Data Transmission Enhancement Using Optimal Coding Technique Over In-vivo Channel (Inter Body Communication)

Mohanad Ahmed Mezher, Muhammad Ilyas, Oguz Bayat, Qammer H. Abbasi Senior *Member, IEEE*

***Abstract*— One of the components of the advanced technologies has been characterized by some of the devices like the wireless in-vivo actuators and sensors. Besides, the in-vivo wireless medical devices, along with their related technologies, are representing the next-stage of such development and offering scalable and inexpensive solutions and wearable devices integration. Reducing the surgeries' invasiveness and offering non-stop health monitoring are provided via in-vivo WBAN devices. Also, the information of patients might be obtained over a large time period; also, physicians have the capability for performing highly-dependable analysis via using the concept of big data compared to depending on the recorded data in short hospital visits. Similarly, taken into account the huge fading regarding in-vivo channels due to the signal path passing through flesh, bones, skins, and blood guaranteeing that the received data is the same as the sent one, channel coding is considered as a solution for increasing the effectiveness and overcoming the wireless links suffering from Inter Symbol Interference (ISI). Besides, all simulations have been utilized with the use of 50 MHz bandwidth at Ultra-Wideband frequencies (3.10-10.60GHz). In the presented study, the data transmission performance over the in-vivo channel is improved by using optimal channel coding. In addition, the results show that the bit error rate performance associated with turbo codes provided significant improvement via enhancing BER and out-performing the polar and convolutional codes while it is used for data. Apart from convolutional code, other methods are performing close to each other, which becomes true when the information block length becomes large. The simulation in this study indicates that because of the dense structure regarding the human body, in-vivo channel provides less performance compared to the Rayleigh channel due to the path by which the signal is coming (Flesh, Skins, Blood, Bones, Muscles, and Fat).**

***Index Terms*— BER, Channel Coding, in-vivo, MAC, Polar, WBAN.**

I. Introduction

Wireless Body Area Networks (WBAN) are defined as wireless networks containing a set of very small biomedical nodes which are spread on the surface of the body, in the vicinity of a body, inside the body, or underneath the skin. WBANs, also referred to as Wireless Body Sensor Networks (WBSNs), are specified in IEEE 802.15.6 (IEEE, 2012), which is one of the specific types of Wireless Sensor Networks (WSNs). The only available standard for the WBANs is the IEEE 802.15.6; such standard is providing short range, reliable communications, and various rates of data for fitting many application types. Sensor nodes with very low power can check the body's essential physiological signs, while a few nodes have the ability to directly injecting a medicine dose in the body. Implantable Medical Devices (IDMs) and wearable devices were developed for sending real time readings regarding bio-signals of the body to a sink node or remote server. In addition, the monitored signals are considerably varying based on the type of the node, blood pressure, body temperature, heart rate, respiration measurement, and blood glucose level, Electromyogram (EMG) or Electrocardiogram (ECG). Monitoring such physiological parameters regarding people with chronic disease or elderly people offers extra freedom and flexibility to patients and rapid interventions when required. Now, there is a dramatic increase in the aging population all over the world [1]. The World Health Organization (WHO) states that [2] diabetes is going to be one of the major deaths causes by the year 2030, in which up to 15% concerting the total national health-care budget has been assigned to the care of diabetes. So, the overall spending of health systems, as well as the overloaded medical staff percentage, are anticipated to witness a significant increase. This encourages benefiting from the latest developments of WBANs for enhancing the life quality of patients, enhancing the procedures of monitoring, making precise intervention decisions, also reducing the entire costs of healthcare systems in addition to the extended operational hours of medical staff. The concerns of privacy and security have been defined as the major issues that face the global use of WBANs. Extremely sensitive and critical information is sent via sensor nodes. Compromises might not be just violating the privacy of patients, yet it might be threatening their lives. For example, in the case when a physician is provided with incorrect ECG sensor readings, it might result in inadequate intervention, which might harm the patient's life. Comparable, in the case when compromised or incorrect command is received via an automated insulin pump, insulin overdose might be injected by it into the bloodstream of the patient.

In the presented study, WBANs are examined from the perspective of signal connection quality such that the channel utilized over WBANs, for instance, in-vivo WBAN channel in terms of many channel coding for driving the optimum channel which combats the noise (fading).

II. WIRELESS BODY AREA NETWORK

The WBAN's significance in health-care systems encourages the process of standardization to allow the interoperability regarding various products from many vendors. In WBANs, MAC and PHY are defined via IEEE 802.15.6 [3]. The very difficult requirements related to the transceivers of WBAN, like power efficiency, forced IEEE Task Group6 (TG-6) to use 3 physical layer types for satisfying various application types [4]. Also, such physical layers might be reported in the following way [5]:

- Narrowband (NB) PHY: by which 7 bands of frequency with various rates of data are supported [6].
- Human body communication (HBC) PHY: supports a single low frequency band which is cantered at 21MHz, in which transmission of data has been carried out through the body of the patient with the use of the technology Electric Field Communication (EFC).
- Ultra-wideband (UWB) PHY: supporting 2 distinctive bands of frequency, high and low, with a distinctive number of channels, whereas possessing an identical bandwidth. In UWB PHY, the design offers durable implementations with low power consumption and complexity.

A. WBAN design properties

In IEEE 802.15.6, the overall design properties are [4] [7] [8]:

- Recoverable when there is a node or link failure.
- The capability for supporting wide range of data rates from tens of the Kbps and up to approximately 10Mbps for meeting all possible applications.
- Providing effective mechanisms of power consumption which source of low power to last for many years.
- Providing adequate communications with good latency and jitter values for non-medical as well as medical applications.
- Supporting the co-existence regarding on-body and in-body sensor nodes.
- Capable of supporting encryption, authentication, and integrity security mechanisms.
- Capable of addressing the node's removing and adding with fairly short time.
- Complying with SAR regulation.
- Supporting the operations in heterogeneous wireless environment.
- Supporting scalability that can reach 64 nodes.

In literature, there has been a little inconsistent information concerning WBAN properties. For example, some studies suggested that WBAN has a scalability of up to 256 nodes [7] [8], while IEEE 802.15.6 specifies it as a maximal value of 64 nodes. Thus, IEEE 802.15.6 information is used in the study for avoiding such inconsistencies.

B. WBAN topology

The Body Area Network (BAN) is defined via IEEE 802.15.6 as a logical set that contains a single hub and sensor nodes. It uses the star topology with 2 communication types, extended two-hop, and simple 1-hop star topology. In the latter, frames are exchanged directly by the nodes with the BAN hub, while in the former, a relay node has been provided, and the nodes can directly communicate with the hub or through a relay node. In BAN, nodes might be categorized according to their roles into Hub: a coordinator or sink node, which are unique names for same type of node. A hub is acting as a gateway to another external network or BAN. It is controlling the BAN while all external communications are going through it. Its resources are better in comparison to BAN's normal nodes. Relay node: a few nodes have the relay capabilities for relaying the messages from end-nodes to hub. Besides, they reside in the communication’s direct range of the hub. Relaying is needed in WBAN extended star topology. End-node: another WBAN node considered as end-nodes. They have been developed for performing certain tasks as well as exchanging messages directly with the hub in the case when they’re in direct range of communication or through relay nodes in the case when they’re out of direct range of communications.

III. BODY CHANNEL COMMUNICATION (IN-VIVO)

A lot of researches are focusing on the design of BANs due to the fact that wearable devices have been majorly utilized in entertainment and health-care industries. WBAN can be defined as a network that consists of sensor nodes, whereas the body sensor nodes are connected together and to a central hub. In terms of health-care aspect, the body state regarding individuals living with chronic illnesses, like diabetes, heart attacks, and asthma, must be controlled thoroughly. Applications of WBAN might warn the hospitals before a heart attack occurs to a patient. A patient with diabetes might be automatically injected with insulin via an on-body syringe. In WBANS, the IEEE 802.15.6 standard is supporting the next 3 physical layers: UWB, NB, and BCC. There are 3 main issues characterizing WBANs. Initially, the operating time regarding battery powered sensor devices is restricted by the battery life. The energy efficiency that is related to RF communication approaches, like Bluetooth and Zigbee, is poor. Even though a few researches reported that Zigbee has 3-years operating time [9], it has low data rates of less than 250kb/s. Secondly, high frequency bands of NB and UWB are suffering from the massive signal attenuations in human body channel because of body-shadowing effect [10–15]. Thirdly, the other wireless products of RF might be operating at an identical frequency band and result in interruption.

With regard to BCC, human body is used as medium of communication for enabling a collection of the on-body sensor nodes for communicating with the coordinator; therefore, it’s distinctive from the propagating approach of RF. In addition, the coordinator, like a smart-watch, is collecting all information via the human body. Then, the information that is gathered through body sensors might be presented to user's smart-phone or a remote server for more processing. When BCC is used, it can offer a few benefits. Firstly, since its operation includes a range of frequency less than 100MHz, BCC has fairly high data rates with the lowest energy/bit, in comparison to Bluetooth, Zigbee, and UWB. Secondly, the signal's path loss for BCC has been found less compared to that in the case of using the method of RF propagations. BCC is somewhat insensitive to human body motion [16].

Along with the RF communication development, a few low power RF approaches were suggested, like low power Bluetooth and NFC. The latter was designed for short term communications. Its consumption of power has been comparable to that associated with low energy Bluetooth, while its time of the setup is short compared to the time of common Bluetooth. Also, low energy Bluetooth has low consumption of power compared to common Bluetooth. Yet, NFC and Bluetooth were specified via many issues of security. Those problems were fairly less in the BCC since the signal is attenuated (largely) in the case when being released from human body [17]. Besides, the BCC security might be prompted more via utilizing human physiological measurements for the purpose of establishing a customized private key between network nodes [18]. Fially, with coordinator being a portable device on body, the BCC's energy efficiency has been found more sufficient compared to the energy efficiency of the NFC and Bluetooth.

The time-domain and path loss properties of capacitive BCC were modelled and evaluated in [19, 20]; also, the magnetic BCC [21] is offering fairly low path loss in comparison with the capacitive BCC. Yet, the variations of the coil resonance because of human body motion and using coil limits on-chip integrations were design obstacles for magnetic BCC [22]. In addition, on-off-keying (OOK) or frequency shift keying (FSK) modulation was used in BCC [23, 21]. The adaptive frequency hopping (AFH) method is suggested in Ref. [23]; with the AFH, each one of the channel statuses is monitored (uninterruptedly), and clean channel is going to be selected for adaptive frequency hopping. There is no less than 10dB enhancement for interference resistance that has been accomplished via 4 channels AFH method. Yet, there are 2 frequency synthesizers needed to reduce AFH hopping time. The timing mismatch and phase discontinuity represent the design obstacles for BCC receivers with 2 phase-locked loops (PLL).

Orthogonal frequency division multiplexing modulation (OFDM) BCC transceiver [24,25,22,26] works by modulating the data on several of the bands of the sub carrier frequencies; also, the OFDM BCC transceiver has the ability for achieving fairly high data rates with high spectrum efficiency characteristics (10MHz band-width for 29.1Mbps) [24]. Yet, the difficult design causes an increase in the chip area and power consumption. Frequency Selective Digital Transmission (FSDT) BCC operates by modulating data with a gain of coding, and it is provided in Refs. [27, 28, 29]. In addition, the code length related to encoded data is large compared to the original data for providing excellent reliability of data. Yet, the code rate is low in terms of utilizing redundant bits for protecting the original data. Apart from the RX pre-amplifier, almost all of the previously-published BCC transceivers can’t be realized as synthesizable digital intellectual property (IP).

IV. WIREKESS NANOSENSOR NETWORK

Wireless Nano-Sensor Networks (WNSNs) was suggested as development of nano-technology. Because of the massive application foreground of WNSN, many studies were conducted on them. Majorly, they are focusing on 2 aspects: the choice of communication approaches and the development of nanodevices. Nanonetwork has been originally suggested via [29]. [30], presenting a way for communicating through electromagnetic waves on nano-scale. A study conducted by Palacioss *etal*. reported that the special opto-electronic characteristics are presented in graphene, while its development is going to encourage the advancements of next generation electronic devices [31]. A study conducted by [32] suggested that future nano electromagnetic communications are going to operate in the tera-hertz band [33]. Their researches showed that the heights of the nano antenna were decreased to some hundred nanometers in comparison to traditional antenna heights, also the communications are requiring very high operating frequencies, nano antennas on the basis of graphene materials have the ability for overcoming such difficulties. In the same year, the concepts of WNSNs were formally suggested [34], while the terahertz wave became the highly demanded communication approach in terms of WNSN. Thus, many researchers started to focus on communication technologies of tera-hertz WNSN. Time Spread On-Off Keying (TS-OOK) has been suggested in [35]. It is a new approach of modulation. A femto-second pulse was utilized for representing bit "1", while a silent state was applied for representing bit "0" in TS-OOK. Besides, a MAC protocol referred to as Phlame has been suggested in [36] and utilized TS-OOK as its approach of modulation. For reducing interference throughout multi user access and maximizing probability of de-coding success, the protocol depends on the parameters of physical layer for adequately choosing the mechanism of communication and mechanism of channel coding for achieving optimization. In addition, a protocol of TCN MAC has been suggested in [37], which suggests time-series channel concept that is transmitting coded information in time series and supporting low-rate and energy-saving application cases. In [38], Chi *etal*. Have examined the relations between encoding length, transmission energy consumption, and encoding weight, while they suggested a low weights encoding system for reducing the transmission energy consumption of equipment. In a study conducted by [39], an energy model has been suggested for nanodevices' energy harvesting. It offered an approach for solving the issue of nanodevices' limited energy of the battery. In a study conducted by [40], a routing framework has been suggested, and a multihop routing has been developed. The routing and framework were depending on the transmission properties of terahertz waves. With a thorough WNSN study, a few scholars suggested using WNSN in human body for constructing in-vivo terahertz WNSNs (iWNSNs) [41] and suggested the potential system structure [42,43]. iWNSNs might be applied for monitoring, analyzing, and warning major human body data. For instance, in health monitoring systems, nano sensors being substituted in human body have the ability for monitoring tumor markers in real-time to assist high risk populations in conducting screening of tumor, aiding in the early tumor diagnoses, and in monitoring prognoses [44]. iWNSNs are of high importance in developing mobile medicine; thus, they turned into a new focus for many researches. Since that time, studies on in-vivo tera-hertz channel modelling were started. The fat absorption path loss at the tera-hertz band has been simulated in [45]. Based on results of analysis, in human tissues, a millimetre range of distance might be adequate for ensuring communications between the located nanodevices. Also, the attenuations regarding the electromagnetic waves in human skin have been examined via Abbasi *etal*. They developed a new channel model that focuses on the skin of humans at tera-hertz band [46]. A study conducted by Saleem *etal*. suggested a tera-hertz electro-magnetic model in blood [47]. The researchers identified that the red blood concentration doesn't affect the path loss in 0.10–0.60THz; therefore, it might be utilized as the optimum operating frequency. On the basis of such researches, Canovas-Carrasco *etal*. Have suggested a nano-network model used in hand [48]. Nader and Ebrahimi suggested developing nano-networks in lungs for monitoring the health of the lungs [49].

EM MODELLING OF THE HUMAN BODY

For the purpose of investigating in vivo wireless communication channel, precise body models, and the knowledge of the EM characteristics of tissue are vital [50]. The materials of the human autopsy and animal tissue were measured through the a range of frequency between 10Hz and 20GHz [51] and frequency-dependent dielectric characteristics of tissues have been modelled with the use of 4-pole Cole–Cole formula that has been represented as:

$$\varepsilon(\omega) = \varepsilon_\infty + \sum_{m=1}^{4} \frac{\Delta\varepsilon_m}{1 + (j\omega\tau_m)^{(1-a_m)}} + \frac{\sigma}{j\omega\varepsilon_0} \qquad (1)$$

ε_∞ represents permittivity of the body material at a frequency of tera-hertz, ε0 represents free-space permittivity, σ denotes ionic conductivity and εm, τm, am represent parameters of body material for every one of the anatomical regions. The anatomical region parameters have been given in [52], and EM characteristics, like the relative permittivity, conductivity, loss tangent, and penetration depth may be obtained by utilizing those parameters in (Fig1).

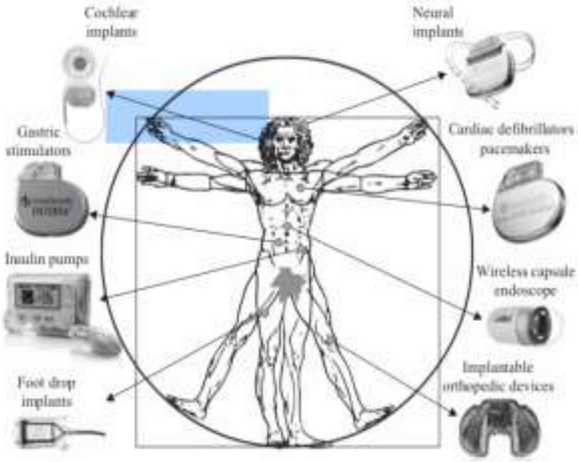

Fig.1 In vivo-WBAN.

A variety of the numerical and physical phantoms were designed for the purpose of simulating dielectric characteristics of tissues for the numerical and experimental investigations [53]. Those may be categorized as multi-layered, homogeneous, and heterogeneous phantom models. Even though the heterogeneous models present more realistic approximations to human body, designs of the physical heterogeneous phantoms has been rather complicated and conducting numerical experimentations on those models is quite complicated and resource intensive. However, the multi-layer or homogeneous models are not capable of differentiating the properties of the EM wave radiation for a variety of the anatomical areas. Figure2 clarifies examples of the heterogeneous numerical and physical phantoms.

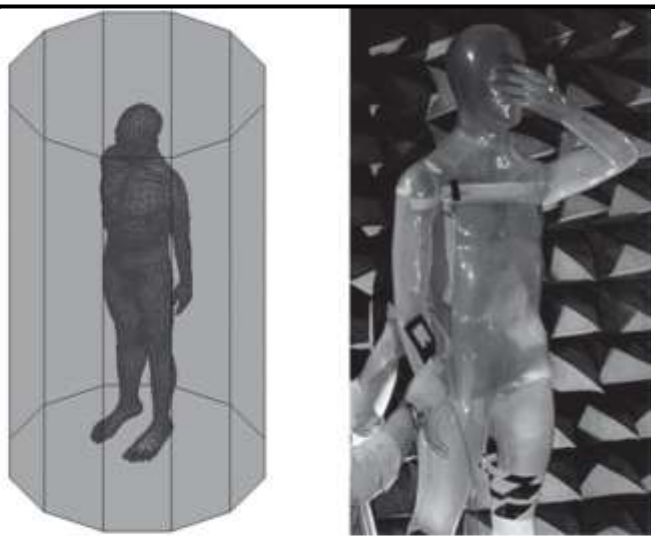

Fig2 Heterogeneous models of the human body: (a) HFSS® model [58] (b) physical phantom [53]. ©2016IEEE.

In general, the Analytical approaches are considered to be infeasible and need much simplification. Which is why, the numerical approaches are utilized for the characterization of in vivo wireless channel of communications. The numerical approaches give less complicated and suitable approximations to the Maxwell equation through a variety of the approaches, like the method of moments (MoM), uniform theory of diffraction (UTD), finite-difference time-domain method (FDTD), and finite element method (FEM). Every one of the methods has it's a certain set of advantages and disadvantages and have to be chosen according to the size and model of the simulation, available computational resources, operational frequency, and interested properties, like the specific absorption rate (SAR), power delay profile (PDP), and so on. A detailed comparison of those approaches can be found in [50] & [54].

It can be preferred that the numerical experimentations have to be confirmed with the real measurements. None-the-less, conducting experimentations on living humans is regulated quite carefully. Which is why, the anesthetized animals [55, 56] or the physical phantoms, which allow the repeatability of the results of the measurement [53, 57] are typically utilized for the experimental investigations. Moreover, the 1st such research that has been performed on human cadaver has been reported in [59].CHANNEL CODING TECHNIQUES

To make the transmission of message more safe and reliable over a noisy medium, redundancy is always added to the data before transmission. At the receiver end, the redundancy helps the decoder to reconstruct the original data sequence in the existence of the interference and noise. Adding redundancy is called channel coding. The set of coded words generated by the channel encoder are known as channel codes. We always call channel codes as error control codes or error correcting codes. Coding theory plays a pivotal role in the modern digital technology and the good ideas from the coding theory have a significant impact in practical applications.

A. Convolutional Codes

Convolutional codes, invented by Elas [60], are a class of powerful codes which are widely used in applications such as satellite communications, cellular mobile, digital video broadcasting and a variety of wireless standards. These codes make a big step in the theory of coding because they are the first class of codes well suited for probabilistic decoding.

Compared with hard decision decoding which reduces the capacity significantly at the decoder, probabilistic decoding avoids the loss by using the channel observation directly during the decoding operations [61]. Convolutional codes possess very beautiful trellis-graph structure and this pleasing feature enables the introduction of various practical and efficient decoding algorithms [62]. One important decoding algorithm which boosted the vast spread of convolutional codes in practice was Viterbi algorithm [63]. Bitwise Maximum a Posteriori (MAP) decoder has been considered, which has been deployed the algorithm of the BCJR [64]. For the information bit u_l at time l, received the code word y, and decoded bit ^u_l, ul Log-Likelihood Ratio (LLR) can be represented as:

$$L_{u_l} = \log\left(\frac{p\{u_l = 0|y\}}{p\{u_l = 1|y\}}\right). \quad (2)$$

As a result of Trellis structure of the convolution codes, those probability cases may be expressed in the following equation [65]

$$L_{u_l} = \log\left(\frac{\Sigma_{U_0} P\{s_{l-1} = s', s_l = s, y\}}{\Sigma_{U_1} P\{s_{l-1} = s', s_l = s, y\}}\right). \quad (3)$$

Where s_l represents state at the time l, U_0 represents the group of the pairs (s0; s) for state transition s_0! s in the case where $u_l = 0$, and U_1 represents group of the pairs (s_0; s) for transition in the case where $u_l = 1$. Utilizing BCJR algorithm, those possibilities may be factorized into

$$P\{s_{l-1} = s', s_l = s, y\} = \alpha_{1-1}(s')\gamma_l(s', s)\beta_l(s). \quad (4)$$

Where l (s_0; s) represents Branch Metric. Probabilities _l, & _l have been recursively computed [4]. Processing that in log-domain, the final LLR expression has been represented as [65]

$$L_{u_l} = \max{}^*[\alpha_{1-1}(s') + \gamma_l(s', s) + \beta_l(s)] - \max{}^*[\alpha_{1-1}(s') + \gamma_l(s', s) + \beta_l(s)]$$

The max_ function can be represented as:

$$\max{}^*(a, b) = \max(a, b) + \log\left(1 + e^{-|a-b|}\right) \quad (5)$$

B. Turbo Codes

Typically, the turbo codes are often constructed with parallel the concatenation of 2 recursive convolutional encoders that have been separated with Interleaver. Then, the task is designing the polynomials of the code for individual encoders, and for using a suitable interleaver. In addition to that, turbo decoder includes 2 decoders of Soft-Input Soft-Ouput (SISO). These decoders have been similar to convolutional decoder, except a few modifications. Systematic stream and 1st parity stream have been fed to 1st decoder, whereas a systematic stream interleaved version, and 2nd parity stream have been fed to 2nd one. The 1st de-coder begins, and rather than the generation of final LLR, it performs the generation of cleared up version, which is referred to as the extrinsic information. Which is interleaved, and sent to 2nd de-coder. It is responsible for performing the de-coding that has higher reliability in comparison with a case where it has no additional data from 1st decoder. Similarly, it produces extrinsic information for 1st de-coder, and rather than interleaving, it carries out the de-interleaving, and then, an iteration has been finished. On following iteration, 1st decoder begins similarly like before, however, it now has extrinsic information from 2nd de-coder, which is why, an output of higher reliability has been computed. Decoding is continued until satisfying a stopping criterion, or maximal number of the iterations was reached. following any iteration, total LLR has been computed as [65].

$$L_{u_1(total)} = L_{u_1(channel)} + L^{e(2\to1)}_{s_{Deint(l)}} + L^{e(1\to2)}_{s_l} \quad (6)$$

$L_{u_1(channel)}$ represents the LLR of the channel, Le(1!2) u_l represents extrinsic information that has been sent from 1st decoder to 2nd decoder. $Deint(l)$ represents DE interleaved u_l position. In the case where interleaver has been appropriately designed, after that it would seem like if the interleaved and original streams have been uncorrelated. Which has been important for turbo gain, due to the fact that it will not be likely that original stream and the interleaved counter-part undergo same transmission, encoding, and/or de-coding conditions.

C. Polar Codes

The polar codes are the ones that are produced due to the transformation of the channel polarization [66]. The concept is that through the combining and splitting of the channel, and at an infinite length, channels (positions of the bits) will result in the polarization in a sense that some channels will have quite high reliability, and the remaining will not be reliable. In the case where information bits have only been put in reliable channels, and fore-known bits (typically 0s) have been put to unreliable channels, after that, the capacity of the channel may be accomplished. The polar code construction task is finding this set of most unreliable of the channels that is typically referred to as Frozen Set. There is a number of the algorithms of the construction [67], with various degrees of the complexity, and as a result of non-universal behaviour of the polar codes, these algorithms need a parameter that has been referred to as Design-SNR. None-the-less, there are universal constructions as well. Even though the polar codes may be de-coded through the Belief Propagation, standard algorithm of decoding is the Successive Cancellation (SC), which may be directly found from encoder, where XOR, and the connection nodes are characterized through f & g probabilistic nodes, respectively as can be seen in the following equations:

$$f(a, b) = \log\left(\frac{e^{a+b} + 1}{e^a + e^b}\right),$$

$$g(a, b, s) = (-1)^s a + b,$$

s represents Partial Summation that can be defined as summation of bits that have been previously decoded, which participate in current node g. Approximation may be applied to f, which yields to:

$$f(a,b) = sign(a)sign(b)\min(|a|,|b|). \qquad (7)$$

The efficiency may be enhanced, in the case where the List Decoder [30] has been utilized, which yielded List-SC decoder. For every one of the decoded bits, the 2 likelihoods of being decoded as 0 or 1 have been taken under consideration. Which has been accomplished through the splitting of current path of decoding to 2 new paths, one of them for every one of the possibilities. The total amount of the possible cases across decoding tree has been restricted by the size of the List. Following the end of the de-coding, the path that has the minimal Path Metric has been selected [68].

V. MODEL FABRICATION

In vivo channel is established to allow communications over WBAN network. Connections through in vivo is perfect for inter body communication where the body is said to be perfect conductor. Signal transmitted from the Nano sensors that lied situated the body (underneath) is suffering from attenuation due to existence of fading resources such as fats and bones. However, no mobility effects are monitored in WBAN. The challenges and topology of WBAN are illustrated above.

However, signal connectivity is major concern where the impact of fading resources are encountered. Channel coding is one of the noteworthy approaches for signal immunity enhancement. Noise and fading impact is being suppressed using suitable signal encryption. In this paper, three kinds of channel coding were applied individually on signal transmitted over in vivo channel. Turbo code, Polar code and Turbo code are being utilized for this purpose. The overall system model is demonstrated in Figure 3.

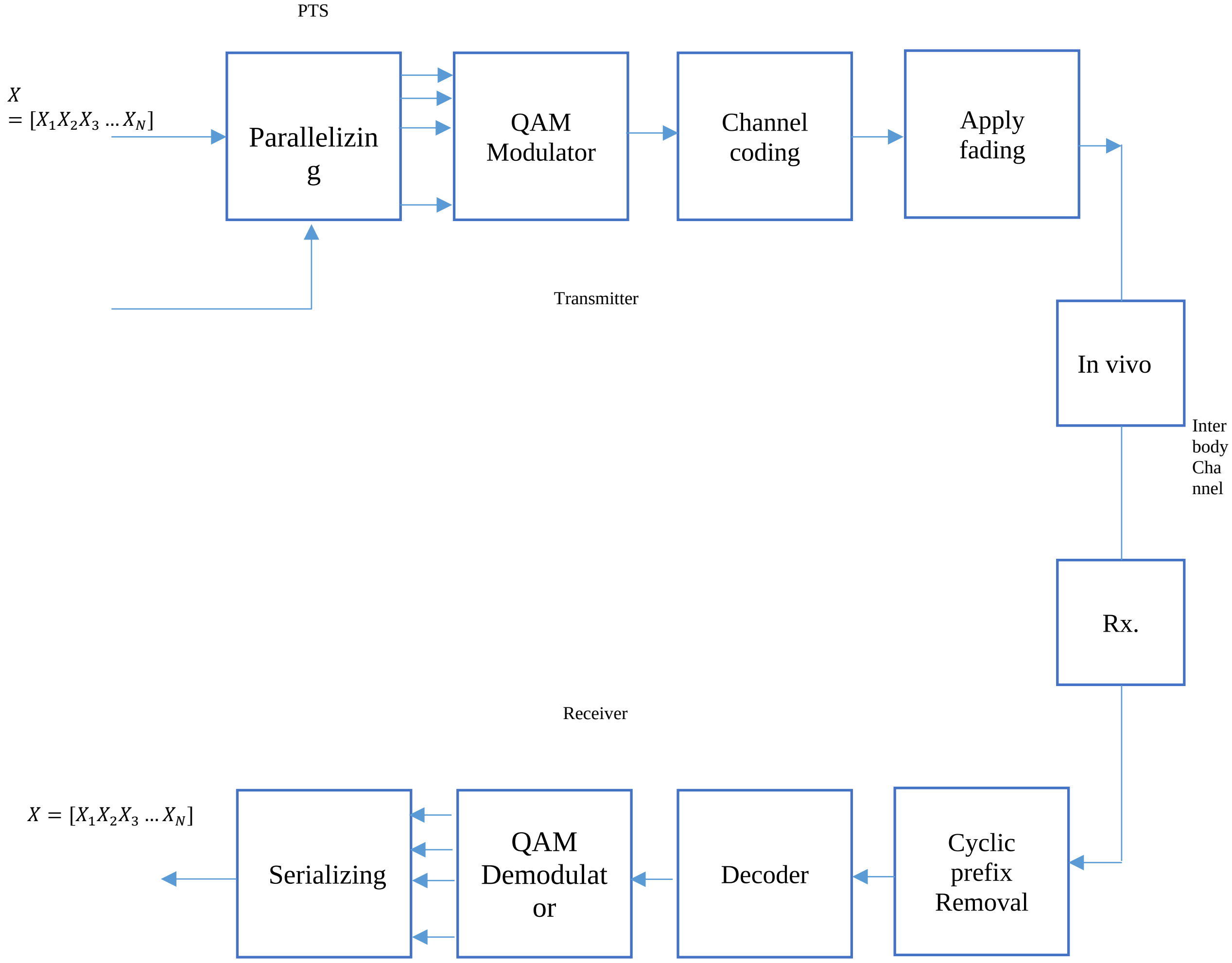

Fig.3. Proposed System Modelling.

TABLE I
SIMULATED SYSTEM PARAMETERS SUMMARY.

Parameter	Value
modulation scheme	QAM
Number of samples (Turbo)	10000
Code rate (Convolutional)	2/3
Encoder type (Turbo)	Viterbi
Polar code packet length	160
Number of samples (turbo)	10000
Metric	BER

A. Results and discussions

Using Turbo encoder with the specifications listed in Table 1 and the model outlined in Figure 3, signal is transmitted over the said in vivo channel. Viterbi encoder is used then for recovering the transmitted signal, bit error rate is compared as with Turbo coding and without Turbo coding (merely QAM modulation). The results are demonstrated in Figure 4. From the other hand, experiment is repeated by replacing the Turbo code by convolutional code and polar code respectively. The bit error rate results are demonstrated in Figure 5 and 6 respectively. In Figure 7 we can clearly notice as a result of the dense structure of a human body how the in-vivo channel giving less performance than Rayleigh channel because of the path that the signal comes from (Flesh, Bones, Blood, Fat and Muscles).

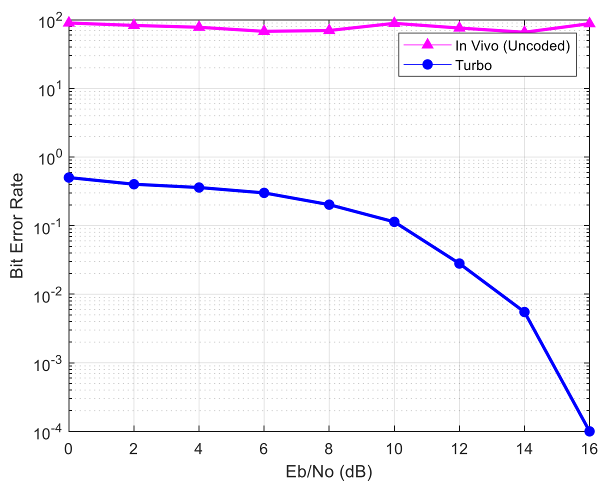

Fig.4. Turbo codes impact on the signal transmission over in vivo channel.

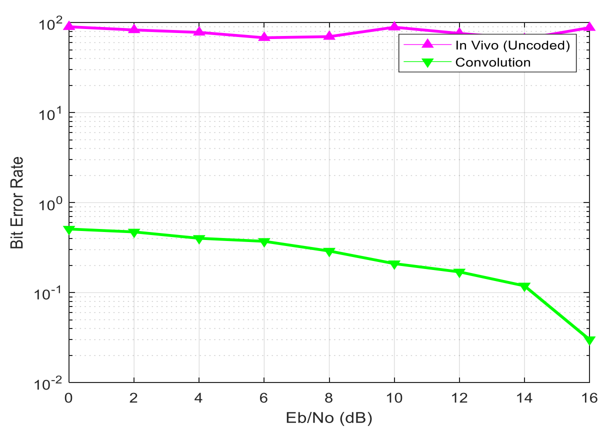

Fig.5. Convolutional codes impact on the signal transmission over in vivo channel.

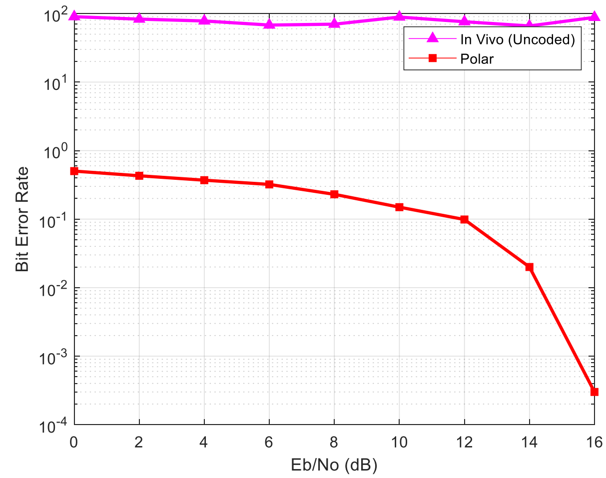

Fig.6. Polar codes impact on the signal transmission over in vivo channel.

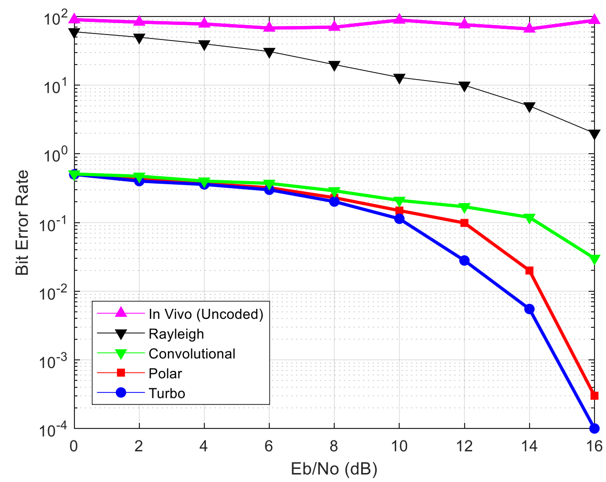

Fig.7. Comparison between different impacts of all proposed channel coding and Rayleigh channel on signal transmission over in vivo channel.

It was observed that Turbo code shown explicit performance on fading impact over in vivo channel as compared to convolutional and polar. Knowing that with increased signal to noise ratio (Eb/No) more bitts are successful transmitted after using of Turbo coding as compared with no-coding case. Polar code could managed to preserve approximately same throughput all over the Eb/No cases. Convolutional code is found biggest degrader of the transmission performance as very few bits are managed to be transmitted successfully while it being used. Table II shows a BER result comparison on Eb/No (dB) =16 between In-vivo, Rayleigh, Convolutional, Polar and Turbo codes simultaneously.

TABLE II
BER PERFORMANCE COMPARISON ON Eb/No = 16.

Parameter	**BER**
In-Vivo (Uncoded)	88
Rayleigh	2
Convolutional codes	0.0301
Polar Codes	0.0023
Turbo Codes	0.0001

VI. CONCLUSION

In the present study we've presented the bit error rate of data transmission enhancement with the use of the optimal channel coding technique. Furthermore; Due to the in-vivo channel fading and complicated human body structure, the Turbo code is clearly shown that its data transmission performance outperformed convolutional and polar codes applied on in-vivo radio channel at the UWB frequency values (3.10-10.60GHz) with an exception of convolution code, the rest of the methods perform close to one another, which becomes more true the larger the length of the information block becomes. Additionally, from the simulations in this paper we can clearly notice as a result of dense structure of human body how the in-vivo channel giving less performance than Rayleigh channel because of the path that the signal comes from (Skins, Flesh, Bones, Blood, Fat and Muscles).

VII. REFERENCES

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