terms of reliability, power efficiency and scalability [30].

- **Reliability**

Reliability of WBANs is directly related to the packet loss probability and the packet transmission delay. Packet loss probability is influenced by the BER of the channel and the MAC layer transmission procedures. The PHY layer of WBANs can reduce the effective bit error rate of a transmission link by using adaptive modulation and coding techniques to suit the transmission channel conditions. Using of FEC codes can reduce the effective BER however; the use of FEC requires transmission of additional redundant bits. Careful design of modulation and coding techniques is essential for the optimum operation of WBANs. The MAC layer has also important role for the reliability of WBANs related to the channel access techniques, packet size selection and packet retransmission strategy used in WBANs. The reliability and power budget of WBANs also depend on the interference situation of a network. If the interference and noise floor of network is high, in order to successfully transmit packets, a node needs to transmit at a higher transmitter power level.

- **Power Efficiency**

Power management in WBANs is a very important operational issue. Optimizing the PHY and MAC layers processes can minimize power usage. A PHY layer can increase the probability of successful transmissions by selecting appropriate modulation and coding techniques. Higher packet transmission success probability reduces the end-to-end packet delay as well as the power budget of a WBANs node. Increasing successful packet transmission probability could optimize power budget of a node. Power optimization scope at the PHY layer is generally limited and fixed. On the other hand, a MAC layer can introduce much higher level of power savings by using a range of techniques including packet transmission scheduling and channel access techniques, use of optimal packet structure, and intelligent signaling techniques. Since WBANs will be operating in a shared communication environment it is necessary to minimize the contentions and interference.

- **Scalability**

A WBANs need to be scalable which is essential for a patient monitoring system. For patient monitoring it is quite often necessary to change the number of WBANs nodes to collect various physiological data from a patient. Scalable WBANs will allow health care professionals to easily reconfigure a WBAN by either adding or removing nodes without affecting the operation of the WBAN. Scalability will largely depend on the MAC protocol design.

2.2.4 WBANs Error Correcting Capabilities Analysis

The International Standard IEEE 802.15.6 has defined new PHY and MAC layers for WBANs. BCH Code plays an important role in the error detection and correction capabilities for IEEE 802.15.6 Standard [1]. BCH Code is cyclic codes and underlies in class of linear block codes. It can be uses to correct error are derived from the noisy channel especially the burst error by correction bound depending on the free distance of the code d_{free}. Therefore, BCH code bound of correcting the error is depending on the d_{free}

of the code [33]. The BCH code performance analysis under AWGN channel has been given in [34]. The BCH Codes (63, 51, t = 2) and (126, 63, t = 10) Play an important role in the error detection and correction capabilities in WBANs Standard [1].

The generator polynomial for a systematic BCH (63, 51, t = 2) code where t is the number of bit errors that can be corrected, is given

$$g(x) = 1 + x^{3} + x^{4} + x^{5} + x^{9} + x^{10} + x^{12} \tag{2-11}$$

The parity bits are determined by computing the remainder polynomial $r(x)$ as

$$r(x) = \sum_{i=0}^{11} r_i x^{i} = x^{12} m(x) \bmod g(x) \tag{2-12}$$

Where, $m(x)$ is the message polynomial as

$$m(x) = \sum_{i=0}^{50} m_i x^{i} \tag{2-13}$$

And r_i ,i = 0,…,11 and m_i ,i = 0,…,50 are elements of $GF(2)$. The message polynomial $m(x)$ is created as follows: m_{50} is the first bit of the message to be transmitted and m_0 is the last bit of the message, which may be a shortened bit. The order of the parity bits is as follows: r_{11} is the first parity bit transmitted, r_{1o} is the second parity bit transmitted, and r_0 is the last parity bit transmitted. On the other hand, the generator polynomial for a systematic BCH (126, 63, t = 10) code is given as

$$\begin{aligned} g(x) = 1 &+ x^{2} + x^{5} + x^{15} + x^{18} + x^{19} + x^{21} + x^{22} + x^{23} + x^{24} + x^{25} + x^{26} + x^{30} \\ &+ x^{31} + x^{32} + x^{33} + x^{35} + x^{36} + x^{38} + x^{40} + x^{47} + x^{48} + x^{49} + x^{51} + x^{53} + x^{55} \\ &+ x^{56} + x^{61} + x^{63} \end{aligned} \tag{2-14}$$

- **Encoding Procedures of BCH Codes**

BCH codes, named after their discoverers Bose,Chaudhuri,and Hocquenghen [35-36], are undoubtedly the most important cyclic codes the codes are among the best codes of moderate length. The biggest advantage of BCH codes is the existence of efficient decoding methods due to the special algebraic structure introduced in the code. Binary BCH code of length $n=2^m-1 (m\geq3)$ is defined as a cyclic code whose code polynomials take $\alpha,\alpha^2,\alpha^3,\alpha^4,\ldots, \alpha^{2t}$ as their roots, where α is the primitive element of $GF(2^m)$ and $t<2^{m-1}$. From the preceding statement it follows that the generator polynomial of a BCH code is the Least Common Multiple (LCM) of the minimum polynomials of α^i (i=1,2,…2t). The binary BCH codes defined in [27] are primitive BCH codes because they are constructed using a primitive element of $GF(2^m)$. Also their generator matrices or parity-check matrics can specify BCH code. The minimum distance of a BCH code is $d_{min}=2t+1$. As such, a BCH code is able to correct up to $[(d_{min}-1)/2]=t$ errors.

- **Decoding Procedures of BCH Codes**

The biggest gain on BCH code is the existence of efficient decoding methods due to the special algebraic structure that introduced in the code [36-39]. The syndrome computation for the codes can be simplified to a great extent. Using the definition of syndrome $S=S_0\ S_1\ S_2\ \ldots\ S_{n-1}=r*H$ which r is a received data and H is a parity check matrix.

The decoding of BCH codes involves; first, calculating a syndrome, determining the error location polynomial, finding the roots of the error location polynomial such as error positions and last corrects the errors. Based on these decoding steps, the block diagram of a BCH decoder is illustrated in figure 2.5. The delay is used to compensate for the processing latency in first three steps. Peterson proposes the algorithm of finding the error location polynomial coefficients in 1960 [38]. Although Peterson's method is conceptually straightforward, it's computationally complex. In practice, a more effective algorithm such as the Berlekamp-Massey algorithm or Euclid's method is often used instead. The last step before decoding the word is to find the root of the error location polynomial ready. Base on that, one simple yet effective method is to do an exhaustive search. This algorithm introduced by Chien and it's called Chien search [39].

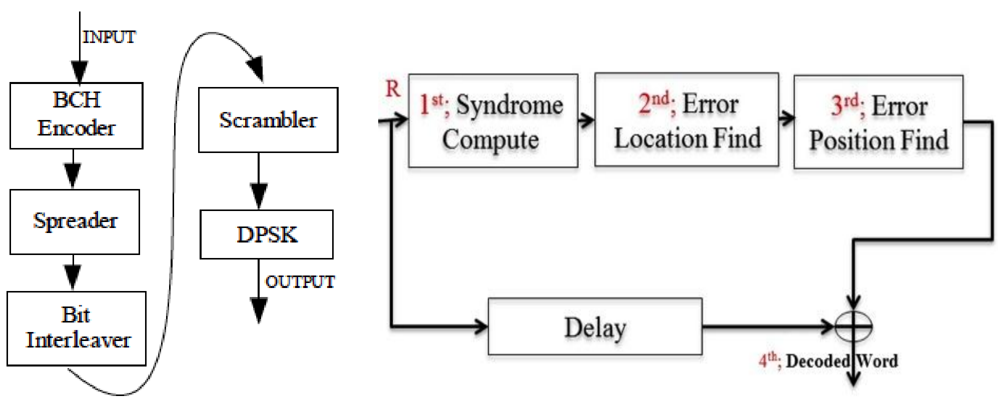

Figure 2.5 WBANs Encoding and Decoding Structure of BCH Code

2.2.5 WBANs Performances Analysis

The calculations of the BER for WBANs standards has been carried out using the computer simulation under AWGN channels by transmitting 100Kb/s. the capability of correcting the channel error depend on the BCH codes inside the standard. Figure 2.6 show the BER performance using the three kind of code for low data rate is (63, 51, t=2), (31, 19, t=3) and for high data rate is (126, 63, t=10).

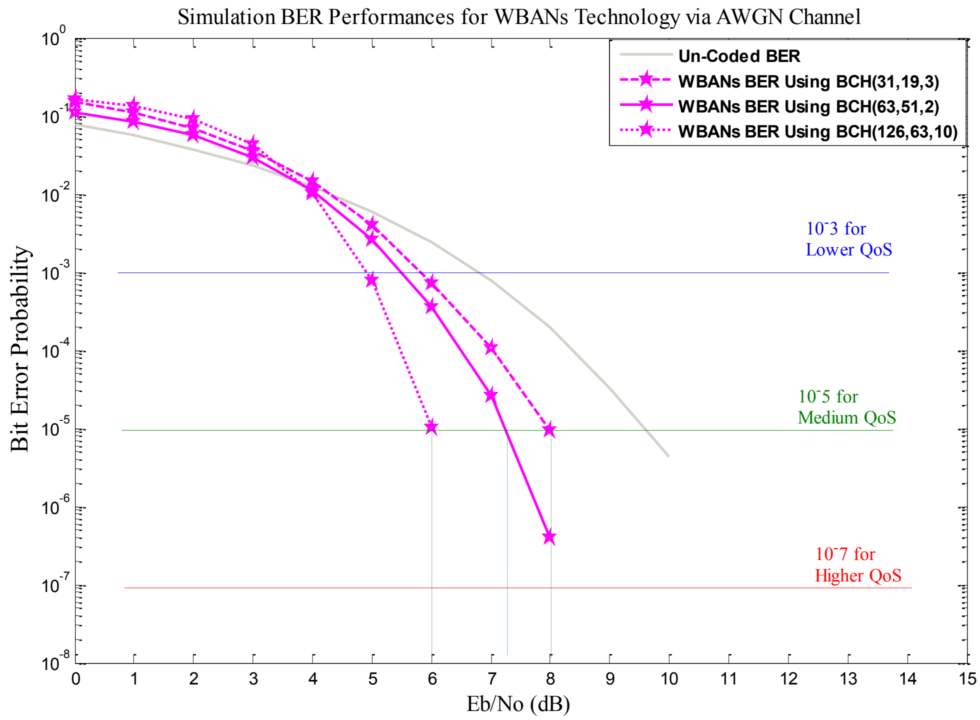

Figure 2.6 WBANs Performances Analysis via Different Channel Codes

2.3 Cellular Network Systems Investigation

3G and 4G of cellular systems are being designed to support wideband services such as high-speed Internet access and high voice quality for daily life communication by supporting high data rates transmission. The 3G standard that has emerged is based on ETSIs and is commonly known as UMTS Terrestrial Radio Access (UTRA). Therefore, UMTS is a main standard of 3G with WCDMA air interface. On the other hand, the 4G is commonly known as LTE and called Evolved Universal Terrestrial Radio Access (E-UTRA). The LTE goal is to provide a high data rate, low latency and a packet optimized radio technology, which supports flexible bandwidth deployment. There are two different modes supported by UMTS and LTE namely FDD and TDD. The UL and DL transmission employ two separated frequency bands for FDD duplex method. A pair of frequency bands with specified separation is assigned for a connection. In the TDD duplex method, UL and DL transmissions are carried over the same frequency band by using synchronized time intervals thus time slots in a physical channel are divided into transmission and reception part.

Table 2.3 General Key Features in UMTS and LTE Systems

	UMTS	**LTE**
Bandwidth	5MHz	1.25-20 MHz
Duplexing	FDD and TDD	FDD and TDD
Peak Data rate	Full coverage 64 to 384 Kb/s	UL 50 Mb/s & DL 100 Mb/s
Modulation	BFSK & QPSK	BFSK, QPSK _& 16-QAM
Channel Coding	Convolution code 1/2, 1/3 & Turbo code	Convolution code 1/3 & Turbo code

2.3.1 Cellular Standards Networks Configuration [UMTS/LTE]

The access scheme is WCDMA and the information is spread over a bandwidth of approximately 5 MHz and it is enough to provide data rates of 64 to 384 Kbps, and even 2 Mbps in good conditions. The data modulation of all uplink channels is Binary Phase Shift Keying (BPSK), and for downlink channels is Quadra Phase Shift Keying (QPSK) [5-6]. The Radio Link Control (RLC) protocol [40] in UMTS provides segmentation and reliable transmission services for both user and control data. This reliability is provided by means of FEC and ARQ techniques. To reduce bit error rate, the first uses coding data adding overhead, whereas, the second uses retransmissions of erroneous packets increasing delay. Depending on the specific requirements of the data to be sent, it is necessary to choose one of these techniques or a combination of them. In fact, the UMTS system considers three different modes in RLC; Transparent Mode (TM), Unacknowledged Mode (UM), and Acknowledged Mode (AM). TM and UM are based on FEC and are suitable for hard delay constraint services where the presence of some packets with errors is not critical.

AM, based on joint FEC and ARQ, is suitable for non-delay constrained applications which require being error-free [40].

LTE integrate a wide variety of wireless multimedia services, with high data transmission rates, capable of providing much more than basic voice calls [7]. The targets for uplink are 50 Mbit/s and for downlink peak data rate requirements are 100 Mbit/s, when 20 MHz spectrums are allocated. The LTE specification provides QoS facilities permitting a transfer latency of less than 5ms in the radio access network. LTE supports accessible carrier bandwidths from 1.4 MHz to 20 MHz and support both FDD and TDD Duplex. The data modulation of all UL and DL channels is BPSK, QPSK, Quadrature Amplitude Modulation (16QAM) and (64QAM). The LTE provides both error detection and error correction as channel coding scheme. Therefore the E-UTRA employs two FEC schemes; convolution codes and turbo codes. Convolution coding can be used for low data rates, and turbo coding for higher rates [7].

2.3.2 Cellular Standards Error Correcting Capabilities

2.3.2.1 UMTS Channels Encoders/Decoders Structure

The WCDMA provides both error detection and error correction as channel coding scheme. Therefore the UTRAN employs two FEC schemes, convolution codes and turbo codes. The UMTS standard used convolution code for low data rates and turbo code for higher data rates in UP and DL traffic channels. The transport channel (TrCH) for UMTS such as, Dedicated Channel UL/DL(DCH), Radio Access Channel UL(RACH), Common Packet Channel UL(CPCH), Broadcast Channel DL(BCH), Paging Channel DL(PCH), Forward Access Channel DL(FACH) and Downlink Shared Channel DL(DSCH). The technical parameters that used are depending on the type of channel as in Table 2.4.

Table 2.4 3UMTS UL/DL Error Correction Techniques

TRCH Type	Coding Type	R Coding Rate / K Constraint Length	# of Encoded Bits
RACH,PCH	Convolution Coding	R=1/2&K =9	Y_i=2*K_i +16
BCH,DCH	Convolution Coding	R=1/3 & K =9	Y_i=3*K_i+ 24
FACH ,DSCH	Turbo Coding	R=1/3 & K = 4	Y_i=3*K_i+12

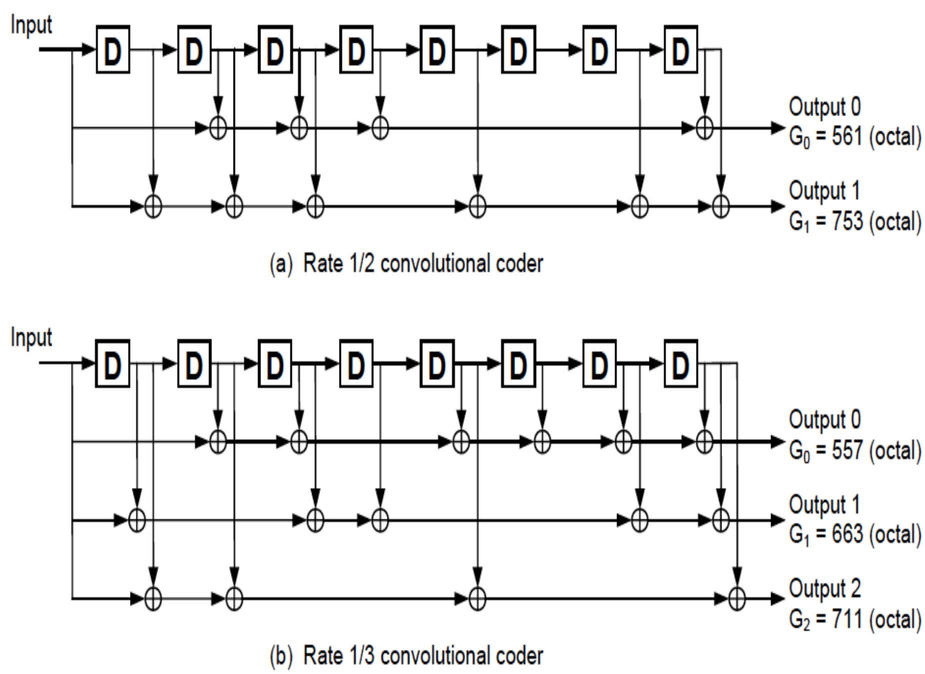

Figure 2.7 UMTS UL/DL Encoders Structures of Convolution codes

The generator polynomials in (2-15)~(2-19) are used in the UMTS encoders with different provided codes. Such as, convolution code with a coding rate 1/2 and convolution code with a coding rate 1/3. The Figure 2.7 shows the encoding structures for UMTS channel. The decoding structure for all convolution codes is working by convolution decoder that assumed to use Soft Decision Viterbi Algorithm (SDVA).

$$G_0 = 1 + D^2 + D^3 + D^4 + D^8 \tag{2-15}$$

$$G_1 = 1 + D + D^2 + D^3 + D^5 + D^7 + D^8 \tag{2-16}$$

$$G_0 = 1 + D^2 + D^3 + D^5 + D^6 + D^7 + D^8 \tag{2-17}$$

$$G_1 = 1 + D + D^3 + D^4 + D^7 + D^8 \tag{2-18}$$

$$G_2 = 1 + D^2 + D^5 + D^8 \tag{2-19}$$

- **Encoding Procedures of Convolution Codes**

The convolution encoder has structure can draw from its parameters, which is m boxes representing the memory registers connecting to n modulo-2 adders to representing the output bits by using the generator polynomial. The code-word sequence calculated from

$$v_l^N = \sum_{i=0}^{m} v_{l-i}\, g_i^N \tag{2-20}$$

Where v_l^N the output (code-word) is bit l from the encoder j, and $\upsilon_{\iota-i}$ is the input (data-word) bit, and g_i^j is the i^{th} term in the polynomial N. The generator polynomials can be expressed as in 2-21; and as a result, the output can be denoted as in 2-22. Different code sequence can be obtained by changing polynomial generators.

$$g(D) = 1 + D + D^2 + ... + D^N \tag{2-21}$$

$$v_l^N = v_0 + v_1 D + v_2 D^2 + ... + v_N D^N \tag{2-22}$$

Generally, the output switch samples each module-2 adder output branch word sequentially and forms the code-word sequence. As a conclusion, the encoder for convolution code uses a table look up to do the encoding. The look up table consists of; the input bit, the state of the encoder 2^L, and the output state, which will be the input state for the next bit. Additional matters regarding to the convolution code is distance properties, as defined in 2-23. The minimum distance of a convolution code, defined as the smallest hamming distance between all possible code sequences of the code, is called the free distance d_{free}. Selection of the particular convolution codes is usually based on the code's free distance properties.

$$d_{free} = [\min d_H(C_A, C_B) where C_A \neq C_B] = [\min d_H(C\ ,0)] = [\min \mathrm{w(C)where\,C} \neq 0] \quad (2\text{-}23)$$

The distance is determining d_{free} of a set of code words is usually deciding the performance of convolution codes because, it can correct up to (t) errors, as in (2-24). In addition, the d_{free} depends on the degree of randomness of the code word from the convolution encoder. As a consequence, the randomness of the code word has significant effect on the achievable performance.

$$t = [(d_{free} - 1)/2] \quad (2\text{-}24)$$

- **Decoding Procedures of Convolution Codes**

Several algorithms have been developed for decoding convolution codes. The one most commonly used is the Viterbi Algorithm (VA) [41-42], which is a Maximum Likelihood Sequence Estimator (MLSE). A variation on the VA; known as the Soft-

Output Viterbi Algorithm (SOVA) [43]. SOVA not only provide decoded symbols but also an indication of the reliability of the decoded values. Another decoding algorithm is the Maximum a Posteriori (MAP) [44-45] decoder frequently referred to as the BCJR algorithm [46], which computes probabilities of decoded bits. The BCJR algorithm is somewhat more complex than the VA, without significant performance gains compared to Viterbi codes [22]. The maximum likely-hood decoding (Viterbi decoding) represents different approaches from the other decoding algorithms to the same basic idea behind decoding. If a message of length k bits is received, then the possible numbers of code words are 2k. How can we decode the sequence without checking each and every one of these 2k code word. This is the basic idea behind decoding. Generally, VA performs maximum likelihood decoding to find the code sequence that was most likely to have been transmitted given the received channel sequence at each stage of progression through the decoding trellis.

VA was discovered and analyzed by Viterbi in 1996 [41]. Viterbi decoding is the best-known implementation of the maximum likely-hood decoding. VA is most popular algorithm that is employed to decode convolution code with time invariant trellis structure. The optimum decoder for a convolution-encoded signal is the Viterbi decoder [42]. The Viterbi decoder examines an entire received sequence of a given length. The decoder computes a metric for each path and makes a decision based on this metric. All paths are followed until two paths converge on one node. Then the path with the higher metric is kept and the one with lower metric is discarded. The path with largest total metric is selected that called the survivors path. Typically, Algorithm can be classified into hard and soft decision decoding based on the received channel sequence.

Figure 2.8 illustrate the VA, begins at stage k=0 of the trellis, calculate the partial metric for the single path entering each state. Compare and select the path that has highest probability and store it as the surviving path for each stat. then increase stage k by 1 and move to the next trellis state. For each state, compare and store the path with the highest metric together with its metric, and discard all other paths with lower path metrics. Then check, if stage k is less than the received symbol length proceeds to next step otherwise stop. After a finite time step, a sequence of zero bits is used to flush the convolution encoder back to zero state. To simplify the decoding process and reduce path memory requirement, a trace back length is used as the decoding widow to produce decoded symbol decision prior to the receiving of entire code sequence [21].

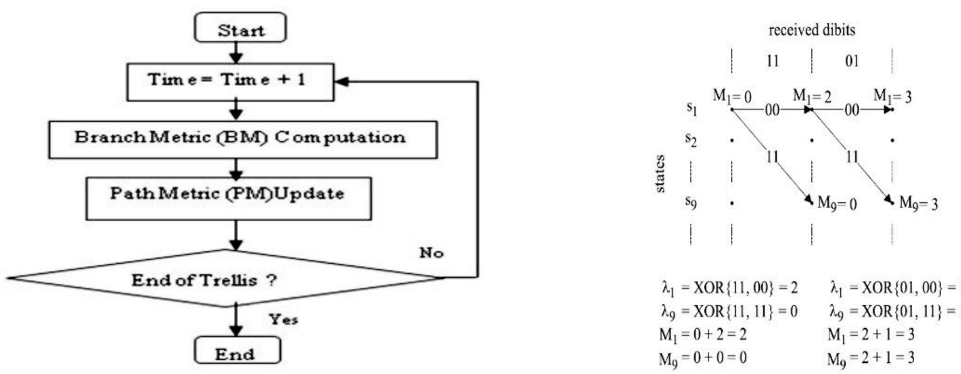

Figure 2.8 Viterbi Algorithm &Metric Calculations of the Decoder Implementation

As the convolution decoder operates on binary information a much simpler metric definition. At any particular discrete time instance, k, a set of metrics is given as

$$\lambda\left(s_0^k\right) = \sum_{i=0}^{k-1} \lambda\left(\varepsilon_0 i\right) \tag{2-25}$$

Where $s_0^k = \{s_0, s_1, s_2, \ldots\ldots s_k\}$ Represents a given sequence of states and $\varepsilon_0 i$ represents the i[th] state transition. Here assuming soft decision, the simple Euclidean distance measure is used to determine the metric increase for a given state transition. Hence, the following definition stands

$$\lambda(\varepsilon_0 i) = (y_k - x_k)^2 = xor\left(y_k^{bin} - x_k^{bin}\right) \tag{2-26}$$

Where y_k^{bin} the received binary symbol, and x_k^{bin} the binary symbols expected to cause a givenstate transition.The calculation of this increase in the metric value for a given state transition is illustrated in figure 2.9, there are 2^{u-1} states, the total number of path examinations for the entire decoding process in 2^{u-1}*L, where L is the sequence length. Generally the computation of the Viterbi algorithm increase linearly with L. two metrics is used in the Viterbi algorithm: a branch metric and a path metric. Let c=($c^{(1)}$ $c^{(2)}$….$c^{(n)}$) be the transmitted code word and r=($r^{(1)}$ $r^{(2)}$….$r^{(n)}$) be the received vector corresponding to the code word. The branch metric BM then defined as

$$BM(r,c) = \left\{ \left[d_H(r,c) harddecision \right] or \left[\sum_{i=1}^{n} \left| r^{(i)} - C^{(i)} \right|^2 softdeciti on \right] \right\} \tag{2-27}$$

Where, r is a binary word for the BSC or a real-valued vector for the AWGN. So the BM measures how close a received vector to the code word. Another metric is the path metric PM of state S, is the accumulation of branch metrics on the path from the beginning of the trellis up to the current decoding point. Where {branch} is denotes all branches on the path. The path metric can be calculated recursively as given by

$$PM_{(S,t)} = \sum_{\{branch\}} BN(r,c) \tag{2-28}$$

$$PM_{(S,t+1)} = PM_{(s',t)} + BM_{(s',t)} \rightarrow (s,t+1) \tag{2-29}$$

That is the path metric of the next node $(S, t + 1)$ is the path metric of current node (S', t) plus the branch metric corresponding to branch$(S', t) \to (S, t + 1)$.

2.3.2.2 LTE Channels Encoders/Decoders Structure

The standard coding techniques for lower data rate in LTE are outlined in Table 2.5. The data rate of the channels is equal to 75 Mb/s. the input bits denoted by $C_0, C_1, C_3, \ldots, C_{K-1}$ where K is the number of bit length that to be encoded. Then in output form the encoder is encoded bits that denoted by $d_0, d_1, d_2, \ldots, d_{D-1}$ where D is the number of encoded bits. The relation between C_k and d_D is depending on the channel coding schemes techniques such as convolution code or Turbo code [16]. The LTE standard code used convolution code for one TrCH that is Broadcast Channel (BCH). The other TrCH UL and DL is using Turbo code is a main error detection and correction techniques. The technical parameters of encoding structures that using are appearing in Figure 2.9.

Table 2.5 LTE Error Correction Techniques

TRCH Type	Coding Type	R & K	# of Encoded Bits
BCH	Convolution Coding	R=1/3 & K =7	$Y_i=K_i$
PCH, MCH, DSCH	Turbo Coding	R=1/3 & K = 4	$Y_i=K_i+4$

In the case of the UL channel that is BCH, the coding rate equal to 1/3 and constraint length equal to 7 for convolution code with a generator polynomials that shown in (2-30)~(2-32) used in to encode the incoming data. The decoding structure works by convolution decoded that use Soft Decision Viterbi Algorithm (SDVA) [36-39]. On the other hand, in the case of the other DL channels, the coding rate equal to 1/3 for the turbo code with generator polynomials that shown in (2-33) ~ (2-35) used in to encode the incoming data. The decoding structure works by iterative decoding that is Soft Input Soft Output (SISO) algorithm [36].

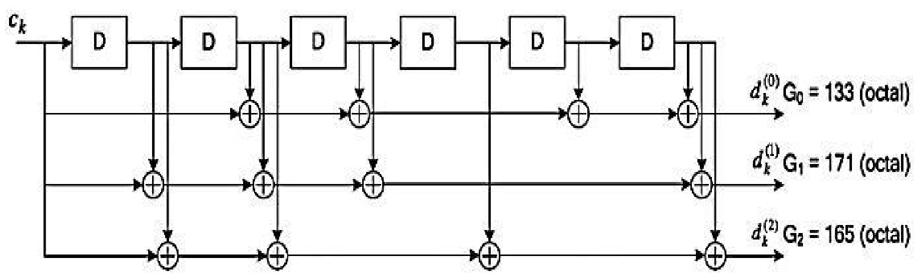

Figure 2.9 LTE UL Encoder Structure of Convolution Code

$$G_0 = 1 + D^2 + D^3 + D^5 + D^6 \tag{2-30}$$

$$G_1 = 1 + D + D^2 + D^3 + D^6 \tag{2-31}$$

$$G_2 = 1 + D + D^2 + D^4 + D^6 \tag{2-32}$$

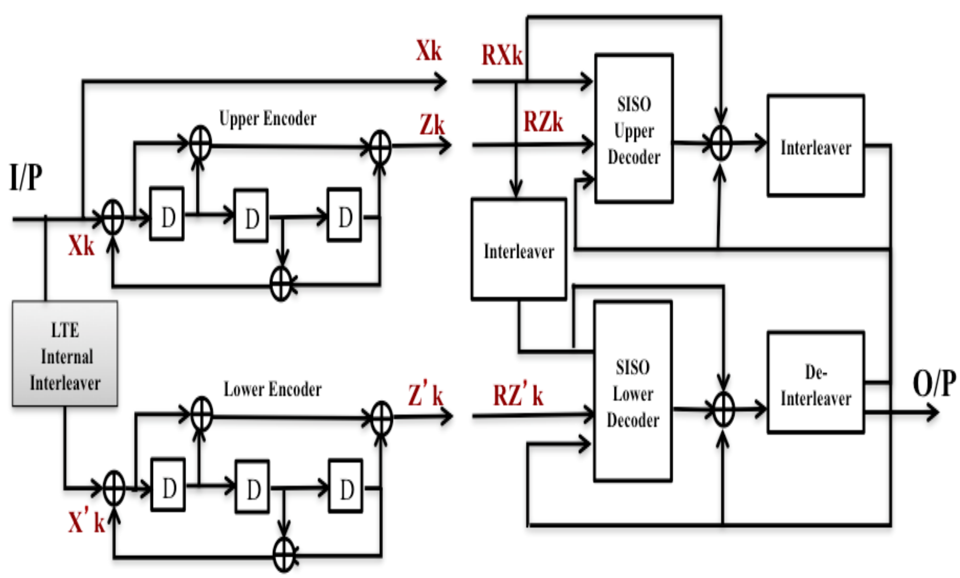

Figure 2.10 LTE DL Encoder/Decoder Structure of Turbo Code

$$G = \left[1, G_1(D) \middle/ G_0(D)\right] \tag{2-33}$$

$$G_0 = 1 + D^2 + D^3 \tag{2-34}$$

$$G_1 = 1 + D + D^3 \tag{2-35}$$

The input bit to the LTE internal interleaver are denoted by $C_0, C_1, C_3, ..., C_{K-1}$, where K is the number of input bits. The bits output from the UMTS internal interleaver are denoted by c', c',..., c'_{K-1} The relationship between the input and output bits for this internal interleaver is a 2-36. Where the relationship between the output index i and the input index $\Pi(i)$ satisfies the following quadratic form 2-37. The parameters f_1 and f_2 depend on the block size K [40~6144] bits. Finally, the proposed system in this thesis work assumed to use Broadcast Channel for low data rates of LTE system network, therefore the analysis here is carried out by using convolution codes with code rate 1/3.

$$C'_i = C_{\pi(i)}, i = 0,1,...,(K-1) \tag{2-36}$$

$$\pi(i) = \left(f_1 . i + f_2 \cdot i^2\right) \bmod K \tag{2-37}$$

- **Encoding Procedures of Turbo Codes**

The block in a turbo code is called Recursive Systematic Convolutional (RSC) code. RSC is an alternative realization of nonsystematic rate 1/n convolutional code. The RSC equivalence involves feedback in the encoding process. To construct an RSC code, we need to transform the nonsystematic feed-forward code generator into a systematic feedback for a convolutional code with generators $g_1(D), g_2(D), \dots, g_n(D)$ the generators of the equivalent RSC code are

$$1,\left[\frac{g_2(D)}{g_1(D)},\frac{g_3(D)}{g_1(D)},\ldots\frac{g_n(D)}{g_1(D)}\right] \qquad (2\text{-}38)$$

Turbo codes are formed by concatenating in parallel two RSC codes separated by an interleaver π such as Pseudo-random interleaver. The turbo code can be systematic or puncturing codes. The performance of turbo code is very impressive. The original turbo code reported in [47] achieved a 10^{-5} BER at only 0.7 dB away from the Shannon limit in an AWGN channel. And an interesting phenomenon is that when the SNR increase to some point, the decrease in the BER suddenly slows down, forming some sort of error floor. This is an inherent drawback of turbo codes, due to the presence of low-weight code words in the code. Other important point related to the turbo code performance, the error performance is improved as the code block length increase, so in order for turbo codes to achieve good performance, the code length is normally chosen to be on the order of several thousand bits. As a result, an interleaver of the same length is needed. This is another major disadvantage of turbo code, since such a large code length results in significant processing delays.

- **Decoding Procedures of Turbo Codes**

The interative decoding of turbo codes is a basic principle applied to all turbo codes. The Maximum a posteriori (MAP) decoding and long Likelihood Ratio LLR is a main algorithm for decoding turbo codes. There are other algorithm such as Soft Output Viterbi Algorithm (SOVA) and BCJR algorithm. The BCJR algorithm suffers from a large amount of multiplications. To reduce this computational burden, two simplified MAP algorithm as often-adopted in practice, max-log-MAP algorithm and log-MAP algorithm [48].

2.3.3 Cellular Networks Performance Analysis

2.3.3.1 The Performances Analysis without End to End of WBANs

The figures below show all the simulated performance results under different estimated channel condition. The Figures 2.11 as well show the BER performances for the cellular UMTS and LTE networks. The performance test carry out for transmit 10Mb/s by adding random noise, first by single path of AWGN and second by Rayleigh fading distribution with parameter 0.55 where scalars 1 affect the transmitted data and third by burst noise with interval 50 and length 5 bit.

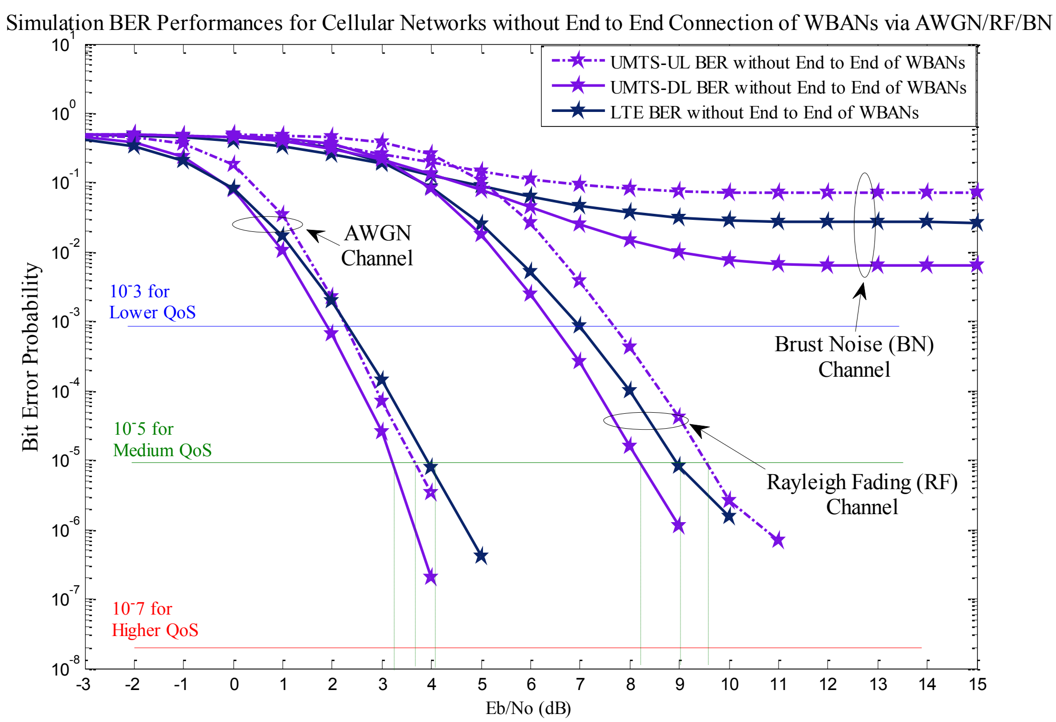

Figure 2.11 Cellular Networks Performances without End to End of WBANs

2.3.3.2 The Performances Analysis with End to End of WBANs

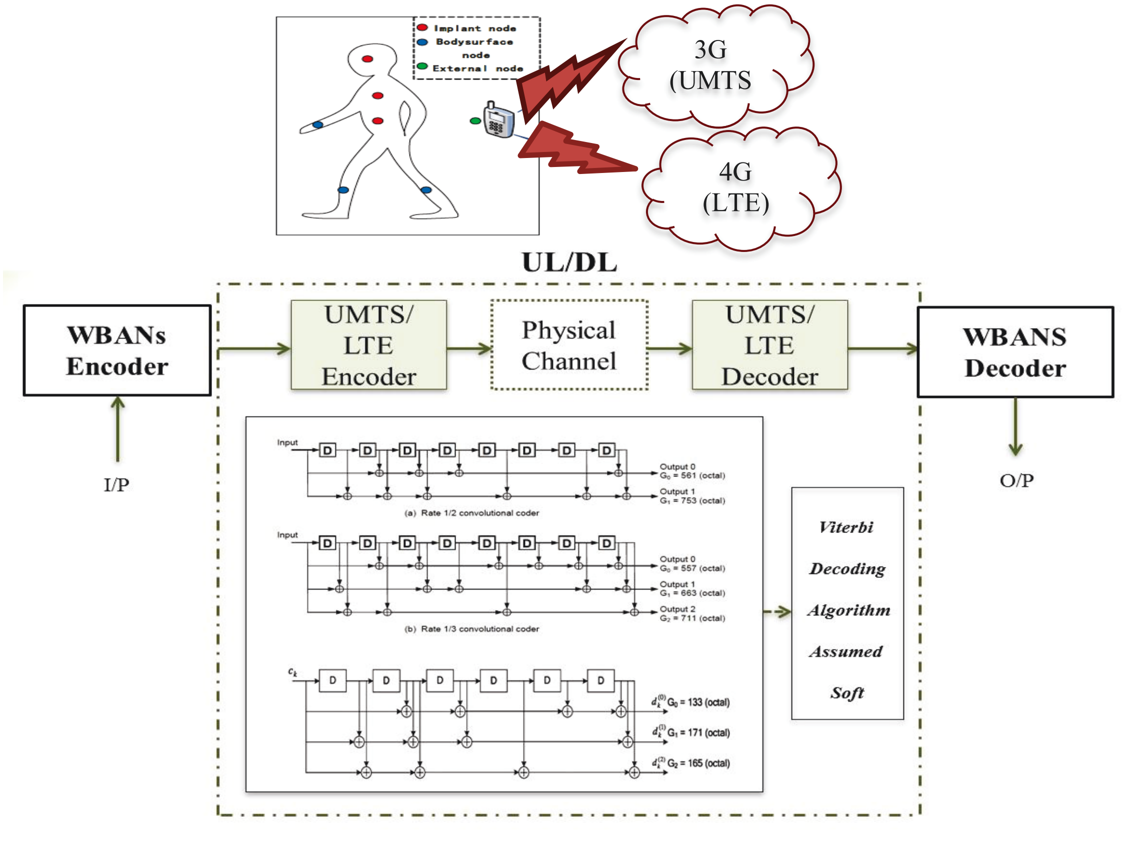

Figure 2.12 Block Diagram of WBANs with Cellular Networks Channels

The connection between the WBANs and UMTS PHY channel or LTE PHY channels is done in this section by assume that WBANs medical data transmitting through the cellular networks as in Figure 2.12. The BCH code is concatenated with the ready existing cellular codes standards, as shown in the block diagram. The reliability levels that studied in this chapter, it will be tested here, to see how reliability given for medical data by the cellular standards. The PHY channels carry sometime unpredictable errors during the transmission, therefore the testing carry by assumption solitary. The step here is to analyze this error by connecting the WBANs through the UMTS and LTE channel for the purpose for transmission medical data.

The criteria are to test the capability of the UMTS or LTE for transmitting WBANs medical data and the performance has been tested under different noise condition to investigate the BER performance of the current UMTS or LTE standards with a WBANs standard. The performance test carry out for transmit 100 Kb/s by adding random noise, first by single path of AWGN and second by Rayleigh fading distribution with parameter 0.55 where scalars 1 affect the transmitted data and third by burst noise with interval 50 and length 5 bit as shown in figure 2.13. The inner code her is UMTS UL or UMTS DL or LTE UL channels and the outer code is a WBANs code and the decoding part work separately from the inner decoder to the outer decoder.

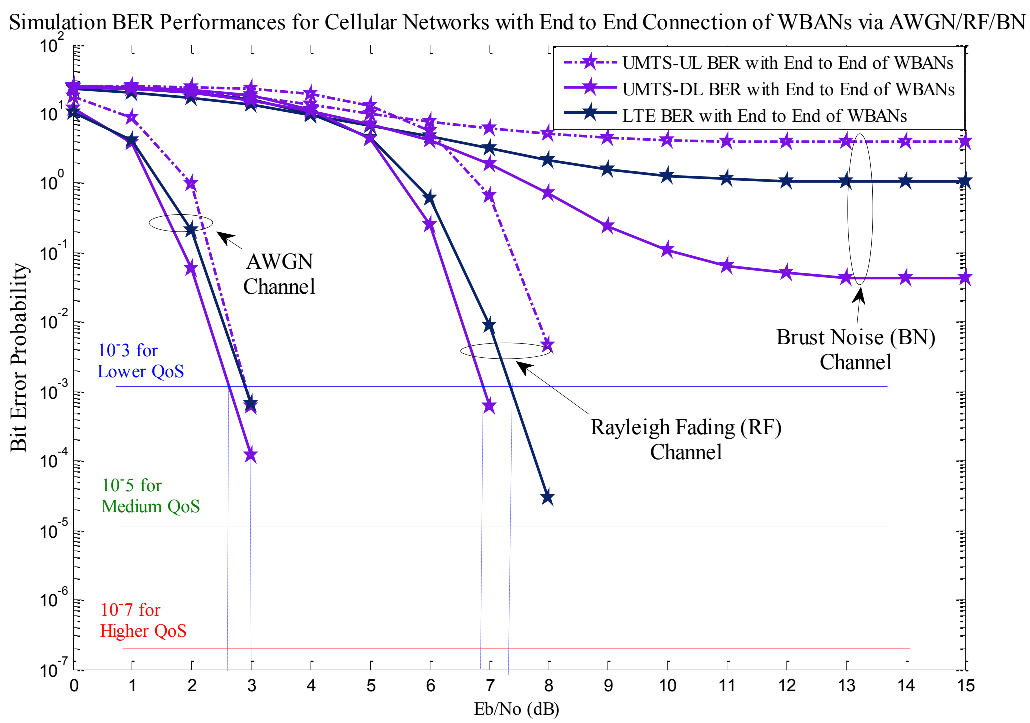

Figure 2.13 Cellular Networks Performances with End to End of WBANs

Chapter 3

The Proposed System Structures Design and Concepts

3.1 Dependable Medical System Configuration

The Medical Network Channel (MNC) system is a new system that adopted in this thesis work to serve transmission of medical data robustly through the cellular standards networks. It's mainly based on the error control coding techniques to ensure the dependability required for such medical data. The idea of the concatenated codes that we have been studied in 2.1.2.3 is used here for connecting the WBANs with the cellular networks under the purpose is to have reliable dependable medical data transmissions through the ready existing cellular network.

The investigations of the cellular network we have been studied in 2.3 motivate us to build the proposed system MNC. The cellular systems is working well for the daily communications, however in some cases when the channel is corrupted by hard noise, above the cellular error corrections capability, then the system become disconnected which unreliable and undependable. On the other hand the medical system is different from the other electronic consumer's networks. Therefore the task of this thesis works under this chapter has been carrying all data. The figures below show the whole MNC system that is the core base of this thesis work. The different medical data QoS levels from the WBANs has been considered in designing phase as well as the different assumed channel conditions. The structure design of the proposal is described in Figure 3.1 by using the concatenated codes techniques as mentioned before.

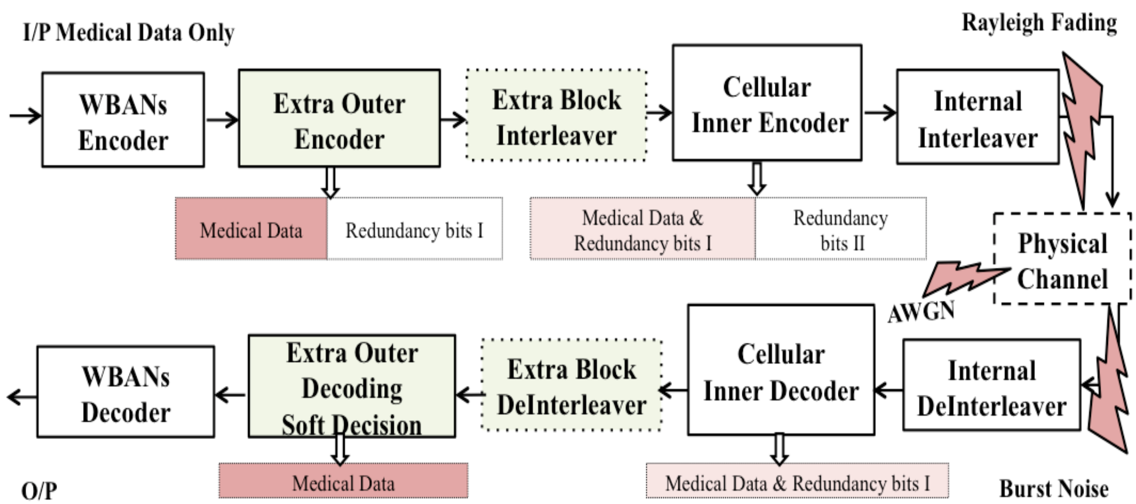

Figure 3.1 MNC Proposed System via Cellular Networks

3.1.1 The Inner Cellular Channels Codes

The inner code in the MNC structure is work as a ready existing cellular networks standard codes such as UMTS and LTE channels. UMTS and LTE channels have specification studied in 2.3 and concerning to the Shannon's theory studied in 2.1.2.3, the transmission of data through MNC supper PHY channel has to be less than the channel capacity for each one individually.

The data modulation of all uplink channels is BPSK, and for downlink channels is QPSK. The input of the cellular inner channel denoted by $C_0,C_1,C_3,\ldots,C_{K-1}$ where K is the number of bit length that to be encoded. Then in output form the encoder is encoded bits that denoted by $d_0,d_1,d_2,\ldots,d_{D-1}$ where D is the number of encoded bits. The relation between C_k and d_D is depending on the channel coding schemes, which mentioned in

Table 3.1. The UMTS and LTE provide both error detection and error correction as channel coding scheme as we studied in 2.3.2. In UMTS, the thesis work is focus to use low data rate UL and DL channels that's use convolution code as a main error correction technique. Since the medical data has low data rate as we studied in 2.2. On the other hand LTE channel the standard coding techniques for lower data rate in LTE. Here we assume the inner channel of the MNC proposed system is using UMTS/UL channel as Radio Access Channel (RACH) working by the convolution code rate 1/2. Similarly we assume using UMTS/DL channel as Downlink Shared Channel (DSCH) working by the convolution code rate 1/3. And assume LTE using Broadcast Channel (BCH) working by the convolution code rate 1/3.

Table 3.1 The Inner Cellular Networks Codes Techniques

	TRCH Type	**Coding Type**	**Coding Rate and Constrain Length**	**Number of Encoded Bits**
3G UMTS	RACH	Convolution	R=1/2&Constrain Length =9	Di= 2*Ki +16
	DSCH	Convolution	R=1/3&Constrain Length =9	Di = 3*Ki + 24
4G LTE	BCH	Convolution	R=1/3&Constrain Length =7	Di= 3*Ki +18

3.1.2 The Outer External Channels Codes

The technical parameters for the extra channel detailed in this section by using extra outer encoder as convolution encoder and extra outer interleaver as block interleaver (in case burst noise happen) concatenated to the inner cellular standard channel codes. Among all the FEC codes, the convolution codes has great advantages by working continuous streams of data, and can be managing the performance by only two parameters the code rate and the constraint length, also convolution codes has high error correction in compare to block codes and less complexity in compare to turbo codes. The decoding algorithm such as soft or hard can easily make change in the performances as well. Since the extra channel is a key point to have high performance for MNC proposed system, the choice here of the extra code is driving by convolution codes. The extra interleaver is adding only when the channel affected by burst noise, the thesis fixed the interleaver work using block interleaver rather than random interleaver after test the performance of the two types. The outer channel is the existing WBANs channel that using BCH code as a main code to correct the error as we studied in 2.2.4. The system MNC has been considering the performance with and without end-to-end connection of the WBANs codes. The assumption is the medical data coming from the WBANs entering the extra outer channel that it will be the only optimized channel in the proposed system MNCs, then entering the inner cellular channels within data rate less than the channel capacities. The transmission rate in the WBANs channel is 75.9Kb/s. suppose we have medical data from WBANs as ECG 3Kb/s or SpO2 32 Kb/s need to be sent. Therefore will design the external outer code to accept data rate within WBANs limit and provide data rates within UMTS limits, in order to not exceed the channel capacity in these standards.

3.2 Dependable Medical System for WBANs Medical Data

The MNC proposed system is dependable, when is ensure to give the different QoS level of medical data transmission that detailed in 2.2.2 within acceptable performance capability such as 10^{-3}~10^{-5}~10^{-7} BER for low, medium and high QoS levels within higher require bit energy to interference (E_b/N_o) values as possible under different assumed noise condition achieving by that, the main target of MNC in comparison to the conventional system cellular networks a lone. The WBANs has eight QoS levels as we have been studied in 2.2. The thesis work have been recognize the all QoS level for medical data into three main levels such as lower priority QoS level, Medium priority QoS level and higher priority QoS level. Depending on these priority levels, the proposed system MNC has been designed as shown in Figure 3.2.

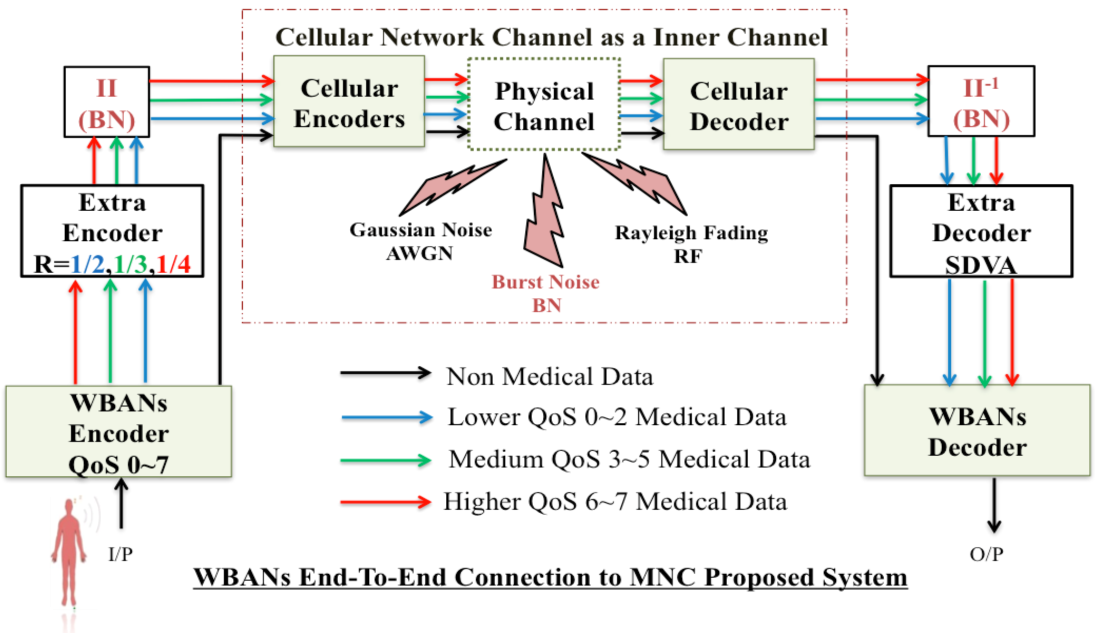

Figure 3.2 MNC Proposed System via Cellular Networks for Various Medical QoS

3.2.1 The Proposed System Design for Random Error

MNC channel structure under AWGN and Rayleigh fading channels carryout without interleaver designed in between inner and outer codes and is introduced here the encoding and decoding parts when the channel affected by random error such as AWGN or simple Rayleigh fading channels. Firstly the UL/DL cases proposed in MNC are introduced in this thesis via UMTS UL/DL-channels which using convolution codes with code rate 1/2and1/3 for UL and DL respectively. Secondly the other tested case is a LTE low data channel which using convolution code with code rate 1/3 for BCH TrCH.

The I/P frame length 100 Kbit/s having block size 51bit/block encoded by BCH code giving block size 63bit/block entering to our extra channel with the different rates of convolution code, giving result of different bit/block encoded bits depending on the used code rates of the extra outer code. The inner encoder is a cellular encoder, which detailed in 3.1.1, giving O/P encoded data sequence regarding to the cellular standard encoders. In the decoding side, the inner decoder is cellular decoders, which is detailed in last chapter and then extra outer decoder that we proposed is works using hard decision VA. At the end, the WBANs BCH blocks decoder giving-out the final decoded data.

3.2.2 The Proposed System Design for Burst Error

MNC channel structure under burst noise channel is carry out with use interleaver designed in between inner and outer codes is introduced here when the channel affected by hard error such as burst noise channels. The interleaver work to spread out the burst errors to random error then can be easy corrected using the MNC channel codes. There are many kind of interleaver such as random interleaver, convolutional interleaver and block interleaver. The thesis work has fixed to use block interleaver in the case of burst error. However the compression between random (pseudo-random interleaver) and block interleaver is given in the simulation result to test the feasibility of using different kind of interleaver. The encoding and decoding parts when the channel is affected by burst error. Firstly the UL/DL cases proposed in MNC are introduced in this thesis via UMTS UL/DL channels which using convolution codes with code rate 1/2 and 1/3 for UL and DL respectively. Secondly the other tested case is a LTE low data channel which using convolution code with code rate 1/3 for BCH channel.

The I/P frame length 100 Kbit/s having block size 51bit/block encoded by BCH giving block size 63bit/block entering to our extra channel with the different rates of convolution code, giving result of different bit/block encoded bits depending on the code rates of the extra outer code. The extra outer interleaver deals with a two-dimensional (encoded data/10)×(10) array. The encoded data sequence from extra outer encoder feed here as, first written into the interleaver in the x (encoded data/10) direction and then read out in the y (10) direction in the case of the burst noise. The inner encoder is a cellular encoders, which detailed in section 3.1.1, giving output encoded data sequence regarding to the kind of the cellular standard encoders. In the decoding side, the inner decoder is cellular decoder, which is detailed in 2.3.2. The outer de-interleaver returns the bits as the normal position. And then extra outer decoder that we proposed is works using hard decision VA. At the end, the WBANs BCH blocks decoder giving-out the final decoded data.

The interleaving is meat to rearrange the relative positions of the bits respectively in the code words. It's so useful for two reasons; firstly, bit errors tend to occur consecutively rather than singly. This is true inside a burst, and comes both from error statistics on radio transmission and from inter-symbol interference introduced by the modulation. The burst structure itself is a reason for error grouping: because of the variations of reception and interference level in time, a burst can have a small number of errors where the next will have a lot. Secondly, it appears that it is more difficult to design efficient codes when several adjacent bits are in error: better performance can be achieved when errors are randomized. Therefore block interleaver proposed between the two encoders outer and inner to separate bursts of error produced by the inner decoder.

The reason behind the block interleaver is to meet the bits organizations since the cellular has block interleaver work as a diagonal way. The idea of interleaving is simply to multiplex the outputs of λ separate encoders with constraint length n_A for transmission over the channel, where λ is the interleaving degree. The received bits are then de-multiplexed and sent to λ separate decoders. A burst of length λ on the channel will then look like single errors to each of the separate decoders. Hence, if each decoder is capable of correcting single errors in a constraint length, then, with interleaving, all bursts of length λ or less relative to a guard space of length $(n_A\text{-}1)\ \lambda$ will be corrected.

The outer block interleaver deals with a two-dimensional (X$\times$Y) as (encoded data/10)$\times$(10) array. The encoded data sequence from extra outer encoder is first written into the interleaver in the X direction and then is read out in the Y direction. Figure.3.3 shows the outer interleaver procedure. The size of the interleaver is multiplying the extra outer code rate with the input data length; therefore, we have different size of interleaver regarding to the code rate that used of the extra outer channel.

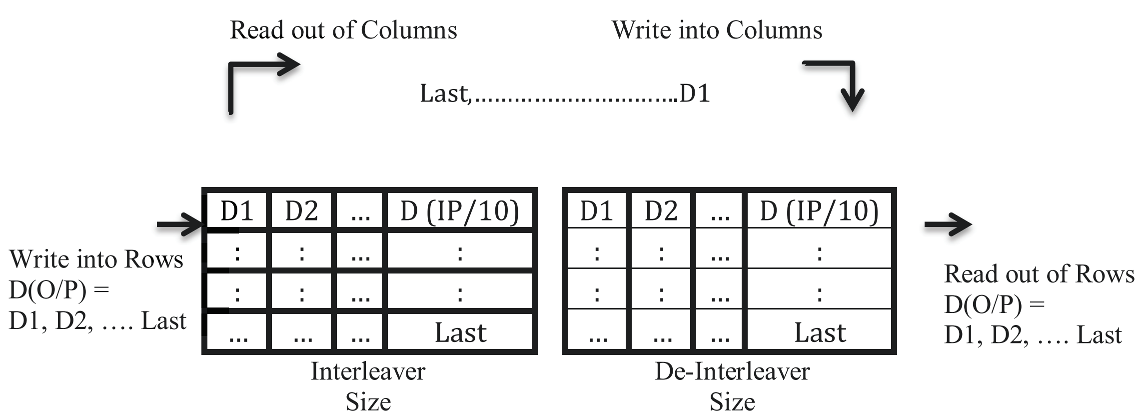

Figure 3.3 Extra Outer Block Interleaver and De-interleaver

3.3 The Capability of the Ready Existing Cellular Inner Network

The cellular network performance analysis has been investigated in 2.3. Generally the capability is carried out with the ready exiting error control coding and modulation inside each of the cellular standards itself. In the case of the random error, the capability is related to the free distance of the code and in the case of the burst noise, the capability is related to the guard space. The cellular code (2,1,9) can correct single errors in a constraint length of n_A = n (m+1) = 18bits. Hence when interleaved to degree λ. Where λ-1 must be a multiple of n=2, this code will correct all bursts of length λ or less with a guard space of$(n_A - 1)\lambda = 17\lambda$. Since$17\lambda/\lambda = 17$, the guard space-to-burst length ratio meets the gallager bound for R=1/2 codes, and this simple interleaved code is optimum for complete burst-error correction. The total memory required in interleaved decoder is$\frac{(\lambda-1)(n-1)}{2} + \lambda\text{nm} = (33\lambda - 1)/2$, which equals 82 for λ=5.

3.3.1 The Inner Channel Network Technical Capabilities

The Table 3.2 shows all the error correcting capability inside the UL and DL channels of the UMTS regarding to the standard Error correction code As well as the LTE channel. The details have been studied in 2.3.

Table 3.2 The Inner Cellular Networks Codes Capabilities

	Data Rate	R	K	G	D_{free}	Error (t)	Guard space (g)	Trellis Paths (E)	Sum W_d
3G-UL	144Kb/s	1/2	9	[561 753]	12	6	17λ	256*L	122694
3G-DL	144Kb/s	1/3	9	[557 663 711]	18	9	26λ	256*L	2275
4G	75Mb/s	1/3	7	[133 171 165]	15	7	20λ	64*L	416

3.3.2 The Inner Channel Network Remaining Errors

The all simulated results tables in appendix shows the error remains from inside the UL and DL channels of the UMTS regarding to the standard error correction code capabilities, as well as the LTE channel, for the both situations with or without end to end connections of WBANs. The remaining error has been fixed from the cellular networks performance analysis that has been studied and investigated in 2.3.3. Table 3.3 shows the free error E_b/N_o for all standards under the estimated condition that explained in 2.3.3. The probability of the errors in the entire appendix tables when is multiple by the number of the all data bits, it give us the exact numbers of the remaining errors inside these data bits.

Table 3.3 Remaining Error Limits of Inner Cellular Networks

	AWGN		**RF 0.55 random variable**		**BN 5 length 50bits interval**	
	Without WBANs	With WBANs	Without WBANs	With WBANs	Without WBANs	With WBANs
	Error probability zero at E_b/N_o **dB**		Error probability zero at E_b/N_o **dB**		Error probability zero at E_b/N_o **dB**	
UMTS - UL	5 dB	4 dB	12 dB	9 dB	No free errors shown	No free errors shown
UMTS - DL	5 dB	4 dB	10 dB	8 dB	No free errors shown	No free errors shown
LTE	6 dB	4 dB	11 dB	9 dB	No free errors shown	No free errors shown

Chapter 4

The Adaptive Selection of External Channel Code

4.1 The Criteria of the Extra Code Selections

The MNC proposed system has two main parts in the structure, the fixed parts, which related to the cellular standards networks or WBANs technology and the changeable parts which external that added for accepting the medical data only. The assumption in this thesis work is a WBANs chip installed in the mobile device to carry-on the medical data via the cellular systems through the proposed system MNC to ensure the reliability required for the different sets of these medical data.

4.2 The Requirements of the Extra Code Selections

The extra channel codes are work using convolutional code as it mentioned in 3.1.2. The extra code with or without interleaver is adaptive by carry parameter that is selectable regarding to the two main requirements, firstly, regarding to various kind of the QoS of medical data entering the extra code from the WBANs code and secondly, regarding to the kind of the channel conditions that affected the transmission in PHY channels.

4.2.1 The Medical QoS Levels Requirements

The main thesis objective is to achieve the medical QoS constrains for the MNC proposed system. Therefore the goal is figured out here is to design the extra code regarding to the QoS by analyzing the WBANs medical data QoS needed in 2.2.3.

Regarding to the QoS of WBANs that studied here the BER from [10^{-3} ~ 10^{-7}] requite for medical data. The technical parameters that targeting for MNC proposed system has to give us the desired BER for each sets of priority level under fixed estimated transmission channel environments, achieving by that, the main target of MNC proposed system in comparison to the conventional cellular system. From here we have been categorize the QoS of the WBANs medical data to three sets, regarding to the priority level, in order to design the proposed system MNC. 1^{st} set is a highest priority level such as a biological signal (ECG, EMG, and EEG), 2^{nd} set is a medium priority level such as a medical data (Temperature, blood pressure, blood sugar), and 3rd set is a lowest priority level such as data management, audio and video. The highest priority level of QoS has to carry out as lower BER 10^{-3} as possible then gradually the level can change. Therefore, we will use the three sets later to design and optimize out MNC proposed system depending on that. 1^{st} set highest priority level will carry on through strong design MNC achieving 10^{-7} BER, then 2^{nd} sets medium priority design system achieving 10^{-5} BER and then 3^{rd} sets lowest priority design system achieving 10^{-3} BER within higher E_b/N_o as possible in compare to cellular alone.

Table 4.1 Designing MNC Channel Codes Related to QoS Priority Levels

QoS Data Sets	**Code**	**R & K**	**G**	**d_f**	**t**	**Sum W_d**	**II Size**
Lowest QoS Level		1/2 & 8	[247 371]	10	5	10970	126 bits/block
Medium QoS Level	Outer	1/3 & 8	[225 331 367]	16	8	425	189 bits/block
Highest QoS Level		1/4 & 8	[235 275 313 357]	22	11	169	252 bits/block

In the MNC Super PHY channel, the inner code is a cellular UMTS or LTE ready existing network that has been studied before in 2.3. The remains error from the inner cellular decoder that cleared in 3.3.2 let us to optimize the technical parameters of the extra outer code. Therefore the extra channel code rate R fixed for lower QoS level is 1/2 and for the medium QoS level is1/3 and for the high QoS level is 1/4 by fixing the constrain length to avoid increases the complexity.

4.2.2 The Channel Environment Condition Requirements

The extra code with or without interleaver is adaptive here under the requirement of good performance for MNC via different assumed channel conditions. End to end services of the MNC proposed system should satisfy the minimum performance, as 10^{-5} BER. The average BER should be better whatever the channel condition is good or bad. Since for medical systems in the worse situation the worse performance must be enough high and good from this point of view we set the MNC without extra interleaver added between the extra code and the inner cellular code when the channel affected by AWGN or simple Rayleigh fading channel. On the other hand, we set the MNC with extra interleaver added between the extra code and the inner cellular code when the channel affected by hard Rayleigh fading or burst noise channels.

The details of the following medical data through the MNC will be explain in the next section as an example the inner channel LTE networks using convolution code R equal 1/3 and K equal 7 and G equal 133 171 165 with d_{free} equal 15. On the UMTS cellular case example, the details are having the same way. However the ability of the UMTS decoder to correct the error for UL channel is 6 error bits and for DL channel is 9 error bits.

4.3 The Adaptive System Design Techniques for QoS Levels

4.3.1 The Lower QoS Priority Level via AWGN and Simple Fading

The block interleaver no need for this channel. The low QoS medical data frame length 100 Kb/s having block size 51b/s encoded by WBANs code that is BCH (63,51,2) giving 63bb/s. then these data bits fits to the extra channel code for lower QoS with code parameters (2,1,8) with d_{free} equal to10 giving 126b/s extra encoded bits. The inner encoder is a cellular LTE encoder with code parameter (3,1,7) giving output-encoded data sequence equal to 378 b/s. In the decoding side, the inner decoder is cellular LTE decoders work using soft decision VA, which is detailed in chapter two and then extra outer decoder that we proposed is works using hard decision VA. At the end, the WBANs BCH blocks decoder giving-out the final decoded data. The capability of correcting the error in this channel it depends on the free distance of each code separately. Firstly, inner LTE decoder can correct about 7 errors bit, then secondly extra outer decoder can correct up to 5 errors bit. Lastly the WBANs decoder can correct just up to 2 error bits. The performance for this channel via AWGN and Rayleigh fading 0.55 it's acceptable for the lower QoS medical data.

4.3.2 The Lower QoS Priority Level via Burst Noise and Hard Fading

The block interleaver no need for this channel. The low QoS medical data frame length 100 Kb/s having block size 51b/s encoded by WBANs code that is BCH (63,51,2) giving 63bb/s. then these data bits fits to the extra channel code for lower QoS with code parameters (2,1,8) with d_{free} equal to10 giving 126b/s extra encoded bits. The extra outer interleaver size 126b/s deals with a two-dimensional (encoded data/10)×(10) array. The encoded data sequence from extra outer encoder feed here as, first written into the interleaver in the x (encoded data/10) direction and then read out in the y (10) direction.

The inner encoder is a cellular LTE encoder with code parameter (3,1,7) giving output-encoded data sequence equal to 378 b/s. In the decoding side, the inner decoder is cellular LTE decoders work using soft decision VA, which is detailed in chapter two and the outer de-interleaver returns the bits as the normal position then extra outer decoder that we proposed is works using hard decision VA. At the end, the WBANs BCH blocks decoder giving-out the final decoded data. The performance for this channel via burst noise assumed with a burst length 5bit each 50bits in the data is carry out by the capability of correcting the error in this channel that it depends on the free distance of each code separately when the interleaver turn all the burst errors into random errors. Firstly, inner LTE decoder can correct about 7 errors bit, then secondly extra outer decoder can correct up to 5 errors bit. Lastly the WBANs decoder can correct just up to 2 error bits.

4.3.3 The Medium QoS Priority Level via AWGN and Simple Fading

The block interleaver no need for this channel. The medium QoS medical data frame length 100 Kb/s having block size 51b/s encoded by WBANs code that is BCH (63,51,2) giving 63bb/s. then these data bits fits to the extra channel code for medium QoS with code parameters (3,1,8) with d_{free} equal to16 giving 189b/s extra encoded bits. The inner encoder is a cellular LTE encoder with code parameter (3,1,7) giving output-encoded data sequence equal to 567 b/s. In the decoding side, the inner decoder is cellular LTE decoders work using soft decision VA, which is detailed in chapter two and then extra outer decoder that we proposed is works using hard decision VA. At the end, the WBANs BCH blocks decoder giving-out the final decoded data. The capability of correcting the error in this channel it depends on the free distance of each code separately. Firstly, inner LTE decoder can correct about 7 errors bit, then secondly extra outer decoder can correct up to 8 errors bit. Lastly the WBANs decoder can correct just up to 2 error bits. The performance for this channel via AWGN and Rayleigh fading 0.55 it's acceptable for the lower QoS medical data.

4.3.4 The Medium QoS Priority Level via Burst Noise and Hard Fading

The block interleaver no need for this channel. The medium QoS medical data frame length 100 Kb/s having block size 51b/s encoded by WBANs code that is BCH (63,51,2) giving 63bb/s. then these data bits fits to the extra channel code for lower medium with code parameters (3,1,8) with d_{fee} equal to16 giving 189b/s extra encoded bits. The extra outer interleaver size 189b/s deals with a two-dimensional (encoded data/10)×(10) array. The encoded data sequence from extra outer encoder feed here as, first written into the interleaver in the x (encoded data/10) direction and then read out in the y (10) direction. The inner encoder is a cellular LTE encoder with code parameter (3,1,7) giving output-encoded data sequence equal to 567 b/s. In the decoding side, the inner decoder is cellular LTE decoders work using soft decision VA, which is detailed in chapter two and the outer de-interleaver returns the bits as the normal position then extra outer decoder that we proposed is works using hard decision VA. At the end, the WBANs BCH blocks decoder giving-out the final decoded data. The performance for this channel via burst noise assumed with a burst length 5bit each 50bits in the data is carry out by the capability of correcting the error in this channel that it depends on the free distance of each code separately when the interleaver turn all the burst errors into random errors.

Firstly, inner LTE decoder can correct about 7 errors bit, then secondly extra outer decoder can correct up to 8 errors bit. Lastly the WBANs decoder can correct up 2 errors.

4.3.5 The Higher QoS Priority Level via AWGN and Simple Fading

The block interleaver no need for this channel. The higher QoS medical data frame length 100 Kb/s having block size 51b/s encoded by WBANs code that is BCH (63,51,2) giving 63bb/s. then these data bits fits to the extra channel code for higher QoS with code parameters (4,1,8) with d_{fee} equal to 22 giving 252b/s extra encoded bits. The inner encoder is a cellular LTE encoder with code parameter (3,1,7) giving output-encoded data sequence equal to 756 b/s. In the decoding side, the inner decoder is cellular LTE decoders work using soft decision VA, which is detailed in chapter two and then extra outer decoder that we proposed is works using hard decision VA. At the end, the WBANs BCH blocks decoder giving-out the final decoded data. The capability of correcting the error in this channel it depends on the free distance of each code separately. Firstly, inner LTE decoder can correct about 7 errors bit, then secondly extra outer decoder can correct up to 11 errors bit. Lastly the WBANs decoder can correct just up to 2 error bits. The performance for this channel via AWGN and Rayleigh fading 0.55 it's acceptable for the lower QoS medical data.

4.3.6 The Higher QoS Priority Level via Burst Noise and Hard Fading

The block interleaver no need for this channel. The higher QoS medical data frame length 100 Kb/s having block size 51b/s encoded by WBANs code that is BCH (63,51,2) giving 63bb/s. then these data bits fits to the extra channel code for higher QoS with code parameters (4,1,8) with d_{fee} equal to22 giving 252b/s extra encoded bits. The extra outer interleaver size 252b/s deals with a two-dimensional (encoded data/10)×(10) array. The encoded data sequence from extra outer encoder feed here as, first written into the interleaver in the x (encoded data/10) direction and then read out in the y (10) direction. The inner encoder is a cellular LTE encoder with code parameter (3,1,7) giving output-encoded data sequence equal to 756 b/s. In the decoding side, the inner decoder is cellular LTE decoders work using soft decision VA, which is detailed in chapter two and the outer de-interleaver returns the bits as the normal position then extra outer decoder that we proposed is works using hard decision VA. At the end, the WBANs BCH blocks decoder giving-out the final decoded data. The performance for this channel via burst noise assumed with a burst length 5bit each 50bits in the data is carry out by the capability of correcting the error in this channel that it depends on the free distance of each code separately when the interleaver turn all the burst errors into random errors. Firstly, inner LTE decoder can correct about 7 errors bit, then secondly extra outer decoder can correct up to 11 errors bit. Lastly the WBANs decoder can correct up 2 errors.

4.4 The Capabilities of the Adaptive External Channel Codes

The system design that detailed in the 3.1, it has been sit for the different QoS levels of medical data. The technical parameters of the extra channel codes are have been fixed for the MNC channels. The capabilities have been determined for the AWGN channel and for the Rayleigh fading with parameter distribution function equal to 0.55 and for burst noise with length 5bits happening each 50 bits. However, for seeking the reality these channel condition it’s may be good or worse than that determined.

Table 4.2 All Error Correcting Capabilities for MNC Proposed System Codes

I/P	100 Kb/s 51bits/s length		
Outer WBANs Encoder	63bits/s		
Extra Channel Encoders	**Lowest QoS Level**	**Medium QoS Level**	**Highest QoS Level**
	(2,1,8) D_{free} 10 T=5 I/P 63b/s O/P 126 b/s	(3,1,8) D_{free} 16 T=8 I/P 63b/s O/P 189 b/s	(4,1,8) D_{free} 22 T=11 I/P 63b/s O/P 252 b/s
Interleaver Size **[Encoded Bits #/10 × 10]**	126bits	189bits	252bits
UMTS UL Inner Encoder	(2,1,9) D_{free} 12 T=6 I/P 126 b/s O/P 252 b/s	(2,1,9) D_{free} 12 T=6 I/P 189 b/s O/P 378 b/s	(2,1,9) D_{free} 12 T=6 I/P 252 b/s O/P 504 b/s
UMTS DL Inner Encoder	(3,1,9) D_{free} 18 T=9 I/P 126 b/s O/P 378 b/s	(3,1,9) D_{free} 18 T=9 I/P 189 b/s O/P 567 b/s	(3,1,9) D_{free} 18 T=9 I/P 252 b/s O/P 756 b/s
LTE UL Inner Encoder	(3,1,7) D_{free} 15 T=7 I/P 126 b/s O/P 378 b/s	(3,1,7) D_{free} 15 T=7 I/P 189 b/s O/P 567 b/s	(3,1,7) D_{free} 15 T=7 I/P 252 b/s O/P 756 b/s

In the optimization chapter will assume different channel condition for the Rayleigh fading and burst noise. Rayleigh fading distributions less and more than 0.55 such as 0.35 and 0.75 will consider. On the other hand, in burst noise, will assume different burst length more and less that 5 bits such as 3bit and 7 bits happening more or less that 50bits such as 30bits and 70bits. The advantage and the drawback of or proposed system MNC will be clear. Table 4.2 details all the MNC adaptive design parameters regarding to the capability of correcting the channels errors. Furthermore its shows also the number of data bit entering each encoder and the number of the encoded bits from each encoder respectively. The interleaver depth here is fixed [#encoded bits/10×10]. However in the optimization chapter will carry out numbers of interleaver depth in simulations results.

Chapter 5

The Theoretical Analyses and Numerical Evaluations

5.1 Theoretical Error Bound Performances Calculation Key-Points

The MNC proposed system has decoding parts that main for theoretical derivation. The error bound probabilities can be calculated depending on the inner, outer and extra outer decoder's separately; continuously, the code performance is analyzed in terms of decoded BER. BER is normally calculated as a function of E_b/N_o. Here E_b represents the average energy transmitted per information bit and N_o represents the single-sided power spectral density of assumed AWGN channel. The MNC proposed system is testing under different estimated noisy channel. First, the performance bounds theoretically are driven under AWGN with and without adding WBANs end to end to MNC proposed system. Second, the performance bounds theoretically are driven under Rayleigh fading channel without adding WBANs end to end, this step is only to demonstrate the feasibility of the proposed system and to find out the numbers of errors in the output of inner cellular decoders and to test the optimized extra channel code that detailed in 4.3 theoretically in MNC for different QoS medical data levels under AWGN and Rayleigh fading channels. Table 5.1 explains all the technical parameters used in the theoretical evaluation. The theoretical bound is done by calculated the probability of finding the errors in each steps of the MNC concatenated channel codes. The steps first in the O/P of the inner cellular decoders, then second in the O/P of the extra channels decoders (the three sets for different QoS levels), then lastly in the O/P of the WBANs outer decoders. These numerical evaluations, has been done in the different assumed inner cellular channel codes such as UMTS codes UL/DL channel and LTE codes as well.

Table 5.1 MNC Technical Parameters for Theoretical Calculations

QoS Data Sets	**Code**	**R & K**	**G**	**d_f**	$C_{2dfreei-1}^{dfreei}$	**Sum of W_d**
LTE	Inner	1/3&7	[133 171 165]	15	29!/15!×14! 77558760	W_d= ∑[7 8 22 44 22 94 219] sum 416
UMTS-UL		1/2&9	[561 753]	12	23!/12!×11! 1352078	W_d= ∑ [33 281 2179 15035 105166] =122694
UMTS-DL		1/3&9	[557 663 711]	18	35!/18!×17! 4.5376e+009	W_d= ∑[11 32 195 564 1473] =2275
Lowest QoS Level	Outer	1/2&8	[247 371]	10	19!/10!×9! 92378	W_d= ∑[2 22 60 148 340 1008 2642 6748] =10970
Medium QoS Level		1/3&8	[225 331 367]	16	32!/16!×15! 300540195	W_d= ∑[1 24 113 287] =425
Highest QoS Level		1/4&8	[235 275 313 357]	22	43!/22!×21! 1.0520e+012	W_d= ∑[2 10 108 10 11 54 64] =169

5.1.1 The Theoretical Error Bound via AWGN Channel

The theoretical calculations for the error bound of the MNC proposed system could be done as many step in the decoding side. The inner and extra channel used convolutional decoder which work using Viterbi algorithm and the outer WBANs channel use the block code decoder, as we mentioned in chapter two. First of all, the UMTS inner decoder calculate the first inner probability bit errors P_{bi} bound as in (5-1 ~ 5-4)

$$P_{bi} \leq \frac{1}{bi} \sum_{di=0}^{\infty} w_{di} P_{ei}(di) \tag{5-1}$$

Where, $P_{ei}(di)$ is the probability of confusing two sequences differing in distances *di* positions of inner cellular code, and can be calculated as in (5-2). W_{di} is weight spectrum that is the average number of bit errors associated with sequences of weigh *di*, and it's calculated for all codes work in these MNC proposed system as in Table 5.1 w(d), $d \geq d_f$. W_{di} term can be evaluated using the transfer function of the convolution code. Generally, for codes whose constraint length is greater than a few units (typically, $\nu \geq 5$), the calculation of the transfer function can prove to be complex. We then prefer to determine the spectrum of the code, or at least the first terms of this spectrum, using an algorithm that explores the various paths of the lattice diagram [49].

$$P_{ei}(di) = Q(\sqrt{2diRi\, E_b/N_0}) \qquad (5\text{-}2)$$

Where, *di* is an inner cellular code free distance and *Ri* is an inner cellular code rate, the both showed in Table 5.1. Q function it's clear in information theory and can be calculated using infinity integration as in (5.3)

$$Q(x) \cong \int_x^{\infty} \frac{1}{\sqrt{2\pi}} e^{-t^2/2}\, dt \qquad (5\text{-}3)$$

$$P_{bi} \leq \frac{1}{bi} \sum_{di=0}^{\infty} w_{di} \bullet Q(\sqrt{2diRi\, E_b/N_0}) \qquad (5\text{-}4)$$

Generally speaking, the data stream coming from the cellular inner codes feed to the extra outer codes. The code performance of the extra outer code is a function of the cellular inner code. Second, the extra outer decoder calculates the second outer probability bit errors P_{bo} bound separately as in (5.5 ~ 5.6) by the outer code parameter introduced in Table 5.1 for the three different QoS levels of WBANs medical data.

$$P_{bo} \leq \frac{1}{bo} \sum_{do=0}^{\infty} w_{do} \bullet Q(\sqrt{2doRo\, E_b / N_0}) \tag{5-5}$$

$$P_b\, withnoWBAN \leq P_{bi} \bullet P_{bo} \tag{5-6}$$

Then, the outer codes performances of MNC, that using in this these can be calculated by (5.6) for lower, medium and higher QoS classes of medical data depending on the parameters applied of the extra channel. The last step here is introduced in the following step by calculating the final outer code performance of the MNC proposed system. The WBANs decoder (63, 51, 2) calculates the last probability bit errors *P* bound using (5-7 ~5-10) that is a function of the optimized extra outer code.

$$P_b \leq \sum_{i=t+1}^{n} \binom{n}{i} P_x^i (1-P_x)^{n-i} \; where \binom{n}{i} = \frac{n!}{(n-i)! \bullet i!} \tag{5-7}$$

$$P_b \leq \sum_{i=2+1}^{63} \binom{63}{i} P_x^i (1-P_x)^{63-i} \tag{5-8}$$

$$P_x = Q(\sqrt{2R\, E_b / N_0}) = Q(\sqrt{2 \times 51/63 \bullet E_b / N_0}) \tag{5-9}$$

By using (5.9) as a function of (5.6) to calculate the final bound, we can have (5-10)

$$P_x\, withWBAN = P_b\, withnoWBAN \bullet P_x \tag{5-10}$$

Then, by apply (5.10) in (5.7) we will have the final MNC proposed system by adding WBANs code end to end for all QoS assumed and via AWGN channel in (5.11)

$$P_b\, withWBAN \leq \sum_{i=2+1}^{63} \binom{63}{i} P_x^i\, withnoWBAN\, (1-P_x withnoWBAN)^{63-i} \tag{5-11}$$

5.1.2 The Theoretical Error Bound via Rayleigh Fading Channel

The theoretical calculations for the error bound of the MNC proposed system via Rayleigh fading channel could be done by the same steps of calculating it via AWGN channel without connection of the WBANs end to end. For this part, the $P_{j,I}$ attenuations are random independent Rayleigh variables of probability density as in (5-12)

$$P_{(\rho_{j,i})} \cong \frac{1}{\sigma_\rho^2} \rho_{j,i} \exp(-\rho_{j,i}^2 / (2\sigma_\rho^2)) \prod_{\rho_{j,i}} \geq 0 \qquad (5\text{-}12)$$

Where $E(\rho_{j,i}^2) = 2\sigma_\rho^2$ and $\prod_{\rho_{j,i}} \geq 0$ is the indicator of the set $\{\rho_{j,i} \geq 0\}$, which equals 1 if $\rho_{j,i} \geq 0$, and 0 if not. In all theoretical and simulation work for our proposed system will be estimate this Rayleigh variable as 0.55 which is greater than 0 to evaluate the supper PHY channel MNC proposed system. First of all, the cellular decoder calculates the first inner probability bit errors P_{bi} bound as a function of the performance of the BFSK modulation as in (5.13).

$$P_{bfsk} \cong \frac{1}{2}\left[1 - \sqrt{\frac{\overline{E}_b / N_0}{1 + \overline{E}_b / N_0}}\right] \qquad (5\text{-}13)$$

$$P_b \leq \frac{w(df)}{b} C_{2df-1}^{df} \left(\frac{1}{4R\overline{E_b}/N_0} \right)^{df} \qquad (5\text{-}14)$$

Where, C can be calculated using the free distance d_{freei} of the inner cellular code by (5.15) and appeared in Table 5.1. E_b is represents the average energy received per symbol of transmitted information, and it's calculated as in (5-16). Then, the inner cellular code performance, that using in this thesis can be calculated by (5-17)

$$C_{2d-1}^{d} = \frac{(2d-1)!}{d! \bullet (d-1)!} \tag{5-15}$$

$$\overline{E_b} = E(\rho_{j,i}^{2}) E_b = 2\sigma_p^2 E_b = 0.55 E_b \, assumed \tag{5-16}$$

$$P_{bi} \le P_{bfsk} \bullet \frac{w(dfreei)}{b} C_{2dfreei-1}^{dfreei} \left(\frac{1}{4Ri \overline{E_b} / N_0} \right)^{dfree} \tag{5-17}$$

Generally speaking, the data stream coming from the cellular inner code feed the extra channel code. The code performance of the extra outer code is a function of the inner cellular code. Second, the outer decoder calculate the second outer probability bit errors P_{bo} bound separately as in (5-18) by the outer code parameters introduced in Table 5.1 for the different QoS levels obtained.

$$P_{bo} \le P_{bfsk} \bullet \frac{w(dfreeo)}{bo} C_{2dfreeo-1}^{dfreeo} \left(\frac{1}{4Ro \overline{E_b} / N_0} \right)^{dfreeo} \tag{5.18}$$

Then, the extra outer codes performances of supper PHY channel MNC system, that using in this thesis under Rayleigh fading can be calculated by (5-19)

$$P_b \le P_{bi} \bullet P_{bo} \tag{5-19}$$

5.2 MNC Proposed System Error Bound Performances Calculations

In order to calculate the theoretical performance for the MNC system for different QoS level using different cellular standards as an inner code, the section is come to calculate that under AWGN and Rayleigh fading channels. Generally here we will add all the technical parameters about all the MNC proposed system components such as, inner, outer and extra codes channels codes.

5.2.1 The Error Bound via AWGN Channel for Inner Code UMTS

In the case of the inner codes works as a UMTS channel, there are two kind of code UL and DL. By using the cellular parameters in (5-4) we will have the probability of errors as (5-20) in case of UL and (5-21) in case of DL.

$$P_{bi}UL \leq 122694Q(\sqrt{12\,E_b/N_0}) \tag{5-20}$$

$$P_{bi}DL \leq 2275Q(\sqrt{12\,E_b/N_0}) \tag{5-21}$$

The second steps, in the O/P of the extra channel code there are three targeting QoS level. Therefore the probability of the error can be calculated from (5-5) as in (5-22 ~ 5-24) for the different code sets.

$$P_{bo}LQoS \leq 10970 \bullet Q(\sqrt{10\,E_b/N_0}) \tag{5-22}$$

$$P_{bo}MQoS \leq 425 \bullet Q(\sqrt{32/3\,E_b/N_0}) \tag{5-23}$$

$$P_{bo}HQoS \leq 169 \bullet Q(\sqrt{11\,E_b/N_0}) \tag{5-24}$$

From here the error probability for the MNC proposed system without end to end connection of WBANS can be calculated from (5-6) as six levels of error probability as in (5-25)

$$P_b withnoWBAN \leq P_{bi}UL/DL \bullet P_{bo}L/M/HQoS \tag{5-25}$$

The final steps here can be done when the WBANs connected end to end through the proposed system. Therefore using (5-25) in (5-11) we can have the final error probability of the MNC system.

$$P_b\, withWBAN \le \sum_{i=2+1}^{63} \binom{63}{i} P_b^i\, withnoWBAN\, (1 - P_b withnoWBAN)^{63-i} \tag{5-26}$$

5.2.2 The Error Bound via AWGN Channel for Inner Code LTE

In the case of the inner codes works as a LTE channel, when using the LTE cellular parameters in (5.4) we will have the probability of errors as (5-27)

$$P_{bi} LTE \le 416Q(\sqrt{10\, E_b/N_0}) \tag{5-27}$$

The second steps, in the O/P of the extra channel code there are three targeting QoS level. Therefore the probability of the error can be calculated from (5.5) as in (5.22 ~ 5.24) for the different code sets. From here the error probability for the MNC proposed system without end-to-end connection of WBANS through the LTE can be calculated from (5-6) as six levels of error probability as in (5.28)

$$P_b\, withnoWBAN \le P_{bi} LTE \bullet P_{bo} L/M/HQoS \tag{5-28}$$

The final steps here can be done when the WBANs connected end to end through the proposed system. Therefore using (5.28) in (5.11) we can have the final error probability of the MNC system.

$$P_b\, withWBAN - LTE \le \sum_{i=2+1}^{63} \binom{63}{i} P_b^i\, withnoWBAN\, (1 - P_b withnoWBAN)^{63-i} \tag{5-29}$$

5.2.3 The Error Bound via Rayleigh Fading Channel for Inner Code UMTS

In the case of the inner codes works as a UMTS channel, there are two kind of code UL and DL. By using the cellular parameters in (5-17) we will have the probability of errors as (5-30) in case of UL and (5-31) in case of DL.

$$P_{bi}UL \le P_{bfsk} \bullet \frac{w(dfreei)}{b} C_{2dfreei-1}^{dfreei} \left(\frac{1}{4Ri\overline{E_b}/N_0} \right)^{dfree} \quad (5\text{-}30)$$

$$P_{bi}DL \le P_{bfsk} \bullet \frac{w(dfreei)}{b} C_{2dfreei-1}^{dfreei} \left(\frac{1}{4Ri\overline{E_b}/N_0} \right)^{dfree} \quad (5\text{-}31)$$

The second steps, in the O/P of the extra channel code there are three targeting QoS level. Therefore the probability of the error can be calculated from (5-18) as in (5-32 ~ 5-34)

$$P_{bo}LQoS \le P_{bfsk} \bullet \frac{w(dfreeo)}{bo} C_{2dfreeo-1}^{dfreeo} \left(\frac{1}{4Ro\overline{E_b}/N_0} \right)^{dfreeo} \quad (5\text{-}32)$$

$$P_{bo}MQoS \le P_{bfsk} \bullet \frac{w(dfreeo)}{bo} C_{2dfreeo-1}^{dfreeo} \left(\frac{1}{4Ro\overline{E_b}/N_0} \right)^{dfreeo} \quad (5\text{-}33)$$

$$P_{bo}HQoS \le P_{bfsk} \bullet \frac{w(dfreeo)}{bo} C_{2dfreeo-1}^{dfreeo} \left(\frac{1}{4Ro\overline{E_b}/N_0} \right)^{dfreeo} \quad (5\text{-}34)$$

From here the error probability for the MNC proposed system without end-to-end connection of WBANS can be calculated from (5.19) as three levels of error probability as in (5-25)

$$P_b withnoWBAN \le P_{bi}UL/DL \bullet P_{bo}L/M/HQoS \quad (5\text{-}35)$$

5.2.4 The Error Bound via Rayleigh Channel for Inner Code LTE

In the case of the inner codes works as a LTE channel, when using the cellular parameters in (5-17) we will have the probability of errors as (5-36)

$$P_{bi}LTE \le P_{bfsk} \bullet \frac{w(dfreei)}{b} C_{2dfreei-1}^{dfreei} \left(\frac{1}{4Ri\,\overline{E_b}/N_0} \right)^{dfree} \tag{5-36}$$

The second steps, in the O/P of the extra channel code there are three targeting QoS level. Therefore the probability of the error can be calculated from (5-18) as in (5-32 ~ 5-34) for the different code QoS sets. Then From here the error probability for the MNC proposed system without end-to-end connection of WBANS can be calculated from (5-19) as three levels of error probability as in (5-37)

$$P_b\, withnoWBAN \le P_{bi}LTE \bullet P_{bo} L/M/HQoS \tag{5-37}$$

5.3 MNC Proposed System Error Bound Performances Results

The figures and tables here show the numerical evaluation of the MNC proposed system with different categories, when the inner channel as UMTS UL and DL and LTE as well. On the other hand, when the extra outer channel is sets for Lower QoS and Medium QoS and Higher QoS.

5.3.1 The Performances Bound Results in Figures

The BER is a main term that has been calculated theoretically for the MNC system. The details for different QoS BER results have been cleared in all curves inside the figures when we considered the inner channel UMTS UL and DL and also considered LTE as well.

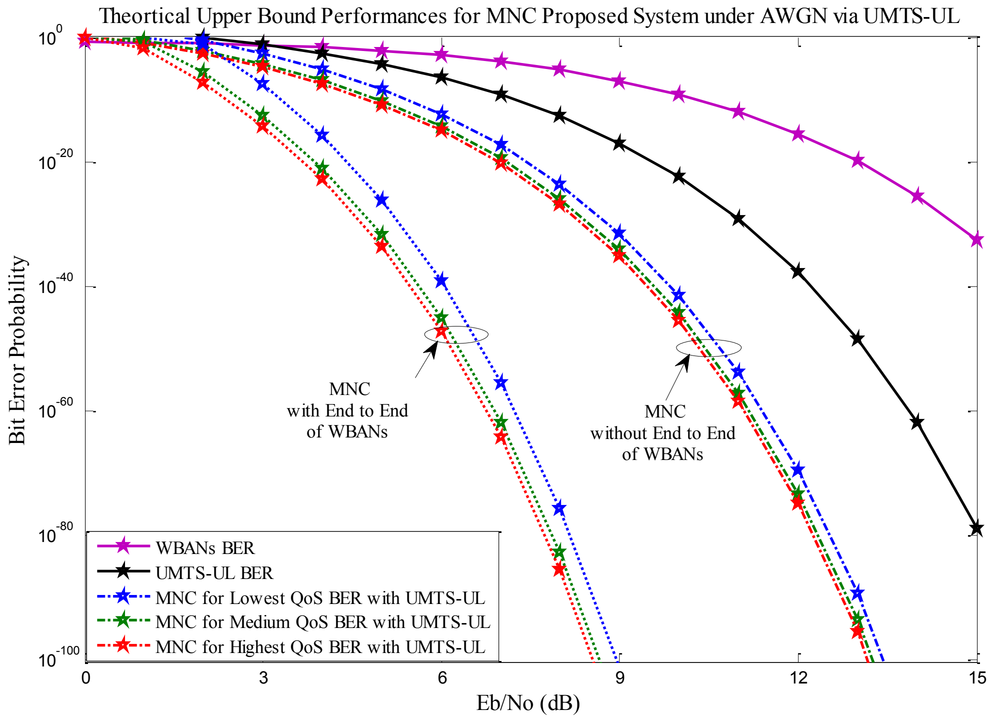

Figure 5.1 All Priority Results via UMTS - UL under AWGN Theoretically

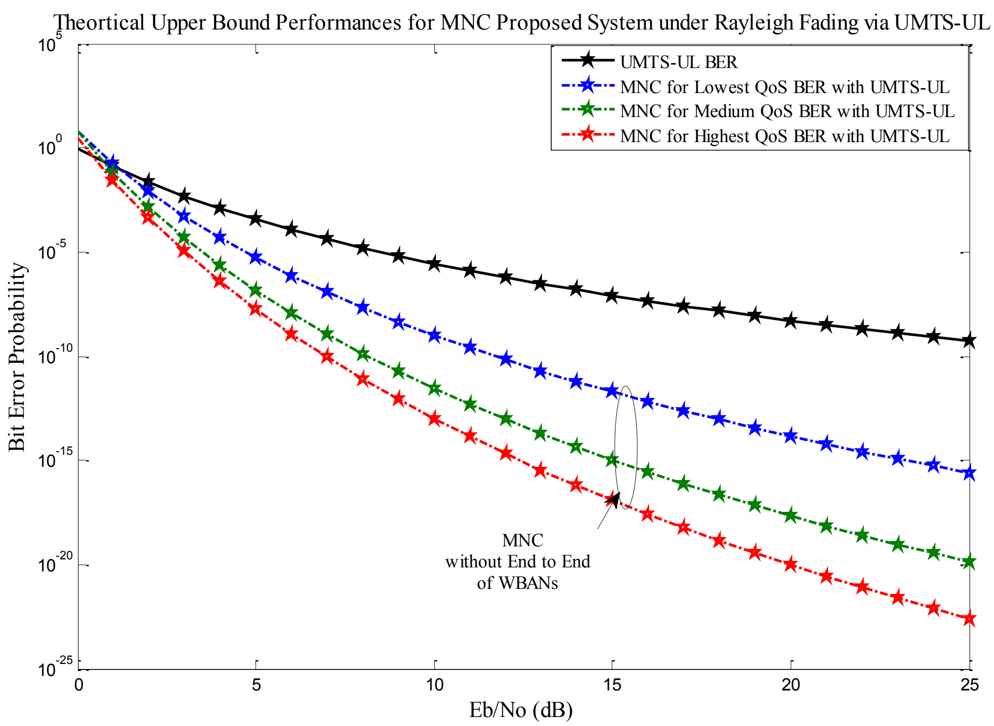

Figure 5.2 All Priority Results via UMTS -UL under Rayleigh Fading Theoretically

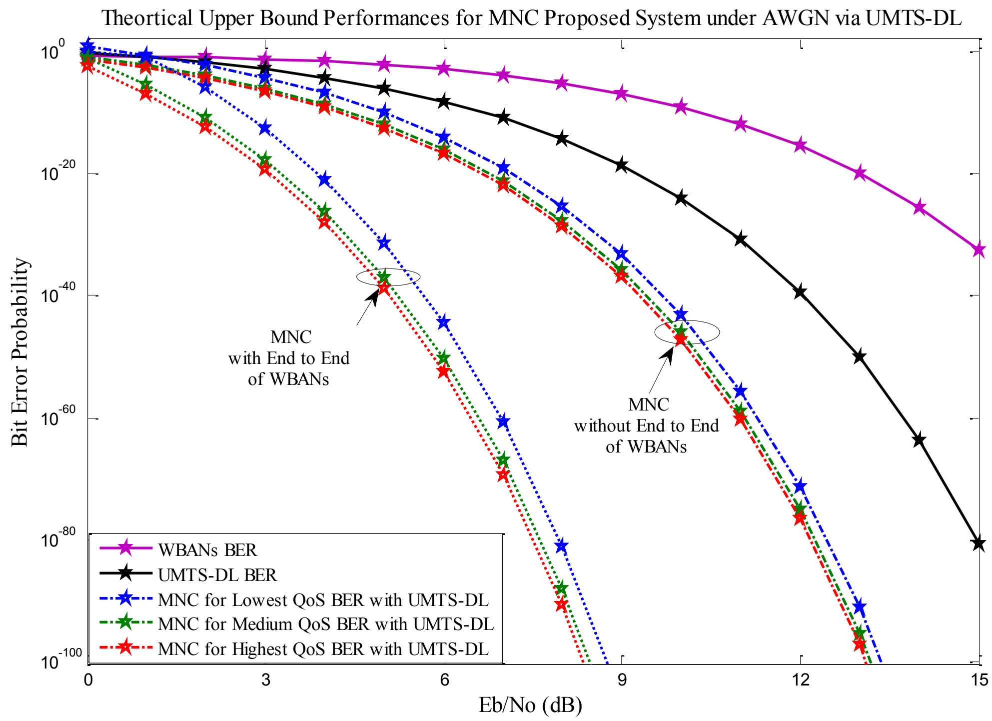

Figure 5.3 All Priority Results via UMTS - DL under AWGN Theoretically

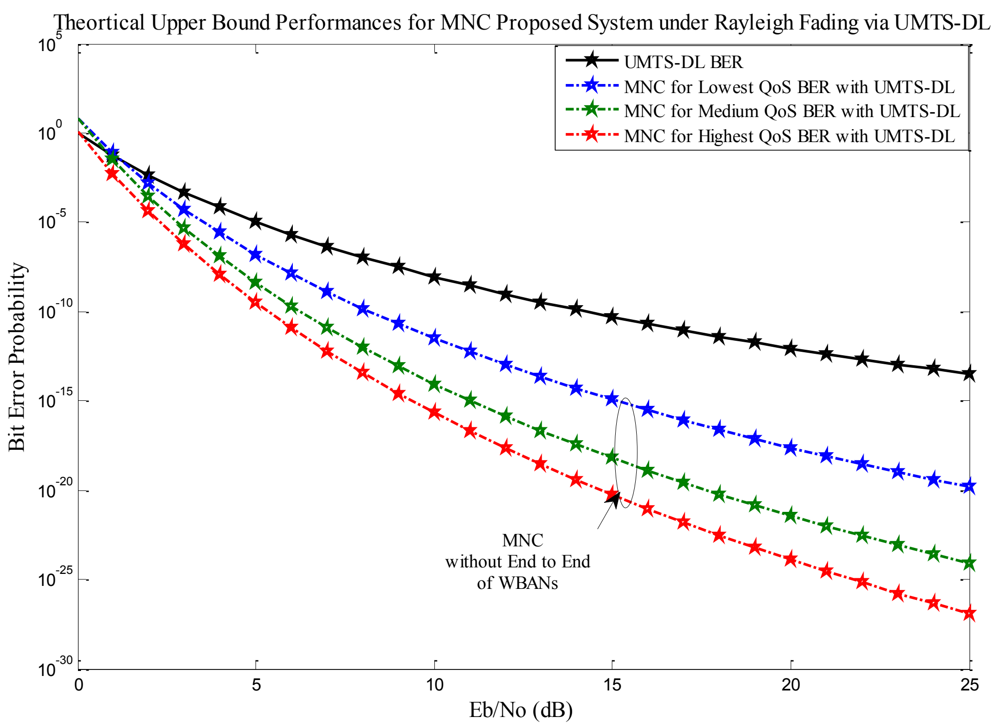

Figure 5.4 All Priority Results via UMTS-DL under Rayleigh Fading Theoretically

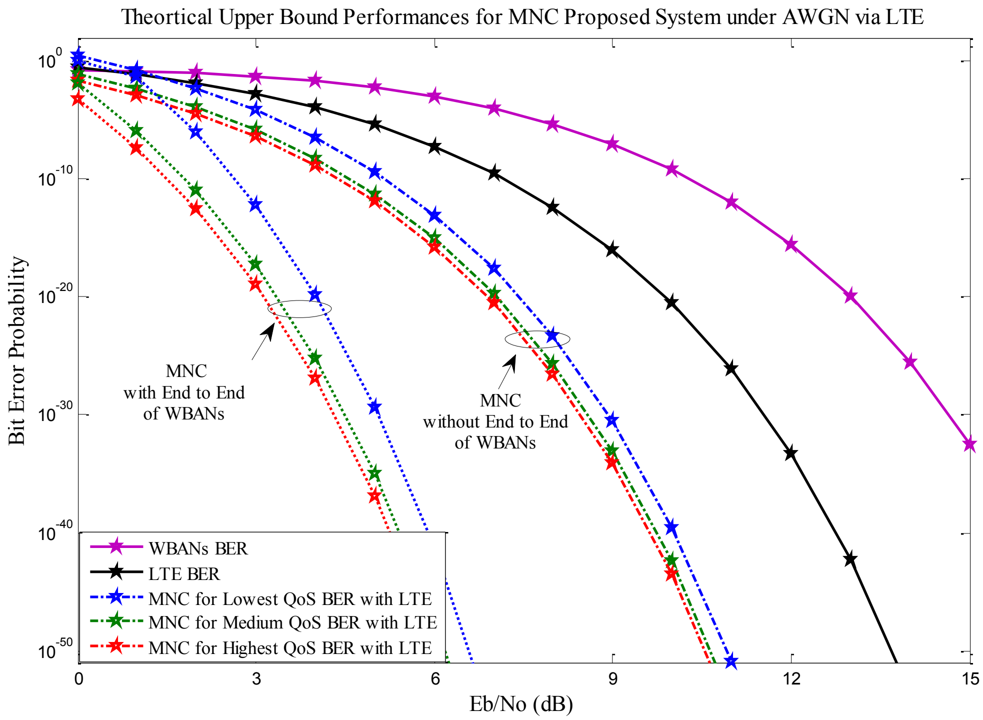

Figure 5.5 All Priority Results via LTE under AWGN Theoretically

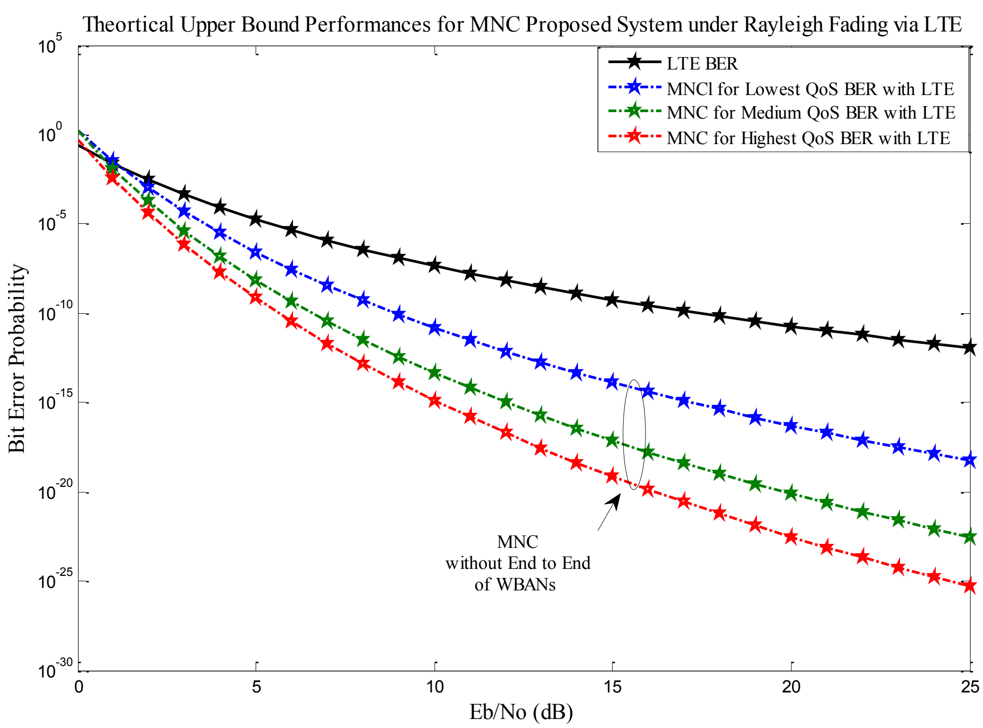

Figure 5.6 All Priority Results via LTE under Rayleigh Fading Theoretically

5.3.2 The Performances Bound Results in Numbers

Figure 5.2 shows the theoretical performance by using (5-6) and (5-11) when the channel affected by AWGN and using (5-19) when the channel affected by Rayleigh fading. The numbers of results here is an example by calculating section 5.2.2 and 5.2.4 when the inner channel is LTE. By the same way it can be calculated when the inner channel for MNC Proposed system is UMTS UL and DL channels, as is shown in all figures in section 5.3.1.

Table 5.2 Theoretical Error Bits Performances for MNC System with Inner LTE Channel

The Results Via AWGN						
E_b/N_o	0 dB	1 dB	2 dB	3 dB	4 dB	5 dB
WBANs	0.1763	0.1379	0.0933	0.0515	0.0215	0.0062
LTE	0.3256	0.0807	0.0143	0.0017	0.0001	0.0000
L-QoS	2.7957	0.1717	0.0054	0.0001	0.0000	0.0000
M-QoS	0.0755	0.0042	0.0001	0.0000	0.0000	0.0000
H-QoS	0.0251	0.0014	0.0000	0.0000	0.0000	0.0000
L-QoS-WBANs	1.0000	0.0506	0.0000	0.0000	0.0000	0.0000
M-QoS-WBANs	0.0127	0.0000	0.0000	0.0000	0.0000	0.0000
H-QoS-WBANs	0.5854	0.0000	0.0000	0.0000	0.0000	0.0000
The Results Via RF of PDF 0.55						
E_b/N_o	0 dB	1 dB	2 dB	3 dB	4 dB	5 dB
LTE	4.9532	0.0001	0.0000	0.0000	0.0000	0.0000
L-QoS	1.9352	0.0000	0.0000	0.0000	0.0000	0.0000
M-QoS	9.0438	0.0000	0.0000	0.0000	0.0000	0.0000
H-QoS	4.5376	0.0000	0.0000	0.0000	0.0000	0.0000

Chapter 6

The Optimizations of the Proposed MNC System

6.1 Simulations Setting Parameters

The performance of the supper PHY proposed channel MNC is evaluated using computer simulation by calculating the BER and Throughput. The parameters that used in the simulations are given in Table 6.1 assuming different channel conditions such as, AWGN and Rayleigh fading as has formula that returns a matrix of random numbers chosen from the Rayleigh distribution with parameter 0.55, where scalars 1 and encoded data are the row and column dimensions of noisy corrupted data and Burst Noise as to happen every 50 bits interval for 5 bits length burst noise.

The simulation considered two way of the MNC proposed system, the first way without end to end connection of WBANs, in this case the I/P data bit is 10Mb/s entering the proposed system. The second way is with end-to-end connection of WBANs; in this case I/P data bit is 100Kb/s with block length 51 bits entering the WBANs standards code before the proposed system. The simulation tests carried by MATLAB programing according to main two steps; First, according to the channel conditions, the use of internal block interval between the inner cellular code and the extra outer code, which helped to improve the performance for burst noise conditions. The extra outer interleaver in encoding side, deals with a two-dimensional (encoded data/10)×(10) array. The encoded data sequence from extra outer encoder feed here as, first written into the interleaver in the x (encoded data/10) direction and then read out in the y (10) direction. The outer de-interleaver in the decoding side returns the bits as the normal position. The results via AWGN, Rayleigh fading and burst noise is proven clearly in the figures. Second, according to the different QoS Levels of medical data, the simulation tests carried by computer programing that are for three sets of the different extra channel codes. For the higher QoS levels, the lower code rate applied with the much of redundancy added. For the medium QoS levels, the medium code rate applied with the medium redundancy added. For the lower QoS levels, the high code rate applied with a less redundancy added.

Table 6.1 The all Simulations Parameters to MNC Proposed System

	Proposed System Simulation Parameters		
Channels	AWGN/ Rayleigh Fading/ Burst Noise		
Modulation	BFSK via UL and QPSK via DL		
Receive E_b/N_o	-2 ~ 15[dB]		
WBANs Encoder	Standard WBANs Encoder [BCH (63,51,2) Encoder]		
Extra Outer Encoder Different QoS	R=1/2,K=8,G=[247 371], dfree=10 W_d =[2 22 60 148 340 1008 2642 6748]	R=1/3,K=8,G=[225 331 367], dfree=16 W_d =[1 24 113 287]	R=1/4,K=8,G=[235 275 313 357], dfree=22 W_d =[2 10 10 8 10 11 54 64]
Inner Encoder Different Ready Existing Networks UMTS/LTE-UL/DL	UMT-UL R=1/2,K=9,G=[561 753], dfree=12 W_d =[33 281 2179 15035 105166]	UMT-DL R=1/3,K=9,G=[557 663 711], dfree=18 W_d =[11 32 195 564 1473]	LTE-UL R=1/3,K=7,G=[133 171 165], dfree=15 W_d =[7 8 22 44 22 94 219]
Interleaver	Block Interleaver size 126/ 189 / 252 bit/block [encoded bit#/10*10]		
Inner Decoder	UMTS/LTE Standard Encoder use SDVA		
Extra Outer Decoder	Convolution Decoder with a Viterbi Algorithm Soft Decision		
WBANs Decoder	Standard WBANs Decoder [BCH (63,51,2) Decoder] Berlekamp-Massey algorithm		
Data Bits	100Kb/s frame length 51 bits or 10Mb/s		

6.2 The Simulation Performance without End to End of WBANs

The MNC proposed system has simulation BER and Throughput results shown in Figure 6.1 to Figure 6.18 under AWGN, Rayleigh fading and burst noise channel. In the designing phase of the proposed channel we assumed to give BER 10^{-3} for lower QoS and 10^{-5} for medium QoS and 10^{-7} for higher QoS within at least higher E_b/N_o in compare to the cellular systems. In the all figures, the solid curve shows the performance without interleaver and the dotted blue curve show it with using block interleaver.in all figures also, the black curve shows the cellular network performances, the blue curve shows the MNC network performances for lowest QoS levels of medical data, the green curve shows the MNC network performances for medium QoS levels of medical data and the red curve shows the MNC network performances for highest QoS levels of medical data.

The use of internal block interleaver helped to improve the performance of MNC proposed system under burst noise condition by converting the burst errors to random errors. Tables 6.2 to Tables 6.7 summarized the E_b/N_o for BER of all QoS required.

6.2.1 MNC via UMTS-UL for Different QoS and Channel Conditions

Table 6.2 E_b/N_o dB Enhancements Gabs for MNC via UMTS-UL under All Conditions

	AWGN			**RF**			**BN**		
	P_e 10^{-3}	**P_e 10^{-5}**	**P_e 10^{-7}**	**P_e 10^{-3}**	**P_e 10^{-5}**	**P_e 10^{-7}**	**P_e 10^{-3}**	**P_e 10^{-5}**	**P_e 10^{-7}**
UMTS - UL	3 dB	4 dB	5 dB	8.5 dB	10 dB	12 dB	-	-	-
MNC-LQoS	2.5 dB			8 dB			-		
MNC-MQoS		3 dB			9 dB			-	
MNC-LQoS			4 dB			10 dB			-

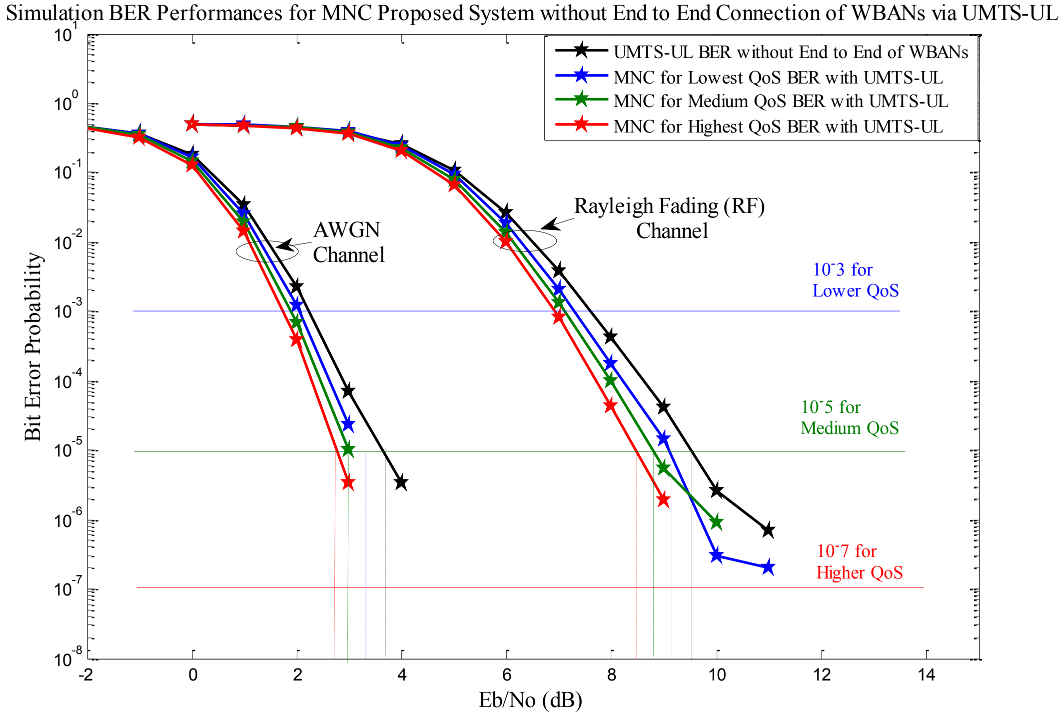

Figure 6.1 MNC Simulation Results via AWGN/RF for Inner UMTS-UL

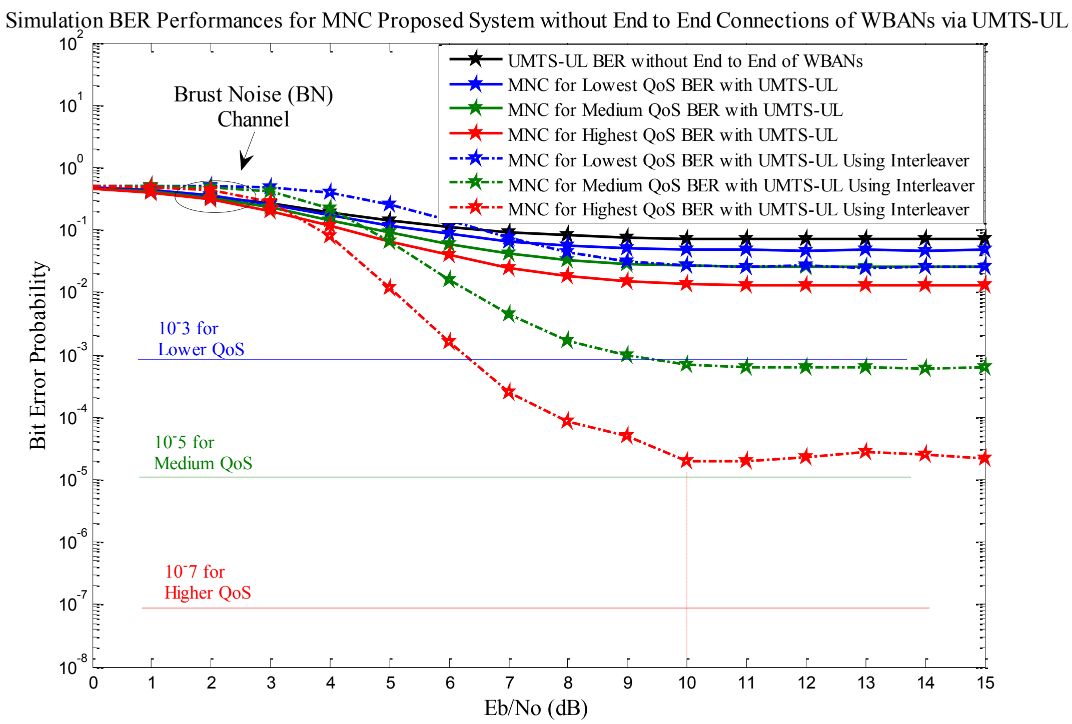

Figure 6.2 MNC Simulation Results via Burst Noise for Inner UMTS-UL

6.2.2 MNC via UMTS-DL for Different QoS and Channel Conditions

Table 6.3 E_b/N_o dB Enhancements Gabs for MNC via UMTS-DL under All Conditions

	AWGN			**RF**			**BN**		
	P_e 10^{-3}	**P_e 10^{-5}**	**P_e 10^{-7}**	**P_e 10^{-3}**	**P_e 10^{-5}**	**P_e 10^{-7}**	**P_e 10^{-3}**	**P_e 10^{-5}**	**P_e 10^{-7}**
UMTS - DL	2	3.5	4.5	7	8.5	10	-	-	-
MNC-LQoS	1.5			6			7		
MNC-MQoS		3			7.5			6.5	
MNC-LQoS			4			9			5.5

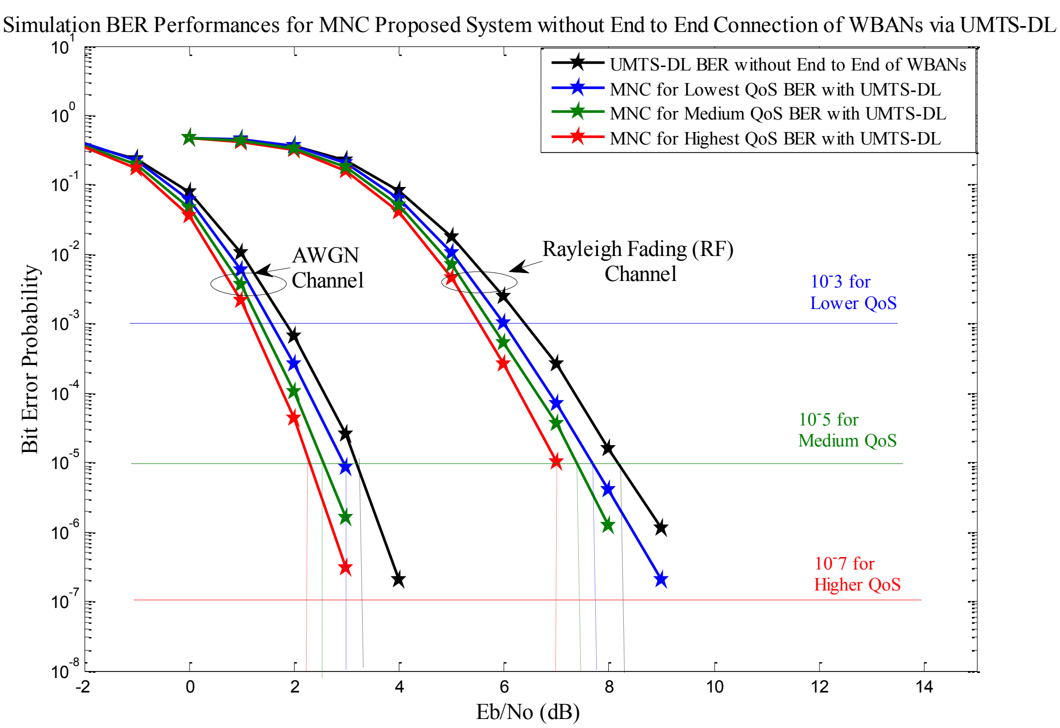

Figure 6.3 MNC Simulation Results via AWGN/RF for Inner UMTS-DL

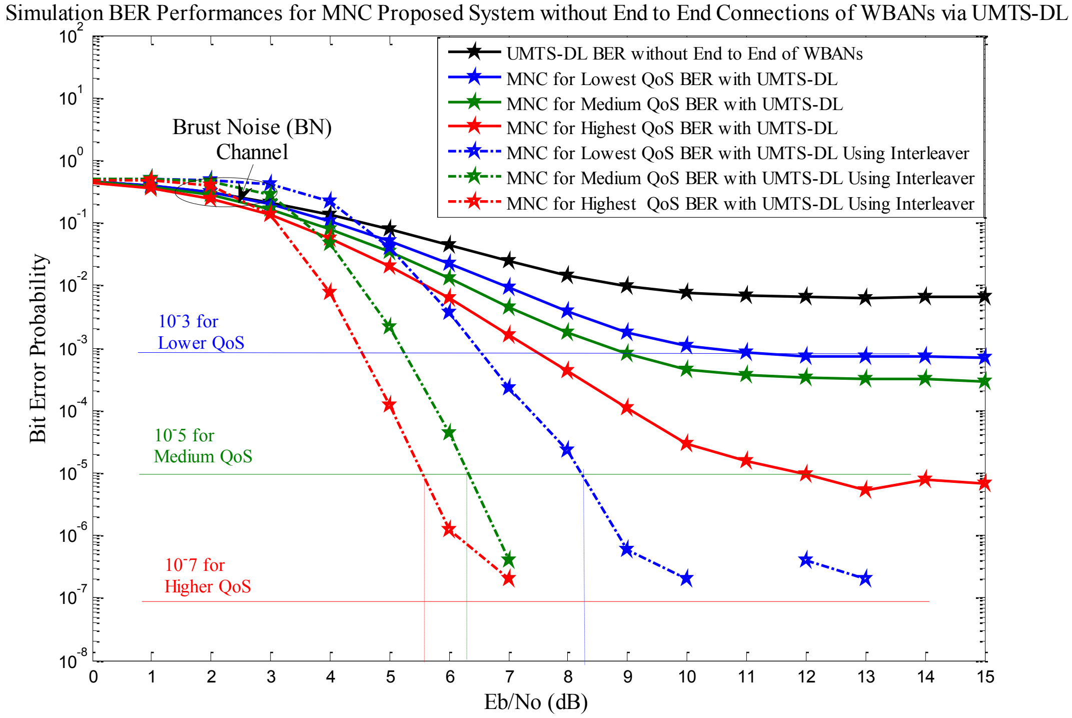

Figure 6.4 MNC Simulation Results via Burst Noise for Inner UMTS-DL

6.2.3 MNC via LTE for Different QoS and Channel Conditions

Table 6.4 E_b/N_o dB Enhancements Gabs for MNC via LTE under All Conditions

	AWGN			**RF**			**BN**		
	P_e 10^{-3}	**P_e 10^{-5}**	**P_e 10^{-7}**	**P_e 10^{-3}**	**P_e 10^{-5}**	**P_e 10^{-7}**	**P_e 10^{-3}**	**P_e 10^{-5}**	**P_e 10^{-7}**
LTE	3 dB	4 dB	5.5 dB	7	9 dB	11 dB	-	-	-
MNC-LQoS	2.5 dB			6.5 dB			7 dB		
MNC-MQoS		3 dB			7.5 dB			6.5 dB	
MNC-LQoS			3.5 dB			8.5 dB			6 dB

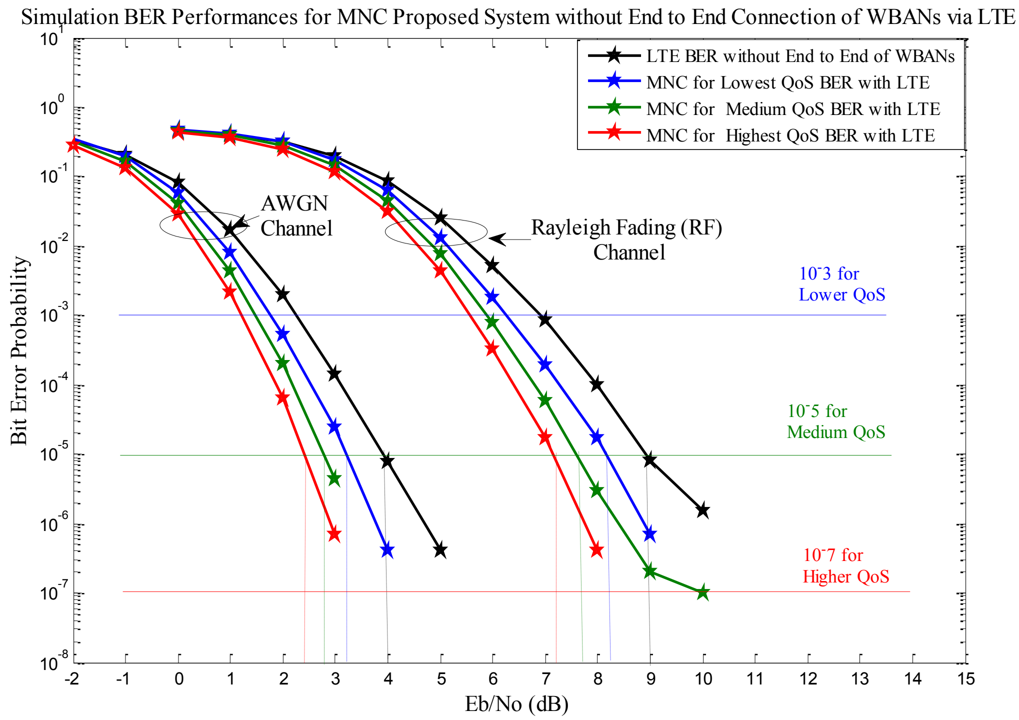

Figure 6.5 MNC Simulation Results via AWGN/RF for Inner LTE

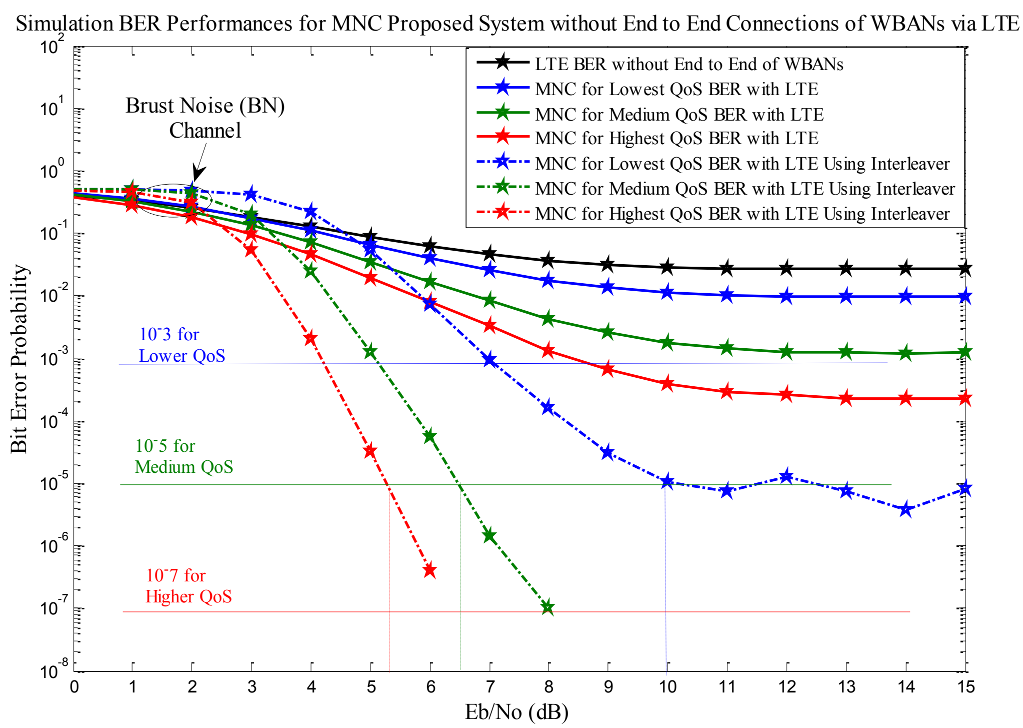

Figure 6.6 MNC Simulation Results via Burst Noise for Inner LTE

6.3 The Simulation Performance with End to End of WBANs

The MNC proposed system has simulation BER and Throughput results shown in Figure 6.1 to Figure 6.18 under AWGN, Rayleigh fading and burst noise channel. In the designing phase of the proposed channel we assumed to give BER 10^{-3} for lower QoS and 10^{-5} for medium QoS and 10^{-7} for higher QoS within at least higher E_b/N_o in compare to the cellular systems. In the all figures, the solid curve shows the performance without interleaver and the dotted blue curve show it with using block interleaver.in all figures also, the black curve shows the cellular network performances, the blue curve shows the MNC network performances for lowest QoS levels of medical data, the green curve shows the MNC network performances for medium QoS levels of medical data and the red curve shows the MNC network performances for highest QoS levels of medical data.

6.3.1 All Simulated Results for MNC via UMTS -UL Networks

Table 6.5 E_b/N_o dB Enhancements Gabs for MNC-WBAN via UMTS in All Conditions

	AWGN			**RF**			**BN**		
	P_e 10^{-3}	**P_e 10^{-5}**	**P_e 10^{-7}**	**P_e 10^{-3}**	**P_e 10^{-5}**	**P_e 10^{-7}**	**P_e 10^{-3}**	**P_e 10^{-5}**	**P_e 10^{-7}**
UMTS - UL	3 dB	4 dB	5 dB	8.5 dB	10 dB	11.5 dB	-	-	-
MNC-LQoS	2.5 dB			8 dB			-		
MNC-MQoS		3.5 dB			9 dB			10 dB	
MNC-LQoS			4.5 dB			10 dB			8 dB

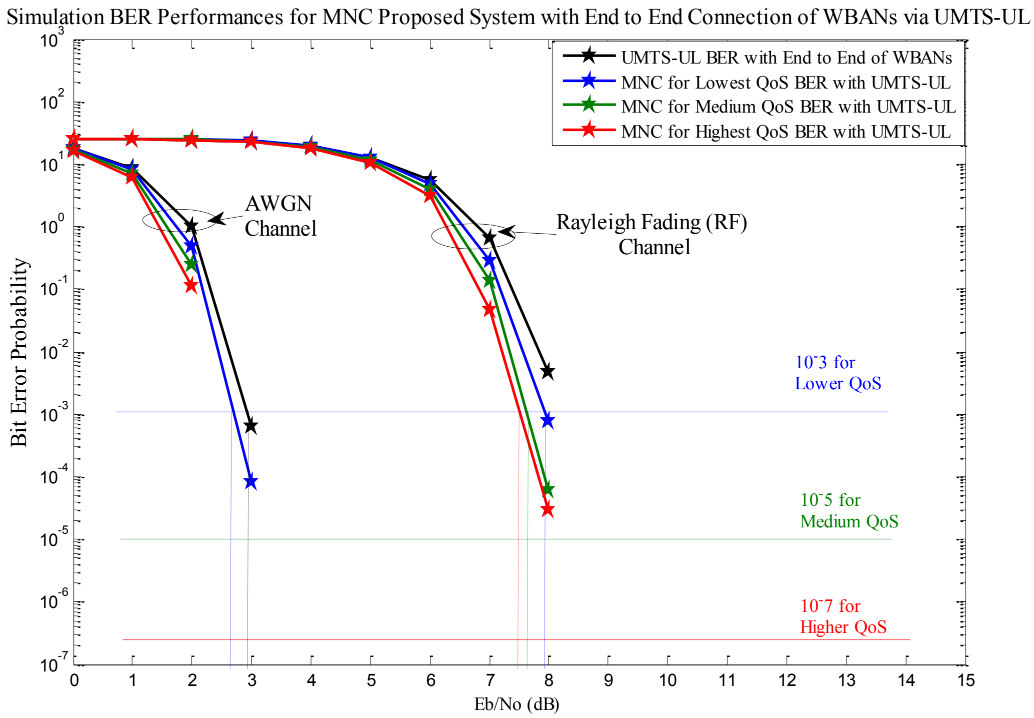

Figure 6.7 MNC Simulations BER via AWGN and RF for Inner UMTS-UL

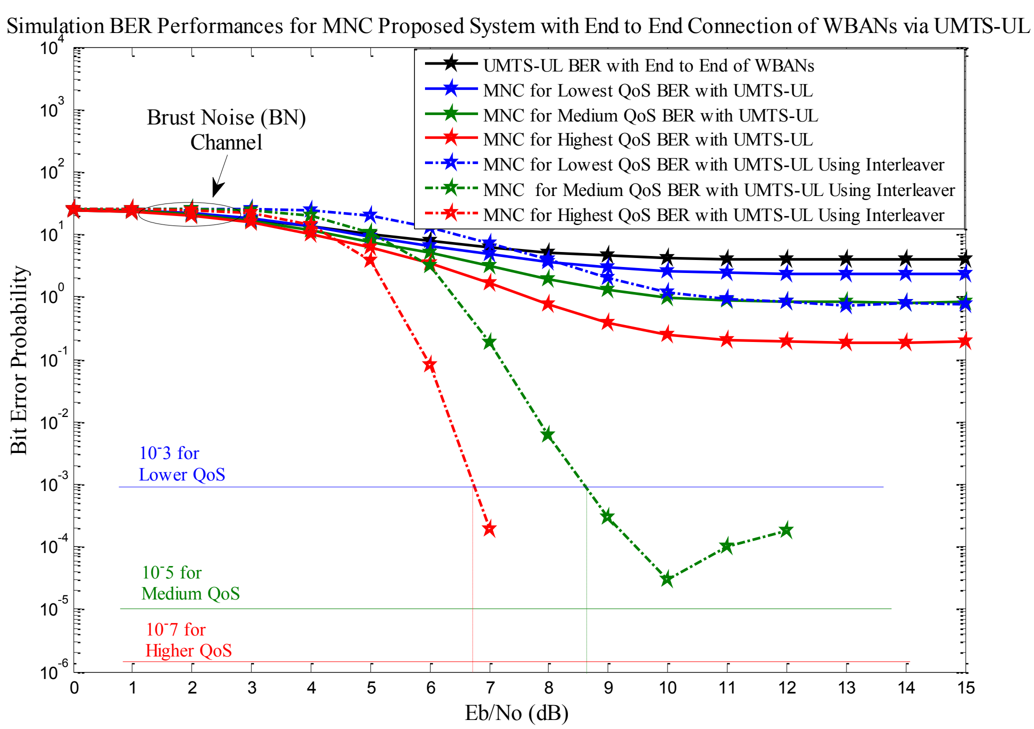

Figure 6.8 MNC Simulations BER via Burst Noise for Inner UMTS-UL

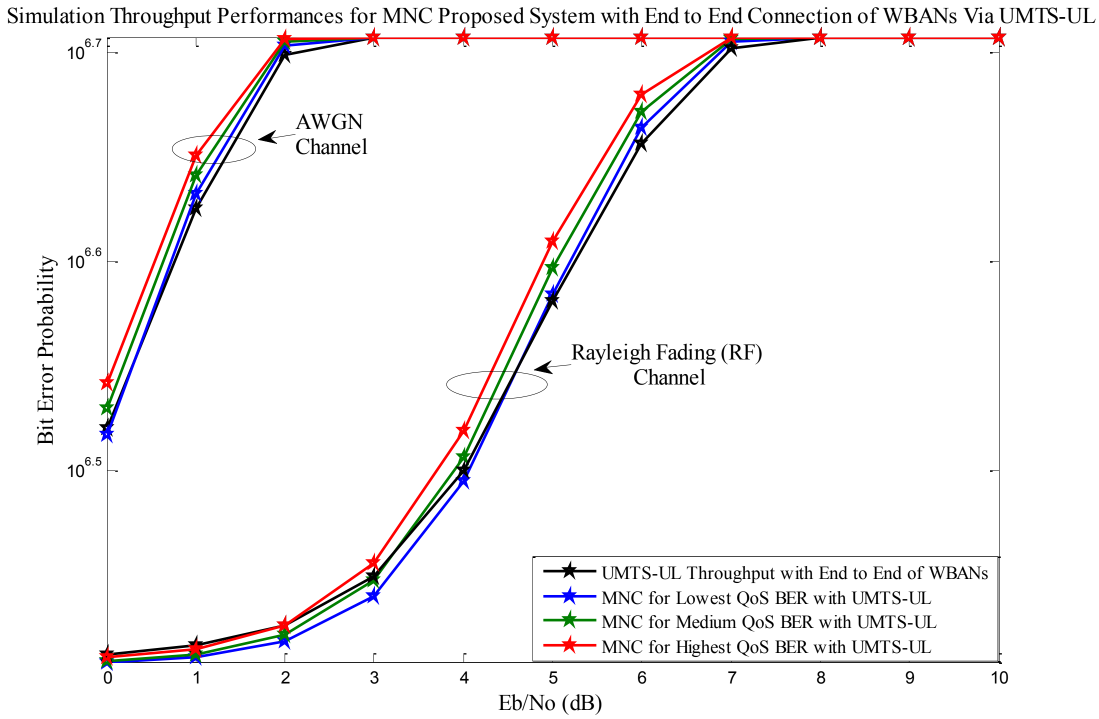

Figure 6.9 MNC Simulation Throughputs via AWGN and RF for Inner UMTS-UL

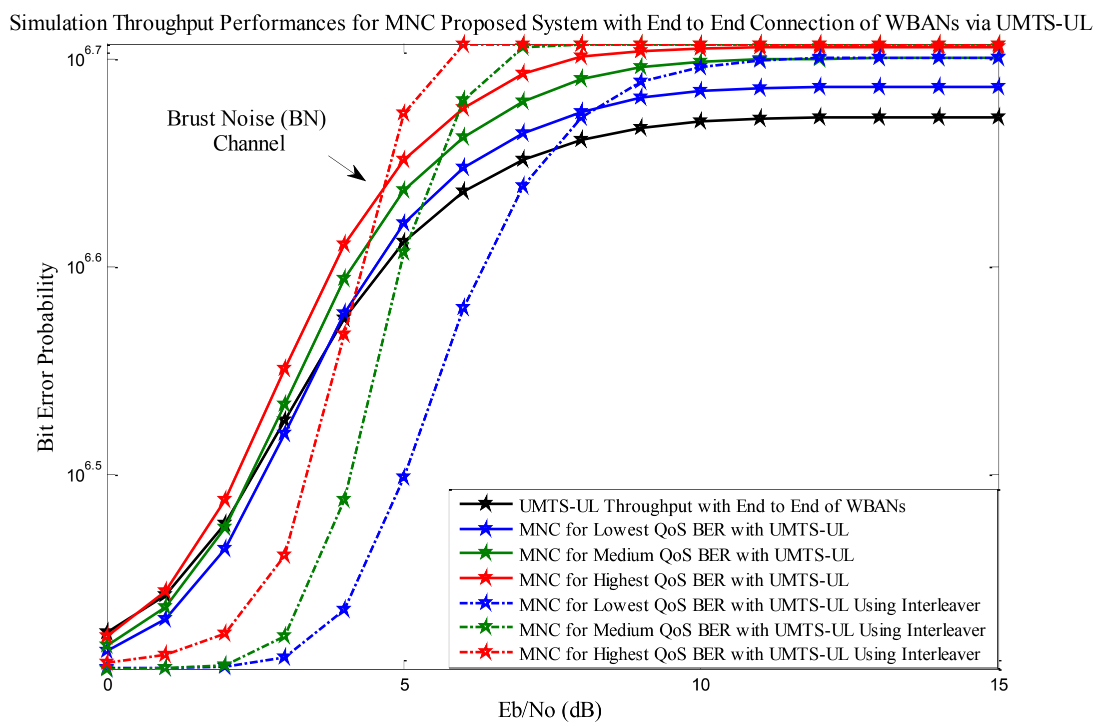

Figure 6.10 MNC Simulation Throughputs via Burst Noise for Inner UMTS-UL

6.3.2 All Simulated Results for MNC via UMTS -DL Networks

Table 6.6 E_b/N_o dB Enhancements Gabs for MNC-WBAN via UMTS in All Conditions

	AWGN			**RF**			**BN**		
	P_e 10^{-3}	**P_e 10^{-5}**	**P_e 10^{-7}**	**P_e 10^{-3}**	**P_e 10^{-5}**	**P_e 10^{-7}**	**P_e 10^{-3}**	**P_e 10^{-5}**	**P_e 10^{-7}**
UMTS - DL	2.5 dB	3.5 dB	4.5 dB	7 dB	8 dB	9 dB	-	-	-
MNC-LQoS	2 dB			6.5 dB			7 dB		
MNC-MQoS		3 dB			7.5 dB			6 dB	
MNC-LQoS			4 dB			8.5 dB			5 dB

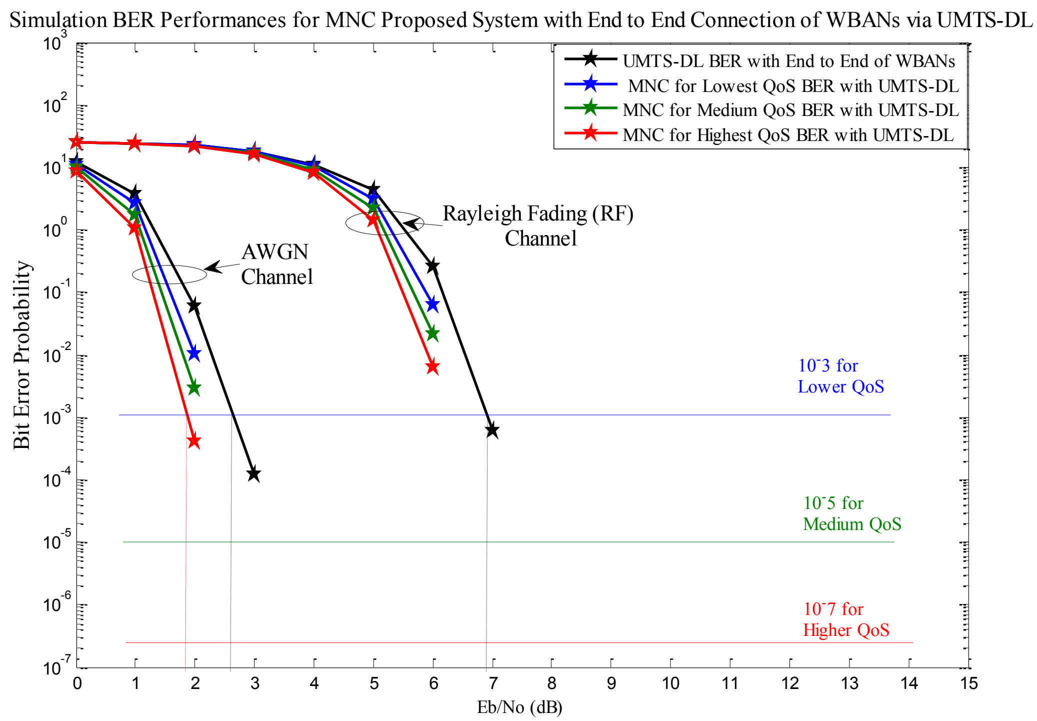

Figure 6.11 MNC Simulations BER via AWGN and RF for Inner UMTS-DL

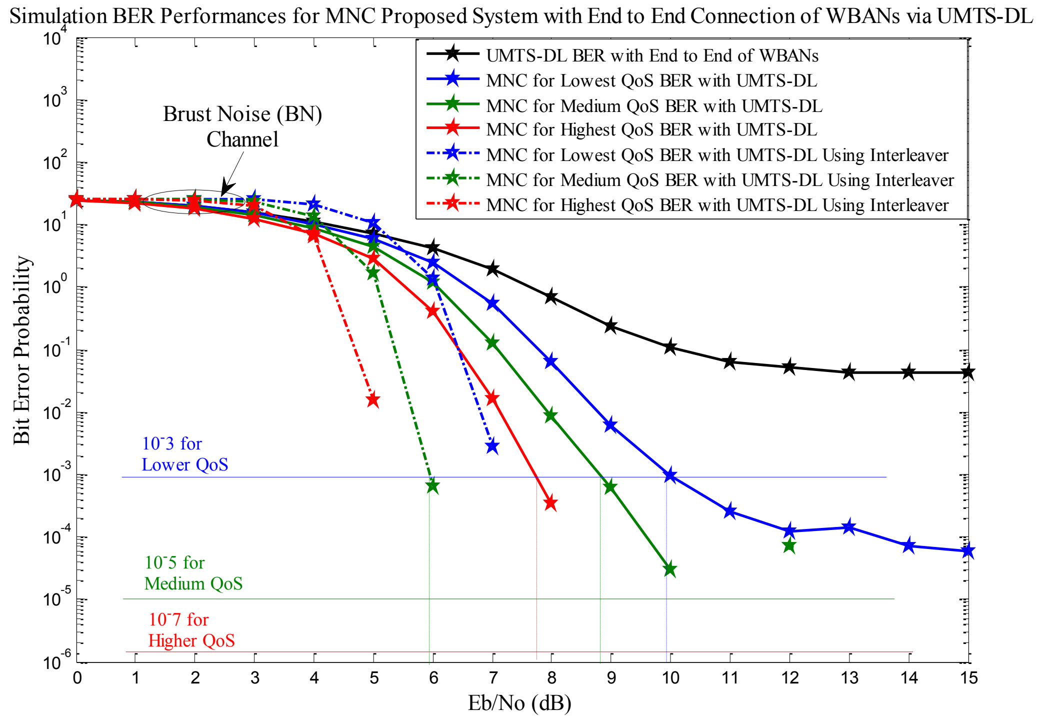

Figure 6.12 MNC Simulations BER via Burst Noise for Inner UMTS-DL

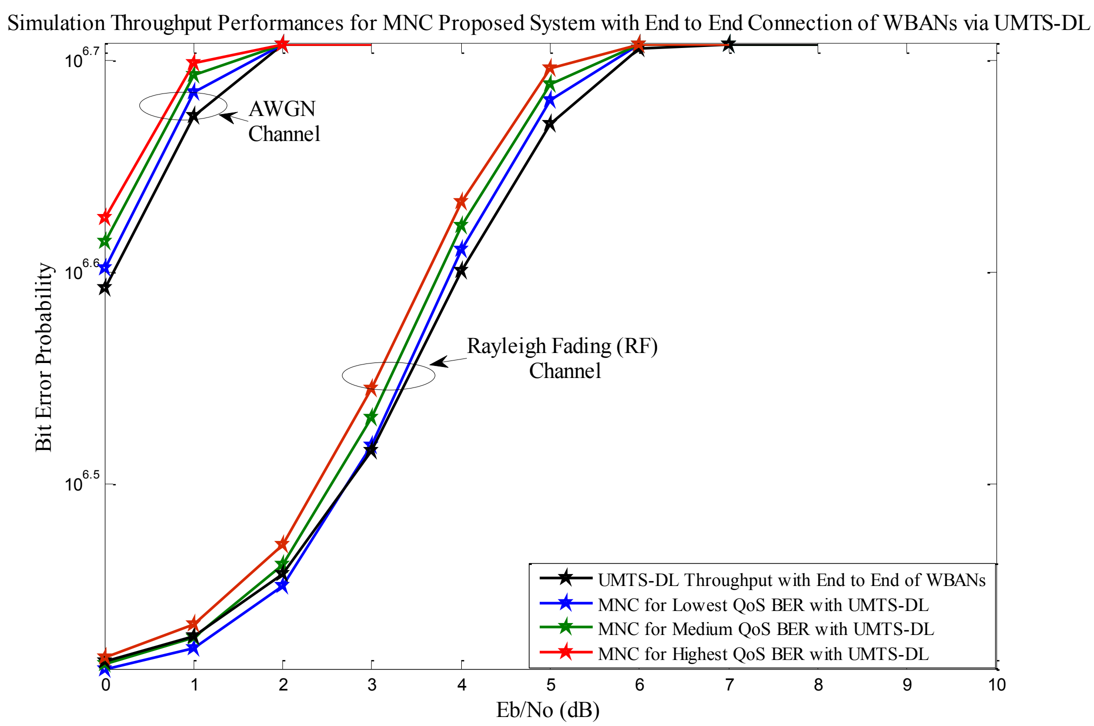

Figure 6.13 MNC Simulation Throughputs via AWGN and RF for Inner UMTS-DL

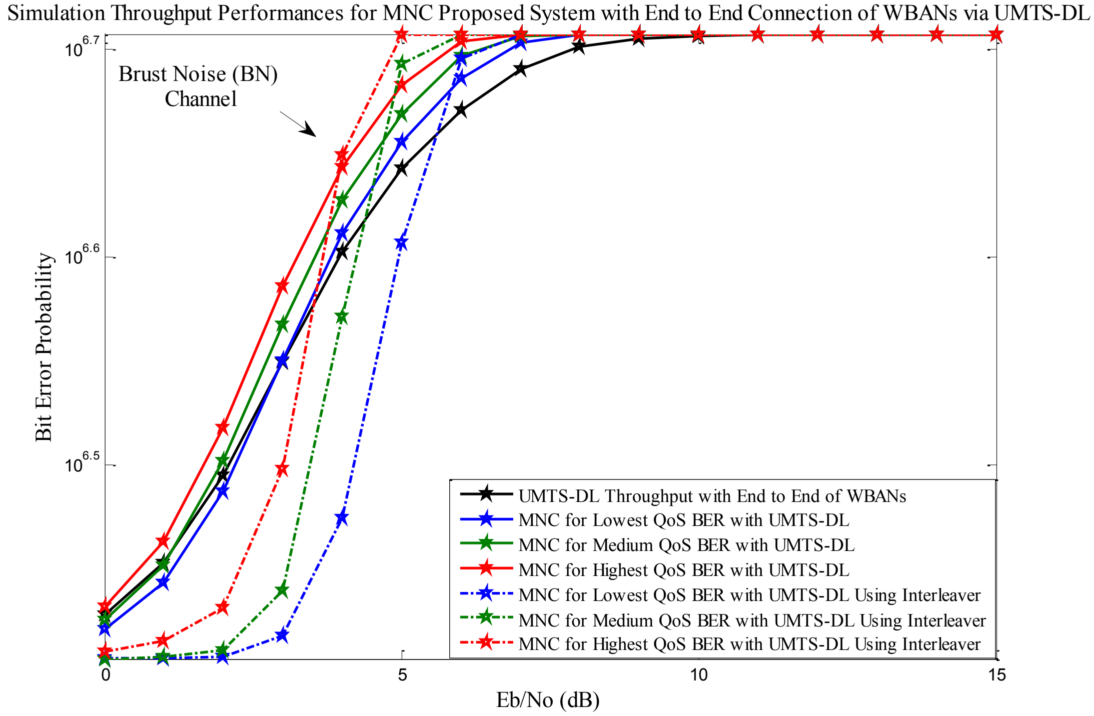

Figure 6.14 MNC Simulation Throughputs via Burst Noise for Inner UMTS-DL

6.3.3 All Simulated Results for MNC via LTE Cellular Network

Table 6.7 E_b/N_o dB Enhancements Gabs for MNC-WBAN via LTE in All Conditions

	AWGN			**RF**			**BN**		
	P_e 10^{-3}	**P_e 10^{-5}**	**P_e 10^{-7}**	**P_e 10^{-3}**	**P_e 10^{-5}**	**P_e 10^{-7}**	**P_e 10^{-3}**	**P_e 10^{-5}**	**P_e 10^{-7}**
LTE	3 dB	4 dB	5 dB	7.5 dB	8.5 dB	9.5 dB	-	-	-
MNC-LQoS	2.5 dB			6.5 dB			7.5 dB		
MNC-MQoS		3.5 dB			7.5 dB			6.5 dB	
MNC-LQoS			4.5 dB			8.5 dB			5.5 dB

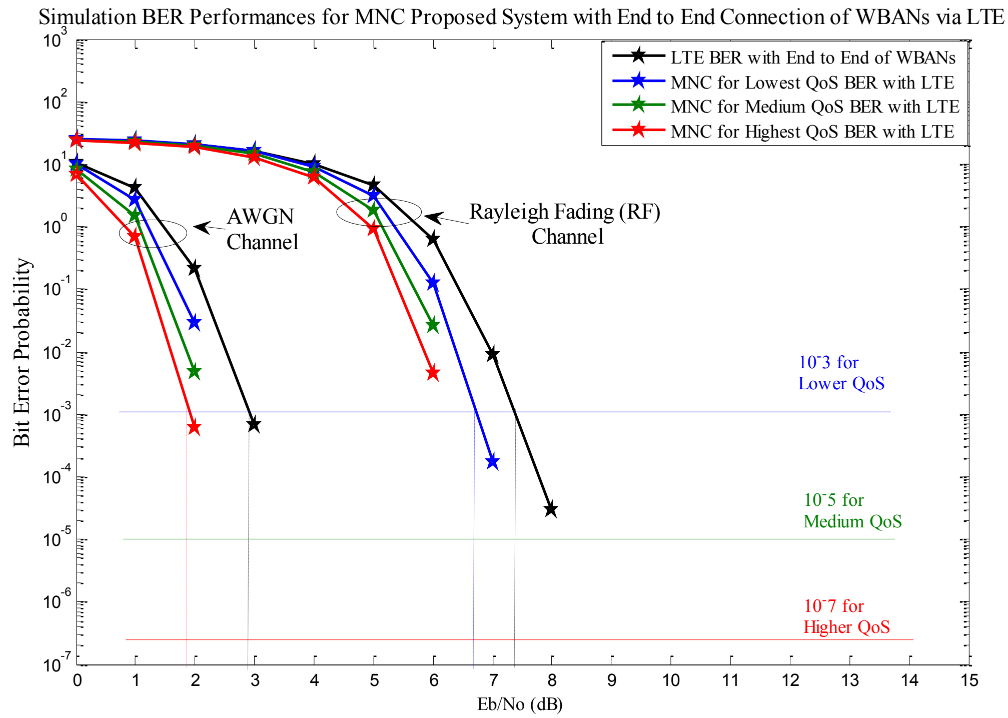

Figure 6.15 MNC Simulations BER via AWGN and RF for Inner LTE

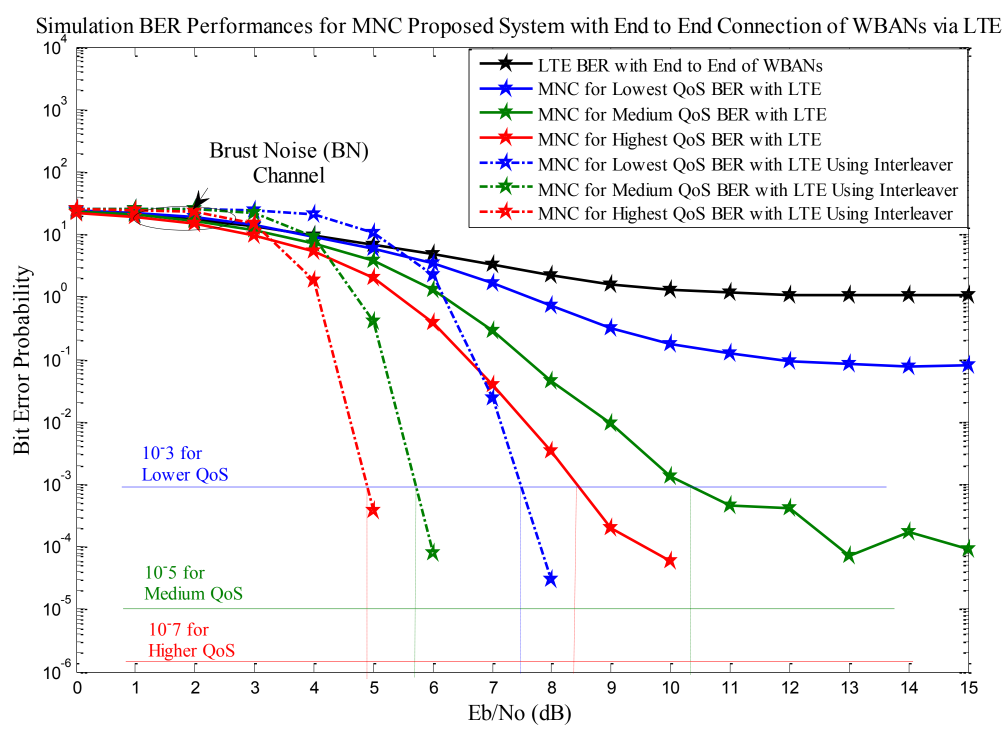

Figure 6.16 MNC Simulations BER via Burst Noise for Inner LTE

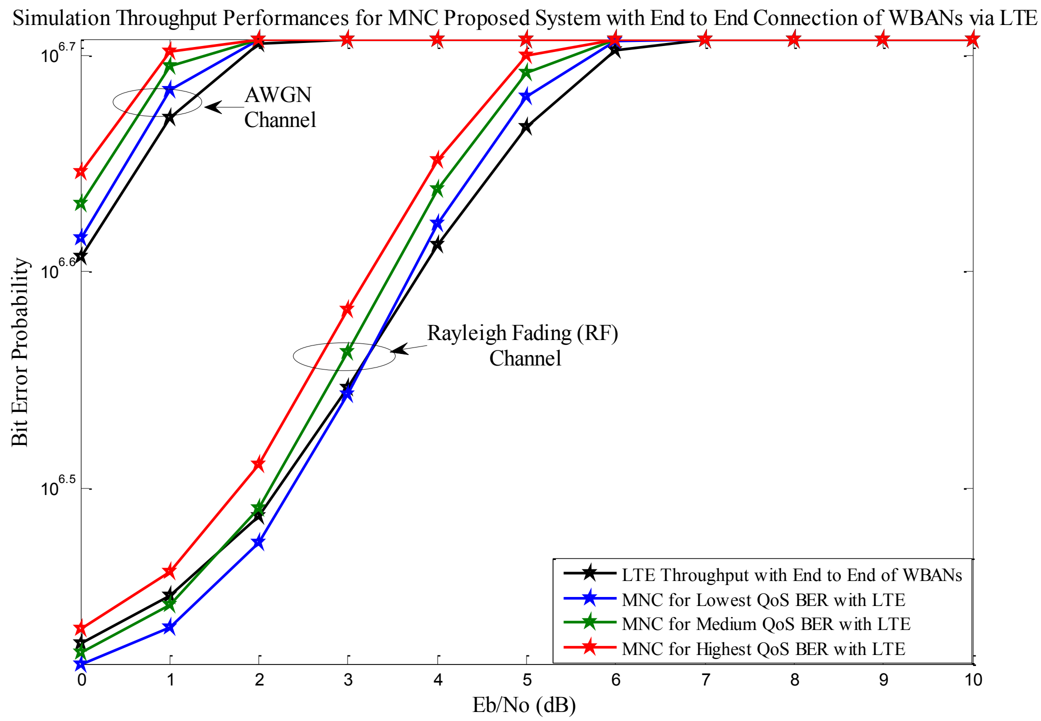

Figure 6.17 MNC Simulation Throughputs via AWGN and RF for Inner LTE

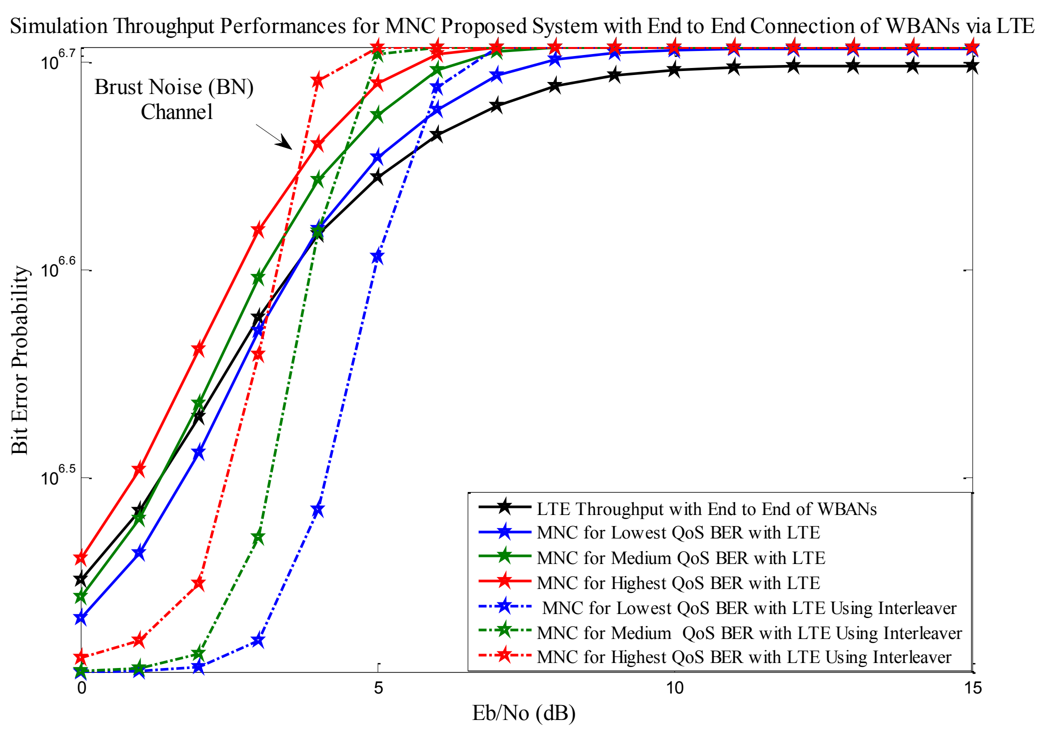

Figure 6.18 MNC Simulation Throughputs via Burst Noise for Inner LTE

6.4 The Simulations Optimization for the Proposed System

6.4.1 The System with Different Assumed Rayleigh Fading Conditions

Rayleigh distribution with parameter 0.55, 0.35 and 0.75 where scalars 1 and encoded data are the row and column dimensions of noisy corrupted data is assumed here for the all QoS extra sets of the codes, when the inner code as an example UMTS-DL has been considered. The worse performances when Raleigh random variable is close to zero and the good performances when the random variable of probability density is close to 1. Figure 6.19 shows the MNC proposed system for Higher QoS via UMTS DL channel.

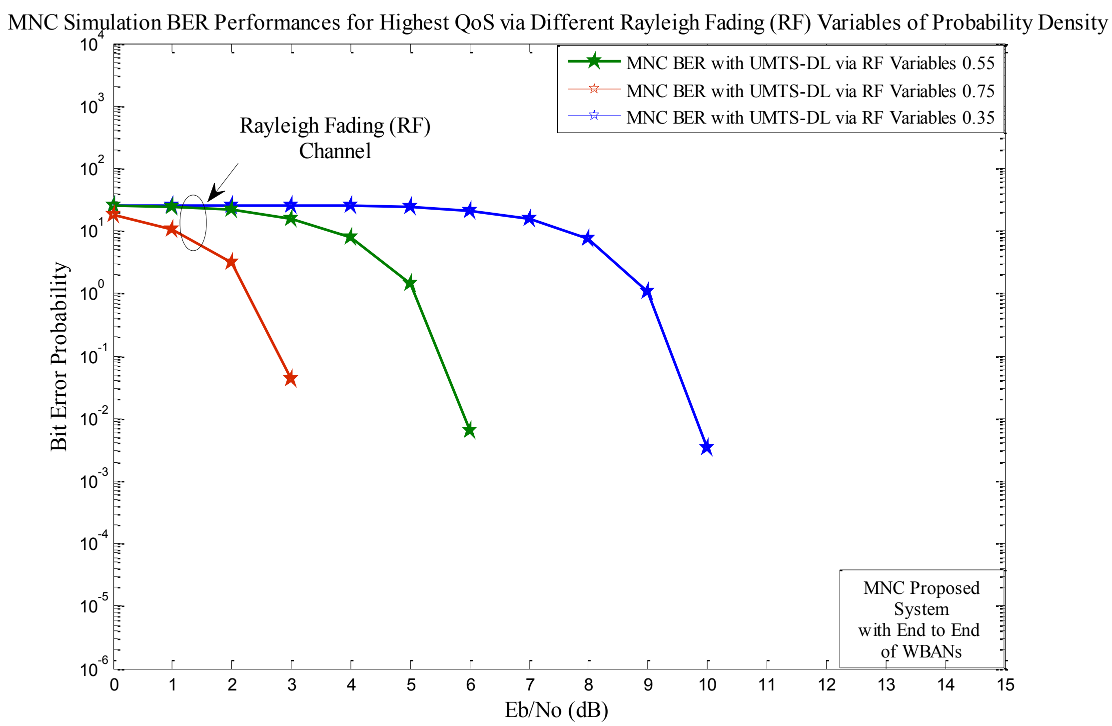

Figure 6.19 MNC Simulation BER via different Rayleigh Fading Channels

6.4.2 The System with Different Assumed Burst Noise Conditions

The burst noise with parameter 5, 7 and 9 burst length with 30 50 ants 70 burst interval for the all QoS extra sets of the codes, when the inner code as an example UMTS-DL has been considered. Figure 6.20 shows different BN lengths and Intervals.

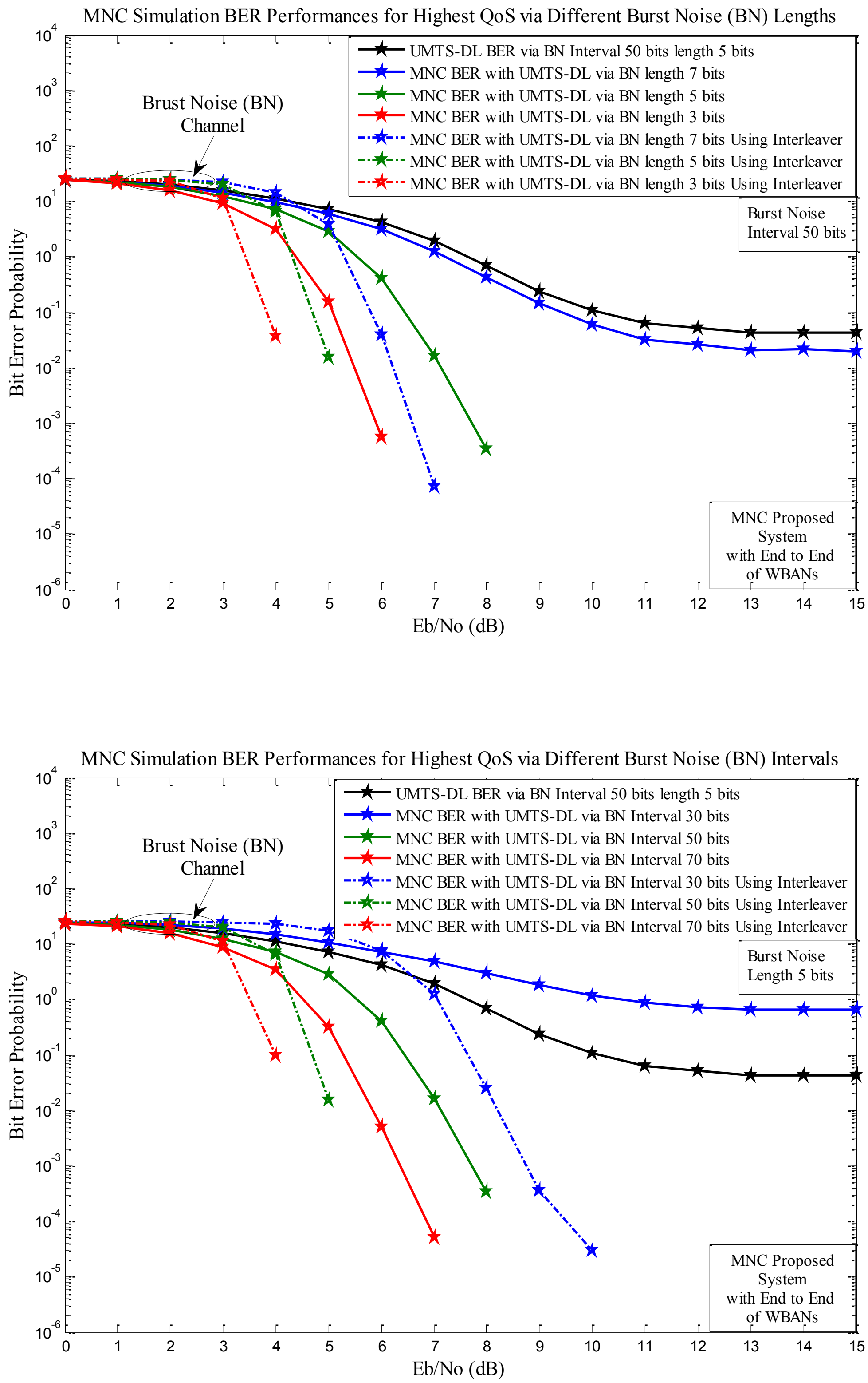

Figure 6.20 MNC Simulations BER via Different Burst Noise Channels

6.5 The Simulation Performance Analysis Advantages and Drawback

The optimization of the MNC proposed system came by optimizing the extra channel only, and from all the results mentioned in the figures and tables in this chapter, we have been confirmed the advantages of applying extra adaptive channel code to the MNC proposed system. Aimed at non-medical data, the extra code can be switch off, and then the inner cellular black curves performance is enough to deliver the non-medical data. Aimed at medical data has low QoS Priority levels, the extra code can be switch on with a code rate 1/2, then the MNC proposed channel with blue curves performance is enough to deliver the lowest QoS levels of medical data. Aimed at medical data has medium QoS Priority levels, the extra code can be switch on with a code rate 1/3, then the MNC proposed channel with green curves performance is enough to deliver the medium QoS levels of medical data. Finally, aimed at medical data has high QoS Priority levels, the extra code can be switch on with a code rate 1/4, then the MNC proposed channel with red curves performance is enough to deliver the highest QoS levels of medical data.

The drawback, for the system, it can be complexity added when the level of the QoS increase such as, MNC for High QoS it's more complex that the MNC for low QoS level. On the other hand, the burst noise environment, if exceed the capabilities of the grad space of the MNC codes, the burst errors it can't be all canceled by the MNC system capabilities. Therefore, the higher layer issue it's much important to complete the remaining issues by optimizing the MAC and Network layers under the MNC system. The optimizations in 6.4 have been considered different channel condition in the case of Rayleigh fading and burst noise channels as well. On the other hand, the extra interleaver in the MNC proposed system has been fixed as block interleaver.

Chapter 7

Conclusions and Future Research

7.1 Conclusions

The main purpose of MNC proposed systems is to have reliable medical network channel via the cellular infrastructure networks by end-to-end WBANs connection. Therefore, the stanchions establishment of medical channel MNC with error controlling coding and decoding through existing infrastructure networks such as UMTS and LTE is introduced in the thesis work with a connection end to end of WBANs and without the connection of WBANs if we consider the medical data coming from different sources. The understanding of the eight levels of the QoS medical data has well done, however, the optimizations here have classified three classes (lower, medium and higher) for all medical data QoS. Therefore, the thesis proposed system is a novel way considering the dependability issues by this way for the first time regarding to the QoS constraint for the different medical applications of WBANs. Although the extra outer code for all of them based on the convolution code, but the choice of the technical parameters is different from one to other depending on the QoS targeted and on the capability of standard itself that is a remain errors in the O/P of the inner cellular code.

Although, the current cellular standards has strong error detection and correction capability, but it's designed well for the daily life communication with no considering medical data transmission, and in some hard noisy channel situations that exceed the design capabilities, the cellular network cannot perform well. Therefore, The thesis comes by strengths is that; WBANs it can be end-to-end connection via the cellular networks providing very large BER for the different assumed QoS levels of medical data to be transmit robustly and achieving the enhancement E_b/N_o gap under all the environments condition that assumed in compare to conventional cellular system alone. Then the proposed MNC system overcomes the weakness of cellular networks regarding to the dependability issues and provides even better performance than the cellular network for the purpose of medical data transmission. These performances allow MNC equivalence for transmitting medical data by the highest possible level of the dependability required. Regarding to the achieving different QoS of WBANs requirements, the results figures in chapter 5 and chapter6 cleared all the study cases carefully.

In the thesis work we have been analyzing the ready existing networks in chapter 2 such as WBANs standards and cellular networks standards regarding to the dependability in each system individually. In order to connect the WBANs with a cellular networks providing far away medical data monitoring the proposed system medical network channel MNC as a supper PHY channel has been introduced in chapter 3. In order to propose system more dependable for such different sets of QoS regarding to the medical data, the adaptive selection of the extra channel code system in MNC has been introduced in chapter 4. The proven of the new PHY channel that is a core techniques in the MNC proposed system it's introduced in chapter 5 through the theoretical derivation that has been calculated the error bound of the MNC when the AWGN and Rayleigh fading affect the channels. The optimization of the proposed system through the simulation results has been cleared in chapter 6 and many testing way has been covered in these chapter. Finally, the target of this thesis work to solve the PHY layers dependability issues has been concluded. Although, the cellular networks is used to design the future MNC proposed system, however, now we assume at least minor modification of the current cellular standards networks UMTS and LTE to get at least soft reliability information, then MNC could be more feasible and reliable to apply for the real products and it can be work for even five generation (5G) of cellular network. Although the thesis target has been cleared carefully in the thesis work, nonetheless for all of that, the restriction of ready existing cellular network standard make the proposal MNC via the standards has a limitation since its cannot change the inner code parameter regarding to the international regulation. But the MNC overcome this point and carry strong enough design for all QoS medical data. One the other hand, the delaying and complexity outcome in highest QoS level made the MNC system somehow carry weakness from this point of view. Therefore the constrain length are fixed in designing phase of optimizing the extra channel code of MNC system.

7.2 Future Research Work

There are still many aspects for the MNC to be future studies and investigated. Thus, the tradeoff between the performance improvement and complexity are required to be decided with the consideration of cost and performance efficiency. The future works following this thesis is to derive the results through the optimization under the MAC layer and solving the issues with a cross PHY-MAC layer for the two way UL assumed for diagnoses medical data and DL assumed for feedback as treatment procedures regarding to the data have been sent with assumption for multiuser environment condition. Also, Investigate the multi user optimization in MNC, in addition focus on higher communication layers technology issues such as multi users congestions on the network layer traffic management issues for end to end services and finally propose different design codes for the extra outer code of MNC, and then we can choose one that most likely to the desired SNR and BER. And focus on the interleaving between the two encoders deeply, to design an efficient interleaver that can produce optimum coding gain for the MNC with signification reduction in memory requirement for the interleaver at large data block sizes under hard noisy channel environment such as burst noise channel situations.

Published Papers

[1] Emtithal Ahmed and Ryuji Kohno, “Error Control Coding and Decoding with QoS Constraints for Medical End-to-End Connection via UMTS Channels” in EURASIP Journal on Wireless Communications and Networking. Special Issue on revolutionizing mHealth through next generation communication technologies. Submitted 31, December. 2015

[2] Emtithal Ahmed and Ryuji Kohno, “The Performances Bounds of Supper PHY Channel using Concatenated Codes to Transmit WBANs Medical Data via LTE” in International Journal of Emerging Trends in Electrical and Electronics (IJETEE) ISSN: 2320-9569, Vol.11, Issue.4, August-2015.

[3] Emtithal Ahmed and Ryuji Kohno, “Dependable Medical Network Based on 2G and 3G Cellular Mobile Standards with External Channel Code in Concatenated Code Structure” in International Journal of Commuter and Communications Engineering (IJCCE), Vol.3, No.4, July. 2014.

[4] Emtithal Ahmed, Ryuji Kohno, “Uplink/Downlink Channels for the Dependable Medical Channel Coding Through the Cellular Standards 3G with End to End Connection of BAN”. The 9th International Symposium on Medical Information and Communication Technology (ISMICT), Kamakura, Japan March 24-26. 2015.

[5] Emtithal Ahmed, Ryuji Kohno, “Dependable Medical Network Based on 4G Cellular Mobile Standard with External Channel Code in Concatenated Code Structure”. International Symposium on Information Theory and its Applications (ISITA), Melbourne, Australia October 26-29. 2014.

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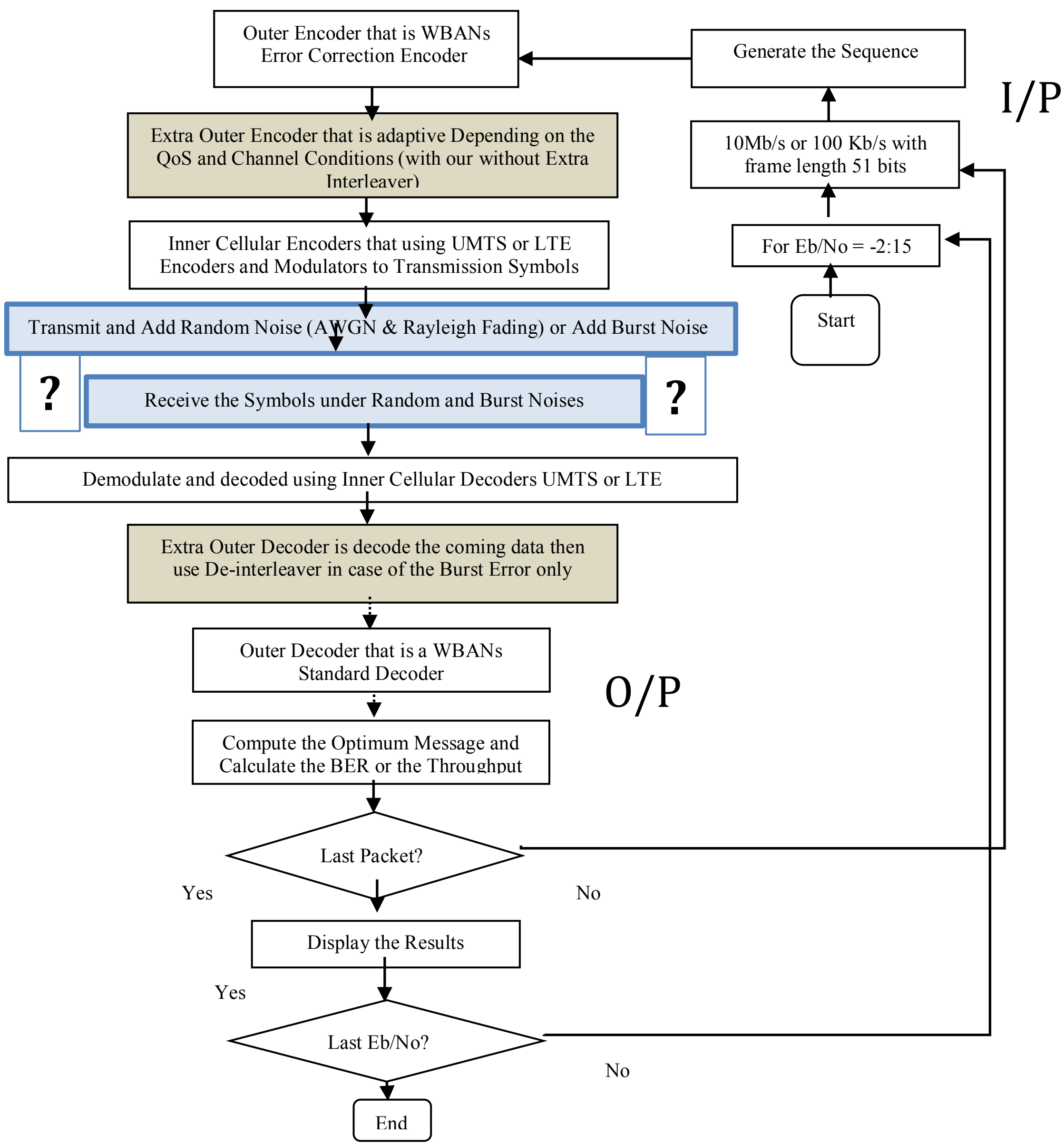
Appendix A

Simulation Main Algorithm



Appendix B

MNC Performances Results without End-to-End Connection of WBANs for I/P data Bits as 10Mb/s

Table 1 Simulations Error Probabilities via AWGN, Rayleigh Fading and Burst Noise for inner UMTS-UL Channel

Channel	E_b/N_o		-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10
AWGN	3G-UL	BER	0.4956	0.4909	0.4801	0.4482	0.3568	0.1778	0.0340	0.0023	0.0001	0.0000	0	0	0	0	0	0
	L-QoS	BER	0.4987	0.4965	0.4883	0.4602	0.3629	0.1658	0.0253	0.0012	0.0000	0	0	0	0	0	0	0
	M-QoS	BER	0.4981	0.4949	0.4854	0.4515	0.3442	0.1453	0.0195	0.0007	0.0000	0	0	0	0	0	0	0
	H-QoS	BER	0.4968	0.4927	0.4802	0.4407	0.3250	0.1254	0.0140	0.0004	0.0000	0	0	0	0	0	0	0
	E_b/N_o		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RF	3G-UL	BER	0.4898	0.4778	0.4508	0.3833	0.2551	0.1081	0.0257	0.0038	0.0004	0.0000	0.0000	0.0000	0	0	0	0
	L-QoS	BER	0.4948	0.4870	0.4613	0.3905	0.2494	0.0930	0.0181	0.0021	0.0002	0.0000	0.0000	0.0000	0	0	0	0
	L-QoS-II	BER	0.5000	0.5000	0.4998	0.4933	0.4136	0.1154	0.0042	0.0001	0.0000	0	0	0	0	0	0	0
	M-QoS	BER	0.4937	0.4826	0.4528	0.3750	0.2272	0.0791	0.0137	0.0013	0.0001	0.0000	0.0000	0	0	0	0	0
	M-QoS-II	BER	0.4999	0.5000	0.4987	0.4858	0.3381	0.0381	0.0003	0.0000	0	0	0	0	0	0	0	0
	H-QoS	BER	0.4905	0.4776	0.4425	0.3572	0.2065	0.0653	0.0098	0.0008	0.0000	0.0000	0	0	0	0	0	0
	H-QoS-II	BER	0.4988	0.4968	0.4897	0.4546	0.2381	0.0113	0.0000	0	0	0	0	0	0	0	0	0
	E_b/N_o		-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10
BN	3G-UL	BER	0.4985	0.4973	0.4950	0.4897	0.4795	0.4579	0.4144	0.3438	0.2613	0.1923	0.1427	0.1119	0.0923	0.0818	0.0755	0.0726
	L-QoS	BER	0.4997	0.4994	0.4985	0.4964	0.4901	0.4728	0.4305	0.3531	0.2567	0.1736	0.1188	0.0852	0.0661	0.0559	0.0506	0.0482
	L-QoS-II	BER	0.5001	0.5001	0.5000	0.4998	0.4999	0.4997	0.4992	0.4944	0.4692	0.3877	0.2565	0.1415	0.0751	0.0447	0.0315	0.0272
	M-QoS	BER	0.4995	0.4994	0.4977	0.4951	0.4870	0.4654	0.4161	0.3292	0.2263	0.1430	0.0899	0.0596	0.0427	0.0331	0.0287	0.0264
	M-QoS-II	BER	0.4997	0.5000	0.5001	0.4997	0.5000	0.4998	0.4977	0.4838	0.4052	0.2156	0.0637	0.0156	0.0044	0.0017	0.0010	0.0007
	H-QoS	BER	0.4992	0.4982	0.4965	0.4925	0.4818	0.4560	0.3993	0.3041	0.1972	0.1150	0.0655	0.0393	0.0250	0.0182	0.0151	0.0135
	H-QoS-II	BER	0.4999	0.4996	0.4994	0.4989	0.4973	0.4931	0.4806	0.4384	0.2843	0.0800	0.0117	0.0016	0.0003	0.0001	0.0000	0.0000

Table 2 Simulations Error Probabilities via AWGN, Rayleigh Fading and Burst Noise for inner UMTS-DL Channel

	E_b/N_o		-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10
AWGN	3G-DL	BER	0.4931	0.4835	0.4570	0.3858	0.2390	0.0776	0.0105	0.0006	0.0000	0.0000	0	0	0	0	0	0
	L-QoS	BER	0.4955	0.4886	0.4641	0.3886	0.2244	0.0591	0.0058	0.0003	0.0000	0	0	0	0	0	0	0
	M-QoS	BER	0.4945	0.4850	0.4559	0.3707	0.2001	0.0466	0.0036	0.0001	0.0000	0	0	0	0	0	0	0
	H-QoS	BER	0.4917	0.4795	0.4447	0.3507	0.1758	0.0357	0.0021	0.0000	0.0000	0	0	0	0	0	0	0
	E_b/N_o		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
RF	3G-DL	BER	0.4756	0.4409	0.3612	0.2215	0.0833	0.175	0.0024	0.0003	0.0000	0.0000	0	0	0	0	0	0
	L-QoS	BER	0.4806	0.4469	0.3591	0.2029	0.0641	0.0104	0.0010	0.0001	0.0000	0.0000	0	0	0	0	0	0
	L-QoS-II	BER	0.5000	0.4998	0.4920	0.3862	0.0668	0.0010	0.0000	0	0	0	0	0	0	0	0	0
	M-QoS	BER	0.4762	0.4358	0.3388	0.1809	0.0511	0.0070	0.0005	0.0000	0.0000	0	0	0	0	0	0	0
	M-QoS-II	BER	0.4999	0.4987	0.4816	0.2770	0.0125	0.0000	0	0	0	0	0	0	0	0	0	0
	H-QoS	BER	0.4691	0.4229	0.3177	0.1581	0.0398	0.0045	0.0003	0.0000	0	0	0	0	0	0	0	0
	H-QoS-II	BER	0.4955	0.4868	0.4403	0.1628	0.0024	0.0000	0	0	0	0	0	0	0	0	0	0
	E_b/N_o		**-5**	**-4**	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
BN	3G-DL	BER	0.4989	0.4974	0.4949	0.4889	0.4747	0.4460	0.3900	0.3054	0.2130	0.1327	0.0777	0.0440	0.0246	0.0145	0.0099	0.0077
	L-QoS	BER	0.4994	0.4988	0.4973	0.4931	0.4827	0.4559	0.3980	0.3032	0.1952	0.1066	0.0516	0.0223	0.0090	0.0038	0.0018	0.0011
	L-QoS-II	BER	0.4998	0.4999	0.5003	0.4997	0.4999	0.4999	0.4985	0.4886	0.432	0.2169	0.0402	0.0037	0.0002	0.0000	0.0000	0.0000
	M-QoS	BER	0.4992	0.4983	0.4962	0.4914	0.4786	0.4459	0.3788	0.2745	0.1635	0.0804	0.0338	0.0128	0.0045	0.0018	0.0008	0.0005
	M-QoS-II	BER	0.552	0.5002	0.5001	0.5002	0.4996	0.4994	0.4958	0.4651	0.2847	0.0468	0.0021	0.0000	0.0000	0	0	0
	H-QoS	BER	0.4984	0.4969	0.4941	0.4871	0.4704	0.4318	0.3554	0.2442	0.1330	0.0573	0.0204	0.0062	0.0016	0.0004	0.0001	0.0000
	H-QoS-II	BER	0.4998	0.4997	0.4996	0.4982	0.4959	0.4899	0.4717	0.3923	0.1250	0.0077	0.0001	0.0000	0.0000	0	0	0

Table 3 Simulations Error Probabilities via AWGN, Rayleigh Fading and Burst Noise for inner LTE Channel

	E_b/N_o		**-5**	**-4**	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
AWGN	4G	BER	0.4817	0.4620	0.4211	0.3391	0.2094	0.0810	0.0171	0.0019	0.0001	0.0000	0.0000	0	0	0	0	0
	L-QoS	BER	0.4911	0.4774	0.4392	0.3479	0.1952	0.0583	0.0080	0.0005	0.0000	0.0000	0	0	0	0	0	0
	M-QoS	BER	0.4869	0.4689	0.4217	0.3186	0.1630	0.0410	0.0043	0.0002	0.0000	0	0	0	0	0	0	0
	H-QoS	BER	0.4758	0.4519	0.3965	0.2847	0.1328	0.0281	0.0022	0.0001	0.0000	0	0	0	0	0	0	0
	E_b/N_o		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
RF	4G	BER	0.4489	0.3993	0.3137	0.1947	0.0854	0.0250	0.0050	0.0008	0.0001	0.0000	0.0000	0	0	0	0	0
	L-QoS	BER	0.4642	0.4147	0.3156	0.1759	0.0622	0.0129	0.0018	0.0002	0.0000	0.0000	0	0	0	0	0	0
	L-QoS-II	BER	0.5000	0.4992	0.4900	0.3791	0.0643	0.0010	0.0000	0	0	0	0	0	0	0	0	0
	M-QoS	BER	0.4527	0.3937	0.2850	0.1454	0.0444	0.0075	0.0008	0.0001	0.0000	0.0000	0.0000	0	0	0	0	0
	M-QoS-II	BER	0.4996	0.4975	0.4695	0.2202	0.0070	0.0000	0	0	0	0	0	0	0	0	0	0
	H-QoS	BER	0.4327	0.3652	0.2498	0.1177	0.0310	0.0043	0.0003	0.0000	0.0000	0	0	0	0	0	0	0
	H-QoS-II	BER	0.4923	0.4782	0.4048	0.0923	0.0008	0.0000	0	0	0	0	0	0	0	0	0	0
	E_b/N_o		**-5**	**-4**	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
BN	4G	BER	0.4962	0.4926	0.4856	0.4721	0.4478	0.4033	0.3377	0.2588	0.1842	0.1276	0.0872	0.0621	0.0460	0.0365	0.0314	0.0290
	L-QoS	BER	0.4987	0.4974	0.4945	0.4867	0.4695	0.4303	0.3617	0.2694	0.1759	0.1082	0.0648	0.0396	0.0252	0.0175	0.0133	0.0110
	L-QoS-II	BER	0.5001	0.4997	0.5001	0.5000	0.5001	0.4997	0.4978	0.4844	0.4119	0.2154	0.0525	0.0073	0.0009	0.0002	0.0000	0.0000
	M-QoS	BER	0.4978	0.4953	0.4910	0.4804	0.4567	0.4079	0.3263	0.2240	0.1317	0.0698	0.0350	0.0169	0.0084	0.0043	0.0026	0.0018
	M-QoS-II	BER	0.5000	0.4999	0.5000	0.5001	0.4999	0.4989	0.4908	0.4306	0.1961	0.0240	0.0013	0.0001	0.0000	0.0000	0	0
	H-QoS	BER	0.4917	0.4879	0.4798	0.4642	0.4334	0.3743	0.2842	0.1809	0.0962	0.0452	0.0193	0.0079	0.0033	0.0013	0.0007	0.0004
	H-QoS-II	BER	0.4994	0.4997	0.4985	0.4967	0.4928	0.4831	0.4517	0.3044	0.0530	0.0020	0.0000	0.0000	0	0	0	0

Appendix C

MNC Performances Results with End-to-End Connection of WBANs for I/P data Bits as 100Kb/s

Table 4 Simulations Error Probabilities via AWGN, Rayleigh Fading and Burst Noise for inner UMTS-UL Channel

	E_b/N_o		0	1	2	3	4	5	6	7	8	9	10
AWGN	3G-UL	BER	17.8993	8.7023	0.9887	0.0006	0	0	0	0	0	0	0
		T	3310843	4222706	5002364	5099952	5100000	5100000	5100000	5100000	5100000	5100000	5100000
	L-QoS	BER	18.0753	8.1875	0.4808	0.0001	0	0	0	0	0	0	0
		T	3289550	4287873	5050889	5100000	5100000	5100000	5100000	5100000	5100000	5100000	5100000
	M-QoS	BER	17.1538	7.1873	0.2471	0	0	0	0	0	0	0	0
		T	3383608	4379632	5075114	5100000	5100000	5100000	5100000	5100000	5100000	5100000	5100000
	H-QoS	BER	16.0926	6.2196	0.1140	0	0	0	0	0	0	0	0
		T	3481529	4473138	5088933	5100000	5100000	5100000	5100000	5100000	5100000	5100000	5100000
	E_b/N_o		0	1	2	3	4	5	6	7	8	9	10
RF	3G-UL	BER	25.2217	24.9592	24.3780	22.8349	19.3099	12.9159	5.6279	0.6452	0.0047	0	0
		T	2579186	2606668	2664307	2812409	3159681	3813249	4535844	5036306	5099646	5100000	5100000
	L-QoS	BER	25.4334	25.2531	24.7918	23.4650	19.7854	12.5326	4.8741	0.2877	0.0008	0	0
		T	2559964	2573196	2619819	2753025	3124773	3841235	4611781	5071561	5099915	5100000	5100000
	L-QoS-II	BER	25.5049	255053	25.5192	25.4779	25.1289	20.6809	5.7333	0.0043	0	0	0
		T	2549306	2551056	2549335	2553028	2584490	3040058	4541004	5099699	5100000	5100000	5100000
	M-QoS	BER	25.3824	25.1445	24.5896	23.0107	18.9225	11.3996	4.0028	0.1334	0.0001	0	0
		T	2563182	2581656	2638937	2799042	3209136	3954725	4699498	5086600	5099955	5100000	5100000
	M-QoS-II	BER	25.5073	25.5023	25.4867	25.4245	24.6757	16.4534	1.0496	0	0	0	0
		T	2548231	2548830	2551307	2556726	2632865	3459052	4996322	5100000	5100000	5100000	5100000
	H-QoS	BER	25.2827	25.0200	24.3174	22.4657	17.9773	10.3656	3.1391	0.0476	0.0000	0	0
		T	2572489	2597222	2666149	2853128	3303128	4067022	4788175	5094670	5099991	5100000	5100000
	H-QoS-II	BER	25.4613	25.4324	25.3170	24.9503	22.9877	11.2240	0.0483	0	0	0	0
		T	2552889	2557579	2569918	2605933	2799360	3976657	5094891	5100000	5100000	5100000	5100000
	E_b/N_o		0	1	2	3	4	5	6	7	8	9	10
BN	3G-UL	BER	24.4490	23.3098	21.0294	17.4410	13.3806	9.9885	7.6914	6.1926	5.1835	4.5231	4.2090
		T	2654074	2765514	2995616	3355697	3761338	4096769	4332025	4482209	4584709	4644276	4677609
	L-QoS	BER	24.9835	24.1053	21.8640	17.9997	13.2009	9.2297	6.5104	4.7630	3.6432	2.9631	2.5680
		T	2600385	2691883	2909792	3307033	3783421	4179359	4447278	4621247	4729826	4804388	4841107
	L-QoS-II	BER	25.5040	25.4880	25.4664	25.1876	23.7640	19.5363	13.0029	7.2993	4.0026	2.0052	1.1818
		T	2549591	2550088	2553830	2582503	2722569	3150783	3803356	4357015	4700580	4891712	4973892
	M-QoS	BER	24.8308	23.7197	21.1528	16.7702	11.6636	7.6404	4.9868	3.1309	1.9575	1.3010	0.9813
		T	2617456	2727764	2982658	3419889	3929218	4333642	4598070	4785984	4903671	4970239	5000253
	M-QoS-II	BER	25.5018	25.5966	25.3739	24.5869	20.3065	10.5556	3.0500	0.1804	0.0059	0.0003	0.0000
		T	2549395	2551902	2560125	2644237	3075555	4046901	4790039	5079403	5099371	5099951	5099986
	H-QoS	BER	24.5708	23.2062	20.2690	15.4298	10.1998	6.2077	3.4783	1.6602	0.7604	0.3796	0.2498
		T	2643814	2778210	3073053	3555178	4083761	4482104	4751351	4935423	5025950	5062664	5074279
	H-QoS-II	BER	25.3411	25.1248	24.4799	22.1865	13.8216	3.7775	0.0784	0.0002	0	0	0
		T	2565053	2587891	2651648	2888836	3695095	4718913	5093837	5099972	5100000	5100000	5100000

Table 5 Simulations Error Probabilities via AWGN, Rayleigh Fading and Burst Noise for inner UMTS-DL Channel

		E_b/N_o	0	1	2	3	4	5	6	7	8	9	10
AWGN	3G-DL	BER	11.8247	3.7868	0.0581	0.0001	0	0	0	0	0	0	0
		T	3910847	4714893	5094069	5100000	5100000	5100000	5100000	5100000	5100000	5100000	5100000
	L-QoS	BER	11.0658	2.6261	0.0104	0	0	0	0	0	0	0	0
		T	3994574	4840882	5098812	5100000	5100000	5100000	5100000	5100000	5100000	5100000	5100000
	M-QoS	BER	9.8971	1.7348	0.0029	0	0	0	0	0	0	0	0
		T	4111216	4926825	5099712	5100000	5100000	5100000	5100000	5100000	5100000	5100000	5100000
	H-QoS	BER	8.8062	1.0542	0.0004	0	0	0	0	0	0	0	0
		T	4223202	4995671	5099938	5100000	5100000	5100000	5100000	5100000	5100000	5100000	5100000
		E_b/N_o	0	1	2	3	4	5	6	7	8	9	10
RF	3G-DL	BER	24.9491	24.2103	22.3217	18.1739	11.1480	4.2415	0.2507	0.0006	0	0	0
		T	2605998	2676314	2864855	3274136	3985852	4676474	5075447	5099917	5100000	5100000	510000
	L-QoS	BER	25.1490	24.3138	22.7025	18.0838	10.2714	3.0690	0.0615	0	0	0	0
		T	2595186	2644813	2827859	3292969	4076627	4797479	5094085	5099990	5100000	5100000	5100000
	L-QoS-II	BER	25.5026	25.4912	25.4686	25.0459	18.9693	2.5880	0	0	0	0	0
		T	2548884	2552050	2552117	2597388	3208671	4842604	5099989	5100000	5100000	5100000	5100000
	M-QoS	BER	25.0614	24.2694	22.1079	17.0556	9.1027	2.1981	0.0218	0	0	0	0
		T	2596421	2673902	2892834	3394715	4185075	4879662	5097865	5099995	5100000	5100000	5100000
	M-QoS-II	BER	25.5097	25.4709	25.4145	24.3677	13.0467	0.0515	0	0	0	0	0
		T	2552051	2549487	25.57487	266045	3802712	5094525	5100000	5100000	5100000	5100000	5100000
	H-QoS	BER	24.8284	23.9000	21.4130	15.9577	8.0358	1.4124	0.0062	0	0	0	0
		T	2617043	2711890	2936809	3502698	4296917	4962669	5099404	5100000	5100000	5100000	5100000
	H-QoS-II	BER	25.4216	25.2787	24.8286	22.1257	7.3846	0.0002	0	0	0	0	0
		T	2554816	2572044	2620741	2885646	4356787	5099965	5100000	5100000	5100000	5100000	5100000
		E_b/N_o	0	1	2	3	4	5	6	7	8	9	10
BN	3G-DL	BER	24.1901	22.6976	19.7871	15.5341	10.8785	7.0908	4.1817	1.9219	0.7037	0.2356	0.1066
		T	2679485	2835746	3123541	3546529	4035241	4392480	4685014	4902586	5031279	5075943	5088957
	L-QoS	BER	24.6350	23.2766	20.2472	15.4721	10.1233	5.7409	2.4576	0.5269	0.0629	0.0060	0.0009
		T	2637974	2774490	3070483	3553957	4090502	4524974	4855067	5049993	5094171	5099419	5099942
	L-QoS-II	BER	25.4781	25.5132	25.4211	24.8465	21.1861	10.4923	1.3449	0.0028	0	0	0
		T	2552543	2552613	2557258	2615819	2981046	4048094	4961978	5099695	5100000	5100000	5100000
	M-QoS	BER	24.3603	22.7349	19.2802	13.9815	8.5068	4.2977	1.1989	0.1276	0.0085	0.0006	0.0000
		T	2663801	2827497	3176507	3697682	4243807	4666895	4981016	5087281	5099116	5099944	5099993
	M-QoS-II	BER	25.4880	25.4531	25.2445	23.4151	13.5881	1.6342	0.0006	0	0	0	0
		T	2550594	2554712	2576030	2752375	3729157	4934753	5099934	5100000	5100000	5100000	5100000
	H-QoS	BER	23.9706	21.9465	18.0150	12.4390	6.9978	2.8049	0.3960	0.0163	0.00003	0	0
		T	2703364	2903574	3294474	3858058	4401175	4818327	5060708	5098218	5099960	5100000	5100000
	H-QoS-II	BER	25.2847	24.9722	23.9893	19.4858	6.4060	0.0155	0	0	0	0	0
		T	2570261	2601290	2698983	3147390	4455809	5098065	5100000	5100000	5100000	5100000	5100000

Table 6 Simulations Error Probabilities via AWGN, Rayleigh Fading and Burst Noise for inner LTE Channel

	E_b/N_o		0	1	2	3	4	5	6	7	8	9	10
AWGN	4G	BER T	10.5503 6042716	4.1314 4691874	0.2131 5078368	0.0007 5099962	0 5100000	0 5100000	0 5100000	0 5100000	0 5100000	0 5100000	0 5100000
	L-QoS	BER T	9.8112 4124066	2.6615 4833784	0.0282 5097244	0 5099996	0 5100000	0 5100000	0 5100000	0 5100000	0 5100000	0 5100000	0 5100000
	M-QoS	BER T	8.1837 4279761	1.4498 4952191	0.0046 5099580	0 5100000	0 5100000	0 5100000	0 5100000	0 5100000	0 5100000	0 5100000	0 5100000
	H-QoS	BER T	6.7363 4538027	0.6836 5100000	0.0006 5100000	0 5100000	0 5100000	0 5100000	0 5100000	0 5100000	0 5100000	0 5100000	0 5100000
	E_b/N_o		0	1	2	3	4	5	6	7	8	9	10
RF	4G	BER T	24.1681 2682650	22.8310 2820043	20.2793 3070543	15.8750 3517273	9.9851 4095471	4.5231 4647212	0.6054 5037485	0.0029 5099085	0.0000 5099997	0 5100000	0 5100000
	L-QoS	BER T	24.7613 2623720	23.7018 2727487	21.1250 2986100	16.0409 3493749	9.1365 4190015	3.0472 4794069	0.1225 5086924	0.0002 5099961	0 5100000	0 5100000	0 5100000
	L-QoS-II	BER T	25.4888 2549736	25.5027 2551585	25.4748 2554759	24.9559 2606116	18.6968 3228711	2.6117 4839641	0.0001 5100000	0 5100000	0 5100000	0 5100000	0 5100000
	M-QoS	BER T	24.4654 2654847	23.0900 2794821	20.0278 3096940	14.4785 3654152	7.5297 4348126	1.8268 4920034	0.0255 5097385	0 5100000	0 5100000	0 5100000	0 5100000
	M-QoS-II	BER T	25.4989 2551605	25.4724 2552906	25.3622 2563732	23.7357 2730747	10.2914 4068970	0.0115 5098670	0 5100000	0 5100000	0 51000000	0 5100000	0 5100000
	H-QoS	BER T	23.7517 2724493	22.0632 2892351	18.5742 3244398	12.7752 3821906	6.1802 4485369	0.8984 5009528	0.0045 5099455	0 5100000	0 5100000	0 5100000	0 5100000
	H-QoS-II	BER T	25.3450 2565973	25.0647 2592021	24.3307 2667246	20.1685 3082429	4.0995 4695383	0 5100000	0 5100000	0 5100000	0 5100000	0 5100000	0 5100000
	E_b/N_o		0	1	2	3	4	5	6	7	8	9	10
BN	4G	BER T	22.7648 2822061	20.4995 3046506	17.1171 3381307	13.3116 3775253	9.6159 4139795	6.8163 4413830	4.7524 4624057	3.2312 4773280	2.1633 4881159	1.6032 4941058	1.2776 4971742
	L-QoS	BER T	23.9411 2707504	21.9654 2906323	18.5072 3252404	13.8099 3721340	9.2825 4169190	5.9193 4511859	3.4556 4759618	1.6285 4937973	0.7225 5029256	0.3105 5067349	0.1729 5082416
	L-QoS-II	BER T	25.4913 2549436	25.4933 2550338	25.3865 2563063	24.5893 2640569	20.5358 3052065	10.4748 4041522	2.2563 4880009	0.0233 5097111	0.0000 5099992	0 5100000	0 5100000
	M-QoS	BER T	23.3284 2769050	20.8092 3022951	16.6278 3434682	11.5105 3948917	6.9996 4399476	3.7119 4729739	1.3044 4972034	0.2898 5071301	0.0454 5094517	0.0092 5099179	0.0014 5099868
	M-QoS-II	BER T	25.4696 2551179	25.4087 2557726	24.9650 2600678	21.5303 2957226	9.3109 4165514	0.4009 5059520	0.0001 5099988	0 5100000	0 5100000	0 5100000	0 5100000
	H-QoS	BER T	22.1264 2891445	19.1475 3188465	14.5309 3647449	9.4081 4160769	5.2046 4578245	1.9898 4900390	0.3844 5062455	0.0390 509563	0.0033 5099281	0.0002 5099965	0.0001 5099995
	H-QoS-II	BER T	25.1089 2587860	24.5848 2639188	22.9269 2810542	14.7283 3624474	1.8560 4912331	0.0004 5099962	0 5100000	0 5100000	0 5100000	0 5100000	0 5100000