

# We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900

Open access books available

185,000

International authors and editors

200M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index  
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?  
Contact [book.department@intechopen.com](mailto:book.department@intechopen.com)

Numbers displayed above are based on latest data collected.  
For more information visit [www.intechopen.com](http://www.intechopen.com)



# The Adaptive Coding Techniques for Dependable Medical Network Channel

*Emtithal Ahmed Talha and Ryuji Kohno*

## Abstract

The readily existing cellular networks play an important role in the daily life communications by integrating a wide variety of wireless multimedia services with higher data transmission rates, capable to provide much more than basic voice calls. In order to increase the demands of reliable medical network infrastructure economically and establish reliable medical transmission via cellular networks, this chapter has been designed as a dependable wireless medical network using an existing mobile cellular network with sophisticated channel coding technologies, providing a new novel way of the network that is adopted as a “Medical Network Channel (MNC)” system. Adding such adaptive outer coding with an existing cellular standard as inner coding makes a concatenated channel to carry out the MNC design. The adaptive design of extra outer channel codes depends on the Quality of Services (QoS) of Wireless Body Area Networks WBANs and also on the remaining errors from the inner-used cellular decoders. The adaptive extra code has been optimized toward “Medical Network Channel (MNC)” for different medical data QoS priority levels. The accomplishment of QoS constraints for different WBAN medical data has been investigated in this chapter for “Medical Network Channel (MNC)” by using the theoretical derivations, where positive acceptable results were achieved.

**Keywords:** UMTS, LTE, WBANs, QoS, concatenated codes

## 1. Introduction

A medical telemonitoring system is one of the telecommunication techniques that access delivery to healthcare services and one of the main applications for Medical Information Communication Technology (MICT). Recently, Information and Communication Technology (ICT) for medical and healthcare application has drawn substantial attention, which plays an important role to support dependable and effective medical technologies to solve significant problems in any society. The WBAN technology has proved out newly in the latest standardization as IEEE 802.15.6 [1]. WBAN 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]. WBAN technology is growing as a key technology for MICT

to transfigure the future of healthcare; therefore, WBANs have been attracting a great treaty of attentions from researchers both in academia and industry in the last few years [3]. A QoS is a major concern for WBAN medical application. Therefore, the researcher concerning QoS issues in WBANs should handle all of that very seriously in an effective way [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. The cellular standards have been developed by considering enhancement in 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 the third generation (3G) with Wide Code Division Multiply Access (WCDMA) air interface, and LTE is the main standard of the 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 bandwidth from 1.4 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 WBAN technology network with other networks such as cellular networks UMTS and LTE is a key point for this chapter to serve the WBAN medical data transmission through the readily existing cellular networks. Therefore, the concept is to use the error controlling coding and decoding based on the concatenated channel codes with the cellular readily existing codes to design the “Medical Network Channel (MNC)” system. Reliable transmission of medical data is critical and essential since it is related to diagnosis and treatments of 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).

The chapter focuses on the dependability of medical telemonitoring system from WBANs through UMTS and LTE via “Medical Network Channel (MNC)” system. Dependability of medical data transmission via MNC is defined as the probability of the “Medical Network Channel (MNC)” system to operate successfully, which means transmitted medical data reach their destination completely uncorrupted and guarantee minimum performances with lower error rate as much as possible under different environmental conditions. There are different methods that 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. A high level of reliability can be obtained by introducing redundancy bits in the signal transmission (encoding).

Medical Network Channel (MNC) system has been introduced to solve the reliability issues for medical data transmission when considering different QoS levels. The WBAN medical data are sensitive and any type of noise can corrupt them during transmission. Although the cellular standards include significant amounts of error detection and correction techniques, which are designed for daily life conversation mainly, some errors may still be present in the received data, and these transmission errors are not serious for the daily communication, but when considered for medical uses, they can have fatal outcomes. For that reason, the UMTS and LTE codes are designed for certain levels of channel condition, and if the error becomes more than the estimated condition, then the error becomes more serious and the cellular network standards perform worse using the preexisting error detection and correction capability. The Medical QoS levels have different

reliability required based on the BER for different medical data and other constraints [8].

The error control coding plays 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 their simplicity and effectiveness [10]. Therefore, the chapter proposes a novel way of conducting error control encoding and decoding with QoS constraints by using the concatenated code techniques to build the MNC system. Consequently, the MNC intends 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 code choice has six pairs of encoding and decoding, three for QoS levels (high, medium, and low) and then two for the channel condition (normal and worse). The restriction of UMTS or LTE channel codes is 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 adaptive extra outer channel codes with strong decoding capabilities resulting in better performance for MNC to transmit the WBAN medical data robustly.

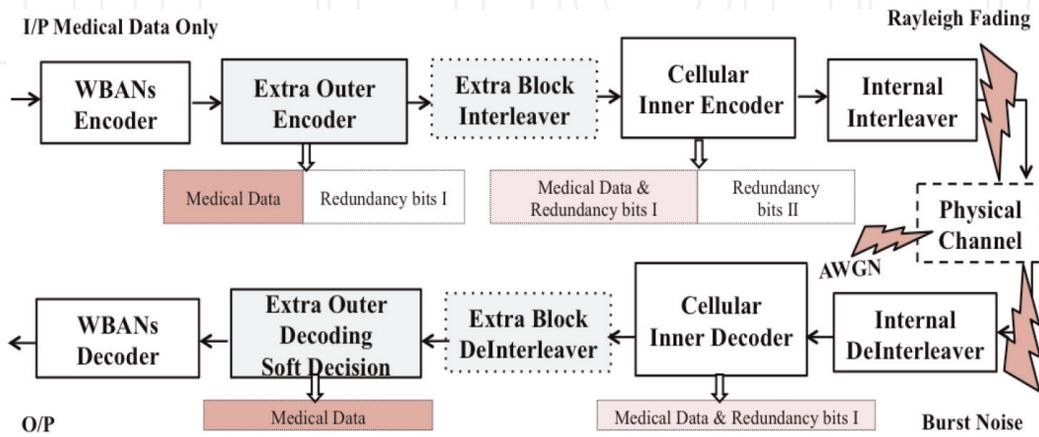
The objective of the chapter is to design a reliable and dependable MNC system through the cellular networks to provide reliable transmission for all QoS medical data coming from WBANs. The structural design of MNC is based on channel coding of those using concatenated channel code techniques in the serial manner which adds extra channel codes to the cellular UMTS or LTE codes. The inner channel codes in MNC are cellular network standard UMTS or LTE error correction codes that cannot be changed in order to enhance the error performances, with regard to the international standards. On the other hand, the extra outer channel code in MNC is a changeable parameter for achieving different QoS constraints of medical data, which used the convolution code as the main error correction technique. Then, it will add end-to-end connection of WBANs to this MNC system using WBAN standard error correction techniques itself. According to QoS of WBANs O/P, MNC can be with or without extra code.

This chapter reflects about categorizing the eighth level QoS of WBANs to three different QoS (lower, medium, and higher) set levels. To achieve the chosen QoS, there is a need for adaptive external code with limited or strong error correcting capability with high, medium, or low coding rate and redundancy. Through those techniques, the MNC system is adaptive to varying propagation conditions and also adaptive to various QoS constraints. Therefore, the work here focuses to overcome different PHY errors that may occur during the transmission in an unpredictable way, making the channel situation time-to-time change, such as Gaussian noise AWGN, Rayleigh fading, or burst noise.

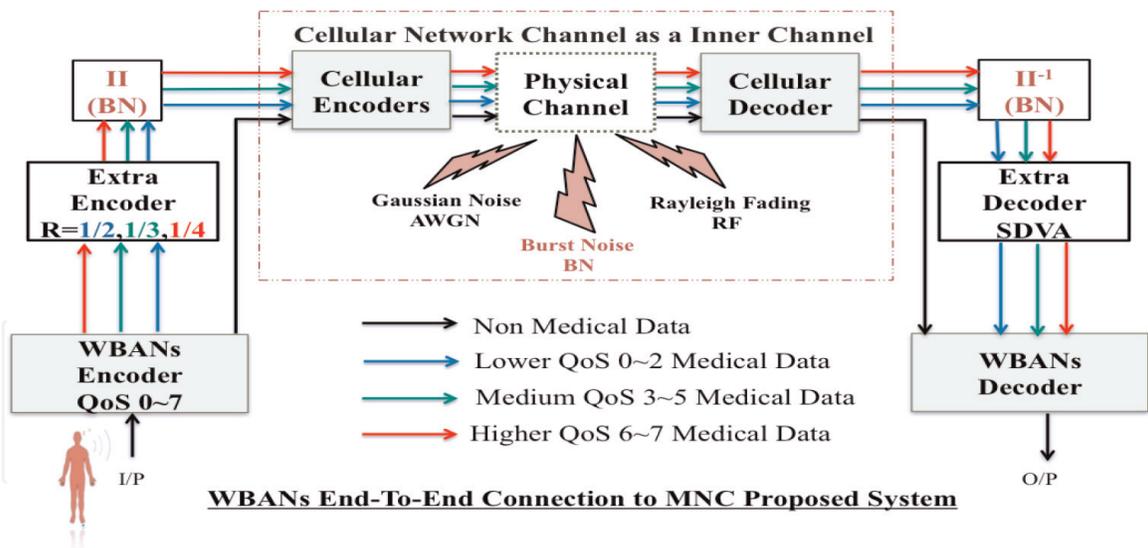
## **2. The dependable medical network channel configurations**

The “Medical Network Channel (MNC)” system is a new system adopted in this chapter, which works to serve transmission of medical data robustly from WBANs through the cellular standard networks. It is mainly based on the error control coding techniques to ensure the dependability required for such medical data. The idea of the concatenated codes was used for connecting the WBANs with the cellular networks. The purpose is to have reliable and dependable medical data transmissions through the readily existing cellular network.

**Figure 1** shows the whole “Medical Network Channel (MNC)” system that is the core base of this chapter. The different medical data QoS levels from the WBANs have been considered in designing the phase as well as the different assumed channel conditions. The structural design of the proposal is described in **Figure 2** by using the concatenated code techniques for different QoS of WBANs. The inner code for the MNC structure is introduced in **Table 1**. The UMTS and LTE provide both error detection and error correction as channel coding scheme. Here, it is assumed that the inner channel of the “Medical Network Channel (MNC)” system uses uplink UMTS channel as Common Packet Channel (CPCH) working by the convolution code rate 1/2. Similarly, the downlink UMTS channel was assumed



**Figure 1.**  
Medical network channel codes via cellular networks.



**Figure 2.**  
The medical network channel system for QoS of WBAN medical data.

	TRCH type	Coding type	Coding rate R and constraint length K	Number of encoded bits
UMTS UL	CPCH	Convolution	R = 1/2 & K = 9	$D_i = 2 \cdot K_i + 16$
UMTS DL	FACH	Convolution	R = 1/3 & K = 9	$D_i = 3 \cdot K_i + 24$
LTE	BCH	Convolution	R = 1/3 & K = 7	$D_i = 3 \cdot K_i + 18$

**Table 1.**  
The inner cellular network code techniques.

using Forward Access Channel (FACH) working by the convolution code rate 1/3. Furthermore, LTE was assumed using Broadcast Channel (BCH) working by the convolution code rate 1/3.

The technical parameters for the extra channel detailed here by using extra outer encoder as convolution encoder are concatenated to the inner cellular standard channel codes. Among all the FEC codes, the convolution codes have great advantages using continuous data streams and can manage the performance with only two parameters: the code rate R and the constraint length K. Also, convolution codes have high error correction in comparison to block codes and less complexity in comparison to turbo codes. The soft decoding algorithm and the hard decoding algorithm, can make easily changes in the performances. Since the extra channel is a key point to have high performance for “Medical Network Channel (MNC)”-proposed system, the choice here of the extra code is driven by convolution codes. The outer channel is the existing WBAN channel that uses BCH code as a main code to correct the error. The system “Medical Network Channel (MNC)” has been considering the performance with and without end-to-end connection of the WBAN codes. The assumption is that the medical data coming from the WBANs with transmission rate 75.9Kb/s are entering the extra outer channel that will be the only optimized channel in “Medical Network Channel (MNC)” system, and then are entering the inner cellular channels within data rate less than the channel capacities.

### 3. Adaptive dependable system for WBAN medical data

The “Medical Network Channel (MNC)”-proposed system is dependable, which ensures to give the different QoS level of medical data transmission within acceptable performance capability such as  $10^{-3}$ ,  $10^{-5}$  and  $10^{-7}$  BER for low, medium, and high QoS levels within higher required bit energy to interference ( $E_b/N_o$ ) values as possible under different assumed noise conditions. The WBAN has eight QoS levels. The QoS levels for the medical data have divided to three parts 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 2**.

**Table 2** shows all the error-correcting capabilities related to the UL and DL inner channels’ technical capabilities for the UMTS and LTE with regard to the international standards of error correction code.

The criteria of the extra code selections in “Medical Network Channel (MNC)” system have two main parts in the structure: the fixed parts, which are related to the cellular standard networks or WBAN technology, and the changeable parts, which are external that are added to receive the medical data only.

	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	$17\lambda$	$256*L$	122,694
3G-DL	144Kb/s	1/3	9	[557 663 711]	18	9	$26\lambda$	$256*L$	2275
4G	75 Mb/s	1/3	7	[133 171 165]	15	7	$20\lambda$	$64*L$	416

**Table 2.**  
 The inner cellular network code capabilities.

QoS data sets	Code	R & K	G	$d_{\text{free}}$	t	Sum $W_d$	II Size
<b>Lowest QoS level</b>		1/2 & 8	[247 371]	10	5	10,970	126 bits/block
<b>Medium QoS level</b>	Outer	1/3 & 8	[225 331 367]	16	8	425	189 bits/block
<b>Highest QoS level</b>		1/4 & 8	[235 275 313 357]	22	11	169	252 bits/block

**Table 3.**

*Designing parameters of MNC adaptive codes related to QoS priority levels.*

The assumption in this chapter is a WBAN chip installed in the mobile device to carry-on the medical data via the cellular systems through the “Medical Network Channel (MNC)” system to ensure the reliability required for the different sets of medical data. The extra code is adaptive by carrying parameters that are selectable with regard to the two main requirements: first, with regard to various kinds of the QoS of medical data entering the extra code from the WBAN code and second, with regard to the kind of the channel conditions that affected the transmission in PHY channels.

The goal of “Medical Network Channel (MNC)” is figured out by designing the extra code with regard to the QoS by analyzing the WBAN medical data QoS needed. **Table 3** categorizes the QoS of the WBAN medical data into three sets, with regard to the priority level, in order to design the MNC system. The first set is the highest priority level such as a biological signal (ECG, EMG, and EEG), the second set is a medium priority level such as medical data (temperature, blood pressure, and blood sugar), and the third set is the lowest priority level such as data management, audio, and video.

“Medical Network Channel (MNC)” used the three sets later to design and optimize the MNC system depending on that. The first set highest priority level will carry on through strong design MNC achieving  $10^{-7}$  BER, then the second set medium priority design system achieves  $10^{-5}$  BER, and then the third set lowest priority design system achieves  $10^{-3}$  BER within higher  $E_b/N_o$  as possible.

In the “Medical Network Channel (MNC)” super PHY channel, the remaining error from the inner cellular decoder optimized the technical parameters of the extra outer code as shown in **Table 3**.

I/P	100 Kb/s [51 bits/s length]		
Outer WBAN encoder	63 bits/s		
Adaptive extra channel encoders	Lowest QoS level	Medium QoS level	Highest QoS level
	(2,1,8) $D_{\text{free}} 10 T = 5$ I/P 63b/s O/P 126 b/s	(3,1,8) $D_{\text{free}} 16 T = 8$ I/P 63b/s O/P 189 b/s	(4,1,8) $D_{\text{free}} 22 T = 11$ I/P 63b/s O/P 252 b/s
<b>UMTS UL inner encoder</b>	(2,1,9) $D_{\text{free}} 12 T = 6$ I/P 126 b/s O/P 252 b/s	(2,1,9) $D_{\text{free}} 12 T = 6$ I/P 189 b/s O/P 378 b/s	(2,1,9) $D_{\text{free}} 12 T = 6$ I/P 252 b/s O/P 504 b/s
<b>UMTS DL inner encoder</b>	(3,1,9) $D_{\text{free}} 18 T = 9$ I/P 126 b/s O/P 378 b/s	(3,1,9) $D_{\text{free}} 18 T = 9$ I/P 189 b/s O/P 567 b/s	(3,1,9) $D_{\text{free}} 18 T = 9$ I/P 252 b/s O/P 756 b/s
<b>LTE UL inner encoder</b>	(3,1,7) $D_{\text{free}} 15 T = 7$ I/P 126 b/s O/P 378 b/s	(3,1,7) $D_{\text{free}} 15 T = 7$ I/P 189 b/s O/P 567 b/s	(3,1,7) $D_{\text{free}} 15 T = 7$ I/P 252 b/s O/P 756 b/s

**Table 4.**

*All error-correcting capabilities for MNC-proposed system codes.*

The system design that is detailed above has been adjusted for the different QoS levels of medical data. The technical parameters of the extra channel codes have been fixed for the “Medical Network Channel (MNC).” The capabilities have been determined for the AWGN channel and for the Rayleigh fading with a parameter distribution function equal to 0.55. However, for seeking the reality, these channel conditions may be good or worse than those determined. **Table 4** details all the “Medical Network Channel (MNC)” adaptive design parameters with regard to the capability of correcting the channel errors.

#### 4. Theoretical error-bound performance calculation key points

The error-bound probabilities are calculated depending on the inner, outer, and extra outer decoders 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 the assumed AWGN channel.

The performance bounds theoretically are driven under AWGN with and without adding WBANs end to end to “Medical Network Channel (MNC)”-proposed system. Then, 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 “Medical Network Channel (MNC)” system and to find out the numbers of errors in the output of inner cellular decoders and to test the optimized extra channel code theoretically in “Medical Network Channel (MNC)” for different QoS medical data levels under AWGN and Rayleigh fading channels.

**Table 5** explains all the technical parameters used in the theoretical evaluations. The theoretical bound follows number of steps to calculate the error probabilities for the adaptive “Medical Network Channel (MNC)” concatenated channel codes: the first step 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), and at last, in the O/P of the WBAN outer decoders. These numerical evaluations have been done in the two assumed inner cellular channel codes: UMTS and LTE.

The theoretical calculations for the error bound of the “Medical Network Channel (MNC)”-proposed system via AWGN could be done as many steps in the decoding side as in (Eq. (1)–(11)). The inner and extra channel used convolutional

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

**Table 5.**  
 Error correcting code capabilities for MNC system.

decoder that works using Viterbi algorithm and the outer WBAN channel used the block code decoder. First of all, the UMTS inner decoder calculates the first inner probability bit errors  $P_{bi}$  bound as in Eq.(1)–(4).

$$P_{bi} \leq \frac{1}{bi} \sum_{di=0}^{\infty} W_{di} P_{ei}(di) \quad (1)$$

where  $P_{ei}(di)$  is the probability of confusing two sequences differing in distance  $di$  and positions of inner cellular code, and can be calculated as in Eq. (2).  $W_{di}$  is the weight spectrum that is the average number of bit errors associated with sequences of weigh  $di$ , and it is calculated for all codes that work in this “Medical Network Channel (MNC)” system as in **Table 5**;  $w(d)$ ,  $d \geq df$ .  $W_{di}$  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; then it is preferred 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 [9, 10].

$$P_{ei}(di) = Q\left(\sqrt{2 di Ri E_b / N_0}\right) \quad (2)$$

where  $di$  is an inner cellular code free distance and  $Ri$  is an inner cellular code rate, both showed in **Table 5**.  $Q$  function is clear in information theory and can be calculated using infinity integration as in Eq. (3).

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

$$P_{bi} \leq \frac{1}{bi} \sum_{di=0}^{\infty} W_{di} \cdot Q\left(\sqrt{2 di Ri E_b / N_0}\right) \quad (4)$$

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 Eq. (5)–Eq. (6) by the outer code parameter introduced in **Table 5** for the three different QoS levels of WBAN medical data.

$$P_{bo} \leq \frac{1}{bo} \sum_{do=0}^{\infty} W_{do} \cdot Q\left(\sqrt{2 do Ro E_b / N_0}\right) \quad (5)$$

$$P_b \text{ withno WBAN} \leq P_{bi} \cdot P_{bo} \quad (6)$$

The outer code performances of the MNC system can be calculated by Eq. (6) for lower, medium, and higher QoS classes of medical data depending on the parameters applied to the extra channel. The last step is introduced by calculating the final outer code performance of the system. The WBAN decoder (63, 51, 2) calculates the last probability bit error  $P$  bound using Eq. (7)–Eq. (10), which is a function of the extra outer code.

$$P_b \leq \sum_{i=t+1}^n \binom{n}{i} P_x^i (1 - P_x)^{n-i} \text{ where } \binom{n}{i} = \frac{n!}{(n-i)! \cdot i!} \quad (7)$$

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

$$P_x = Q\left(\sqrt{2R E_b/N_0}\right) = Q\left(\sqrt{2 \times 51/63 \cdot E_b/N_0}\right) \quad (9)$$

By using Eq. (9) as a function of Eq. (6) to calculate the final bound, we can have Eq. (10).

$$P_x \text{ with WBAN} = P_b \text{ withno WBAN} \cdot P_x \quad (10)$$

Then, by applying Eq. (10) in Eq. (7), we will have the final MNC system by adding WBAN code end to end for all QoS assumed and via AWGN channel in Eq. (11).

$$P_b \text{ with WBAN} \leq \sum_{i=2+1}^{63} \binom{63}{i} P_x^i \text{ withno WBAN} (1 - P_x \text{ withno WBAN})^{63-i} \quad (11)$$

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

$$P(\rho_{j,i}) \cong \frac{1}{\sigma_\rho^2} \rho_{j,i} e^{-\frac{\rho_{j,i}^2}{2\sigma_\rho^2}} \prod_{\rho_{j,i}} \geq 0 \quad (12)$$

where  $e^{-\frac{\rho_{j,i}^2}{2\sigma_\rho^2}}$  and  $\prod_{\rho_{j,i}} \geq 0$  are the indicators of the set  $\{\rho_{j,i} \geq 0\}$ , which equals 1 if  $\rho_{j,i} \geq 0$ , and 0 if not. In all theoretical work of MNC system, this Rayleigh variable has been estimated as 0.55, which is greater than 0, to evaluate the super PHY channel of MNC 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 Eq. (13).

$$P_{bfsk} \cong \frac{1}{2} \left[ 1 - \sqrt{\frac{\overline{E_b}/N_o}{1 + \overline{E_b}/N_o}} \right] \quad (13)$$

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

where  $C$  can be calculated using the free distance  $d_{freei}$  of the inner cellular code by Eq. (15) and appeared in **Table 5**.  $E_b$  represents the average energy received per symbol of transmitted information, and it is calculated as in Eq. (16). Then, the inner cellular code performance can be calculated by Eq. (17).

$$C_{2df-1}^{df} = \frac{(2d-1)!}{d! \cdot (d-1)!} \quad (15)$$

$$\overline{E_b} = E(\rho_{j,i}^2) E_b = 2\sigma_\rho^2 E_b = 0.55 E_b \text{ assumed} \quad (16)$$

$$P_{bi} \leq P_{bfsk} \cdot \frac{w(df_{freei})}{bi} C_{2df_{freei}-1}^{df_{freei}} \left( \frac{1}{4Ri \overline{E_b}/N_o} \right)^{df_{freei}} \quad (17)$$

Generally speaking, the data stream coming from the cellular inner code feeds the extra channel code. The code performance of the extra outer code is a function of the inner cellular code. Second, the outer decoder calculates the second outer

probability bit errors  $P_{bo}$  bound separately as in Eq. (18) by the outer code parameters introduced in **Table 5**.

$$P_{bo} \leq P_{bfsk} \cdot \frac{w(df_{freeo})}{bo} C_{2^{df_{freeo}-1}} \left( \frac{1}{4Ro \overline{E_b/N_0}} \right)^{df_{freeo}} \quad (18)$$

Then, the extra outer code performances of super PHY channel MNC system under Rayleigh fading can be calculated by Eq. (19).

$$P_b \leq P_{bi} \cdot P_{bo} \quad (19)$$

The theoretical performances have been calculated for the MNC system with different QoS levels by using the cellular standards as an inner code via AWGN and Rayleigh fading noisy channels.

The first case is via WBANs. In this case, where the inner codes work as a UMTS channel, there are two kinds of codes, when using the cellular parameters in **Table 2**. One is the error probability as in Eq. (20) for UL and other is the error probability as in Eq. (21) for DL.

$$P_{biUL} \leq 122694 Q\left(\sqrt{12 E_b/N_0}\right) \quad (20)$$

$$P_{biDL} \leq 2275 Q\left(\sqrt{12 E_b/N_0}\right) \quad (21)$$

In the second step in the O/P of the extra channel code, there are three targeting QoS levels. Therefore, the probability of the error can be calculated from Eq. (5) as in Eq. (22)–Eq. (24) for the different code sets.

$$P_{bo LQoS} \leq 10970 Q\left(\sqrt{10 E_b/N_0}\right) \quad (22)$$

$$P_{bo MQoS} \leq 425 Q\left(\sqrt{32/3 E_b/N_0}\right) \quad (23)$$

$$P_{bo HQoS} \leq 169 Q\left(\sqrt{11 E_b/N_0}\right) \quad (24)$$

From here, the error probability for the “Medical Network Channel (MNC)”-proposed system without end-to-end connection of WBANs can be calculated from Eq. (6) as six levels of error probability as in Eq. (25).

$$P_b \text{ withno WBAN} \leq P_{bi UL, DL} \cdot P_{bo LQoS, MQoS, HQoS} \quad (25)$$

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

$$P_b \text{ with WBAN} \leq \sum_{i=2+1}^{63} \binom{63}{i} P_x^i \text{ withno WBAN} (1 - P_x \text{ withno WBAN})^{63-i} \quad (26)$$

The second case is via WBANs. In this case where the inner codes work as an LTE channel, when using the LTE cellular parameters in **Table 2**, we will have the probability of errors as in Eq. (27).

$$P_{bi LTE} \leq 416 Q\left(\sqrt{10 E_b/N_0}\right) \quad (27)$$

In the second step in the O/P of the extra channel code, there are three targeting QoS levels. Therefore, the probability of the error can be calculated from Eq. (5) as in Eq. (22)–(24) for the different code sets. From here, the error probability for the MNC system without end-to-end connection of WBANs through the LTE can be calculated from Eq. (6) as six levels of error probability as in Eq. (28).

$$P_b \text{ withno WBAN} \leq P_{bi} \text{ LTE} \cdot P_{bo} \text{ LQoS, MQoS, HQoS} \quad (28)$$

The final step here can be done when the WBANs are connected end to end through the proposed system. Therefore, using Eq. (28) in Eq. (11), we can have the final error probability of the “Medical Network Channel (MNC)” system.

$$P_b \text{ with WBAN} - \text{LTE} \leq \sum_{i=2+1}^{63} \binom{63}{i} P_b^i \text{ withno WBAN} (1 - P_b \text{ withno WBAN})^{63-i} \quad (29)$$

The third case is via Rayleigh fading. In this case where the inner codes work as a UMTS channel, there are two kinds of codes: UL and DL. By using the cellular parameters, we will have the probability of errors as in Eq. (30) in the case of UL and Eq. (31) in the case of DL.

$$P_{bi} \text{ UL} \leq P_{bfsk} \cdot \frac{w(df_{freei})}{b} C_{2df_{freei}-1}^{df_{freei}} \left( \frac{1}{4Ri \overline{E}_b/N_o} \right)^{df_{freei}} \quad (30)$$

$$P_{bi} \text{ DL} \leq P_{bfsk} \cdot \frac{w(df_{freei})}{bi} C_{2df_{freei}-1}^{df_{freei}} \left( \frac{1}{4Ri \overline{E}_b/N_o} \right)^{df_{freei}} \quad (31)$$

In the second step in the O/P of the extra channel code, there are three targeting QoS levels. Therefore, the probability of the error can be calculated from Eq. (18) as in Eq. (32)–(34).

$$P_{bo} \text{ LQoS} \leq P_{bfsk} \cdot \frac{w(df_{freeo})}{bo} C_{2df_{freeo}-1}^{df_{freeo}} \left( \frac{1}{4Ro \overline{E}_b/N_o} \right)^{df_{freeo}} \quad (32)$$

$$P_{bo} \text{ MQoS} \leq P_{bfsk} \cdot \frac{w(df_{freeo})}{bo} C_{2df_{freeo}-1}^{df_{freeo}} \left( \frac{1}{4Ro \overline{E}_b/N_o} \right)^{df_{freeo}} \quad (33)$$

$$P_{bo} \text{ HQoS} \leq P_{bfsk} \cdot \frac{w(df_{freeo})}{bo} C_{2df_{freeo}-1}^{df_{freeo}} \left( \frac{1}{4Ro \overline{E}_b/N_o} \right)^{df_{freeo}} \quad (34)$$

From here, the error probability for the “Medical Network Channel (MNC)”-proposed system without end-to-end connection of WBANs could be calculated from Eq. (19) as three levels of error probability as in Eq. (35).

$$P_b \text{ withno WBAN} \leq P_{bi} \text{ UL, DL} \cdot P_{bo} \text{ LQoS, MQoS, HQoS} \quad (35)$$

The fourth case is via Rayleigh fading. In the case where the inner codes work as an LTE channel, when using the cellular parameters in Eq. (17), we will have the probability of errors as Eq. (36).

$$P_{bi} \text{ LTE} \leq P_{bfsk} \cdot \frac{w(df_{freei})}{b} C_{2df_{freei}-1}^{df_{freei}} \left( \frac{1}{4Ri \overline{E}_b/N_o} \right)^{df_{freei}} \quad (36)$$

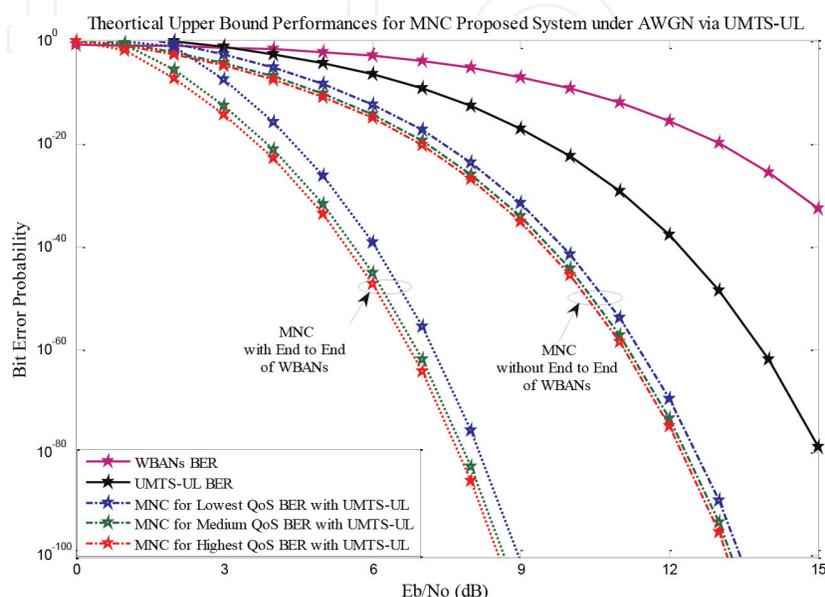
Then, from here, the error probability for the “Medical Network Channel (MNC)” system without end-to-end connection of WBANs can be calculated from Eq. (19) as three levels of error probability as in Eq. (37).

$$P_b \text{ withno WBAN} \leq P_{bi} \text{ LTE} \cdot P_{bo} \text{ LQoS, MQoS, HQoS} \quad (37)$$

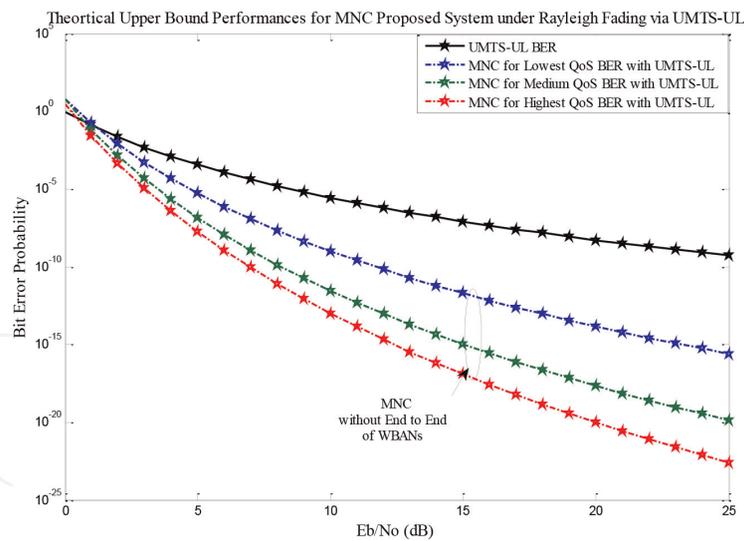
Finally, **Table 6** shows the numerical evaluation of the “Medical Network Channel (MNC)” system with different categories, with the inner channel as UMTS UL, DL, and LTE as well. Regarding to the figures results, **Figure 3** shows the theoretical performance when the channel is affected by AWGN for MNC via

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
Low-QoS	2.7957	0.1717	0.0054	0.0001	0.0000	0.0000
Medium-QoS	0.0755	0.0042	0.0001	0.0000	0.0000	0.0000
High-QoS	0.0251	0.0014	0.0000	0.0000	0.0000	0.0000
Low-QoS-WBANs	1.0000	0.0506	0.0000	0.0000	0.0000	0.0000
Medium-QoS-WBANs	0.0127	0.0000	0.0000	0.0000	0.0000	0.0000
High-QoS-WBANs	0.5854	0.0000	0.0000	0.0000	0.0000	0.0000
The results via Rayleigh fading of PDF 0.55						
$E_b/N_o$	0 dB	1 dB	2 dB	3 dB	4 dB	5 dB
UMTS-UL	4.9532	0.0001	0.0000	0.0000	0.0000	0.0000
Low-QoS	1.9352	0.0000	0.0000	0.0000	0.0000	0.0000
Medium-QoS	9.0438	0.0000	0.0000	0.0000	0.0000	0.0000
High-QoS	4.5376	0.0000	0.0000	0.0000	0.0000	0.0000

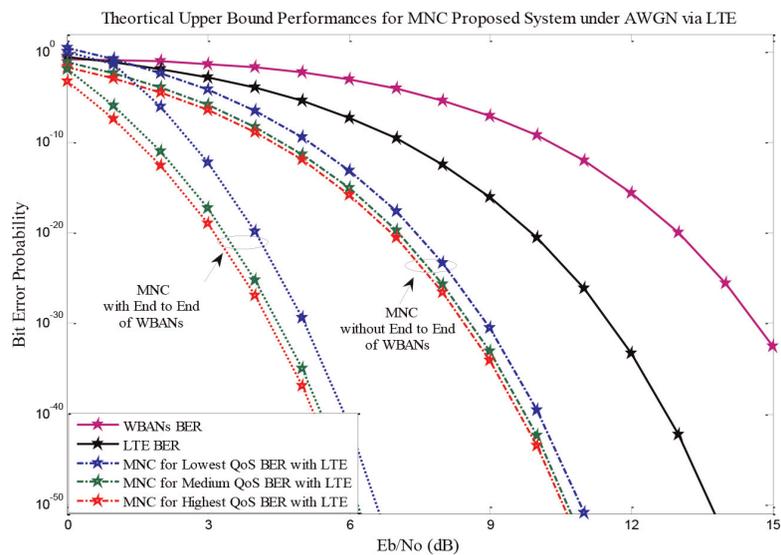
**Table 6.**  
Theoretical error bit performances for MNC system.



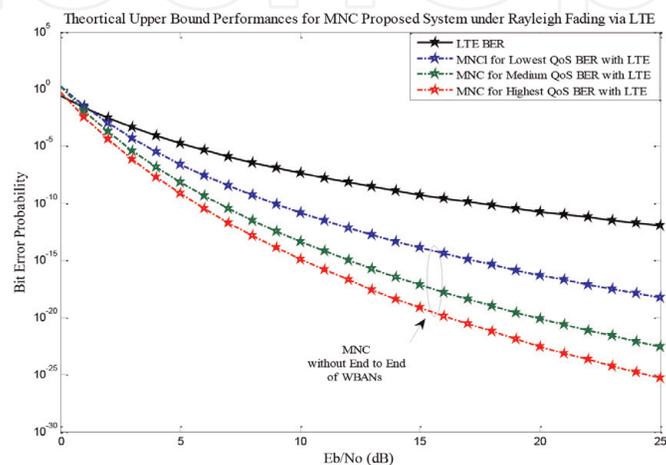
**Figure 3.**  
All priority results via UMTS under AWGN theoretically.



**Figure 4.**  
 All priority results via UMTS under Rayleigh fading theoretically.



**Figure 5.**  
 All priority results via LTE under AWGN theoretically.



**Figure 6.**  
 All priority results via LTE under Rayleigh fading theoretically.

UMTS networks. **Figure 4** shows the theoretical performance when the channel is affected by Rayleigh fading for MNC via UMTS networks. **Figure 5** shows the theoretical performance when the channel is affected by AWGN for MNC via LTE networks. Finally, **Figure 6** shows the theoretical performance when the channel is affected by Rayleigh fading for MNC via LTE networks.

## 5. Conclusions

The main purpose of “Medical Network Channel (MNC)” systems is to have a reliable medical network channel via the cellular infrastructure networks by end-to-end WBAN connection. Therefore, the stanchions establishment of “Medical Network Channel (MNC)” with error controlling coding and decoding through existing infrastructure networks such as UMTS and LTE is introduced in this chapter with an end-to-end connection of WBANs and without the connection of WBANs considering the medical data coming from different sources. The understanding of the eight levels of the QoS medical data has been done well; however, the optimizations here have been classified into three classes (lower, medium, and higher) for all medical QoS data. Therefore, the MNC system is a novel way considering the dependability issues by this way for the first time with regard to the QoS constraint for the different medical applications of WBANs. Although the adaptive extra outer code for “Medical Network Channel (MNC)” is based on the convolution code, the choice of the technical parameters is different from one to another depending on the QoS targeted and on the capability of cellular standard itself, which is a remaining error in the O/P of the inner cellular code.

Although the current cellular standard has strong error detection and correction capability, it is designed well for the daily life communication without considering medical data transmission, and in some hard noisy channel situations that exceed the design capabilities, the cellular network cannot perform well. Therefore, the Medical Networks channel MNC system has been introduced new novel approach to connect WBANs end-to-end via the cellular networks by 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 adaptive “Medical Network Channel (MNC)” system overcomes the weakness of cellular networks with regard 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. In regard to achieving different QoS of WBAN requirements, the results in **Table 6** and BER **Figures 3–6** cleared all the study cases carefully for adaptive “Medical Network Channel (MNC)” system. Generally, the adaptive medical network channel introduced in this chapter is through the cellular networks. However, all communication network standards can be applied using error correcting techniques to be adaptive for medical data transmission.

## Acknowledgements

The first author would like to express thanks to the academic supervisor Prof. Ryuji Kohno for his help and guidance and to all Kohno-Lab members in Yokohama National University. Correspondingly, the first author would like to express thanks to the dean and engineering members in Sudan International University.

## **Conflict of interest**

There is no conflict of interest for this work from anyone.

IntechOpen

IntechOpen

## **Author details**

Emtithal Ahmed Talha<sup>1\*</sup> and Ryuji Kohno<sup>2</sup>

1 Sudan International University, Khartoum, Sudan

2 Yokohama National University, Yokohama, Japan

\*Address all correspondence to: [Emtithal-talha-xb@ynu.jp](mailto:Emtithal-talha-xb@ynu.jp)

## **IntechOpen**

© 2019 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/3.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. 

## References

- [1] IEEE. IEEE standard for local and metropolitan area networks–Part 15.6: Wireless Body Area Networks. IEEE Std 802.15.6-2012; 2012
- [2] Yuce MR, Khan J. Wireless Body Area Networks: Technology, Implementation, and Applications. Pan Stanford: CRC Press; 2011
- [3] Movassaghi S, Abolhasan M, Lipman J, Smith D, Jamalipour A. Wireless body area networks: A survey. IEEE Communications Surveys & Tutorials. 2014;**16**(3):1658-1686. Third
- [4] Murtaza S. QoS Taxonomy towards wireless body area network solutions. International Journal of Application or Innovation in Engineering & Management (IJAIEEM). 2013;**2**(4)
- [5] ETSI. Universal Mobile Telecommunications System (UMTS); Multiplexing and Channel Coding (FDD). European Telecommunications Standards Institute, Technical Specification TS 125 212; 2011
- [6] ETSI. Universal Mobile Telecommunications System (UMTS); Multiplexing and Channel Coding (TDD). European Telecommunications Standards Institute, Technical Specification TS 125 222; 2010
- [7] ETSI. LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Multiplexing and Channel Coding. European Telecommunications Standards Institute, Technical Specification TS 136 212; 2013
- [8] Xing J, Zhu Y. A Survey on body area network. In: 5th International Conference on Wireless Communications, Networking and Mobile Computing, 2009. WiCom '09. pp. 1-4; 2009
- [9] Alain Glavieux, Channel Coding in Communication Networks: From Theory to Turbocodes. ISTE Ltd, Wiley; 2007
- [10] Semenov S, Krouk E. Modulation and Coding Techniques in Wireless Communications. John Wiley & Sons; 2011