$32^{nd}$ *URSI GASS, Montreal, 19-26 August 2017*

# Maximum Allowable Data Throughput and Error Performance of On-Body Medical Body Area Networks (MBANs)

Nada El-Maradny*(1), Heba Shaban(1), and Mohamad Abou-Al-Nasr(1)
(1) Arab Academy for Science, Technology & Maritime Transport (AASTMT), Abu Kir Campus, P.O. Box 1029, Alexandria, Egypt, http://www.aast.edu

## Abstract

Medical Body Area Network (MBAN) is a narrowband body area network (NB-BAN), with 2360 – 2400 MHz allocated band. This paper studies the bit-error-rate (BER) performance and maximum allowable data throughput in the on-body scenario of the 2360 – 2390 MHz band, allocated for indoor applications, for different node positions and different activities including standing, walking and running. Numerical results show that the achieved bit energy to noise energy ratio ranges from 11 – 38.5 dB for the wrist to chest on-body link (first scenario) depending on the activity, and from 12.2 – 16.9 dB for the back to chest link (second scenario). The achieved data throughput is 0.097- 218.29 Mbps for the first scenario, and 44.57- 165.59 Mbps for the second scenario, also assuming different activities. The back to chest link achieves a better BER performance and data throughput as compared to the wrist to chest link in the walking and running activities due to the high movement of the transmit node in the latter case, which results in a highly dense environment.

## 1. Introduction

Due to the increasing awareness of healthcare among people, it is very important to find new and effective ways to monitor patients with better quality. This is achieved by using communication technologies that achieve good maximum data rates with minimal amount of errors [1], [2]. Generally, wireless body area networks (WBANs) are networks that consist of actuators and/or a number of sensors implanted inside the human body, placed on the human body and/or around it. The IEEE 802.15 task group 6 [1] is responsible for the standardization of body area networks (BANs). One of the main applications of BANs is healthcare, and typically they have to work with a very low power, which leads to small range of coverage.

There are different types of WBANs based on the position of placement of the sensors in or outside the body, and the frequency band that it can operate at. According to the IEEE 802.15.6, there are three main scenarios for WBAN channels namely, in-body (implant-to-on-body), on-body (from one point on the body surface to another), and off-body (from one point on the body to an external point) [1]. The IEEE 802.15.6 WBAN has also divided the radio propagation methods to three physical layers, which are narrowband (NB) layer, human body communication (HBC) layer, and ultra wide band (UWB) layer. NB is the best band for medical applications because as the frequency decreases, the signal suffers less attenuation from the human body. Furthermore, the small bandwidth leads to minimal multipath, which in turn decreases the possible inter symbol interference (ISI) [1].

Medical Body Area Network (MBAN) is a body area network specifically for medical applications. MBAN was first adopted in May 24, 2012. The Federal Communications Commission (FCC) allocated the MBAN spectrum from 2360 MHz to 2400 MHz [3]. This band is used for medical diagnostic and therapeutic purposes only. MBAN is considered as a narrowband BAN (NB-BAN). It is very promising as it has all the advantages of the ordinary BAN modules like low power transmitters and high accuracy. Until now, there have been few studies which addressed the MBAN, and to the best of our knowledge, no study considered the bit error rate (BER) performance or maximum allowable data throughput.

In this paper, we study the BER performance and data throughput of on-body MBANs assuming two different transmitter and receiver node positions and different activities namely, standing, walking and running. The organization of this paper is as follows. Section 2 gives an overview of MBANs, and Section 3 introduces the channel model. Then, Section 4 studies the BER performance and data throughput with numerical results in the on-body to on-body communication (CM3) channel. Finally, Section 5 provides the conclusion.

## 2. Overview of MBAN

According to the FCC [3], MBAN is allocated in the band between 2360 MHz to 2400 MHz with a maximum bandwidth of 5 MHz. The MBAN works as a secondary basis, which means that this band has primary users that may cause interference like the aeronautical mobile telemetry (AMT). To overcome this problem this band is divided into two smaller bands, one of them from 2360-2390 MHz, and the other from 2390-2400 MHz [3].

The 2360-2390 MHz band is used only for indoor applications. The applications in this band need registration and control from the coordinator to access it. For this band, the transmitter (Tx) power should not exceed 1 mW.

As for the 2390-2400 MHz band, it is used anywhere including indoor and outdoor applications, and those applications do not need any registration or control from any coordinator. For the latter band, the Tx power should not exceed 20 mW for outdoor applications.

## 3. MBAN Channel Model

According to IEEE 802.15.6 standardization, the 2360-2400 MHz is operating in different scenarios with two channel models [4] namely, channel model 3 (CM3) and channel model 4 (CM4). CM3 represents the on-body to on-body communication channel, where the Tx and Rx are placed on different parts of the human body. Whereas, CM4 represents on-body-to-off-body communication channel, where the Tx is placed on the human body and the Rx is on an external point. Each of those channel models can be divided to line-of-sight (LOS) and non-line-of-sight (NLOS) communications. Figure 1 shows the different types of MBAN channel models.

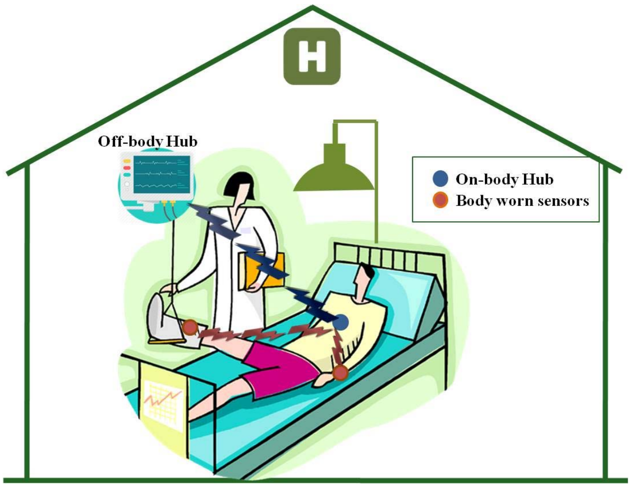



**Figure 1.** Possible communication links for Medical Body Area Networks (MBANs)

In this paper we investigate two different node locations assuming the on-body channel model CM3. There have been some studies presented in the literature, where the fading distribution of actual data was compared to the most commonly known fading distributions like normal, Rayleigh, Lognormal, Nakagami-*m*, Gamma, and Weibull distributions. The actual measured data was taken from a Tx and a Rx attached to different body parts with different separation distances [5]. It was found that the perfect fit distribution changed among the different scenarios. As typically, the channel changes with the angles between the transmitter and the receiver, and the placement of the nodes on the human body. The channel was also found to differ with different activities of the human body. Activities like standing, walking and running were investigated in the literature for different node positions. Among all the distributions, it was found that the lognormal distribution represents the best fit all environments.

In general, it is considered as the best accurate distribution because of many factors that lead to the attenuation of the signal like, reflection, diffraction and energy absorption. According to the central theory, the equivalent distribution of these many factors will be normal in the log domain [4].

The lognormal distribution is given by:

$$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} e^{\frac{-(\ln(x)-\mu)^2}{2\sigma^2}} \quad (1)$$

where $\mu$ is the mean and $\sigma$ is the standard deviation of the lognormal distribution.

For CM3, the mean and standard deviation vary according to the place of the Rx and Tx on the human body, and type of activity [6].

In the next section we consider two scenarios for Tx and Rx node positions in the CM3 channel model to study the BER and data throughput assuming different body activities and various distances.

## 4. BER and Data Throughput Performance

In this section, the BER and data throughput performance in the CM3 communication channel of MBAN is studied for the 2360-2390 MHz band. We assume binary phase shift keying (BPSK) modulation. Numerical results are based on Monte-Carlo simulations using MATLAB. The channel information for the different scenarios was obtained from the literature based on actual on-body measurements at the band of frequency under investigation.

**Table 1.** The channel parameters for the studied scenarios [6]

| Tx location | Activity | Channel Parameters |
|---|---|---|
| Right Wrist | Standing | $\mu = -0.071$, $\sigma = 0.03$ |
| Right Wrist | Walking | $\mu = -1.46$, $\sigma = 0.60$ |
| Right Wrist | Running | $\mu = -1.80$, $\sigma = 0.86$ |
| Back | Standing | $\mu = -0.25$, $\sigma = 0.10$ |
| Back | Walking | $\mu = -0.54$, $\sigma = 0.21$ |
| Back | Running | $\mu = -0.60$, $\sigma = 0.24$ |

The BER is calculated from a lognormal fading channel that has the Tx on the right wrist and on the back of the human body and the Rx on the chest. Table 1 summarizes the values of the mean and standard deviation of the lognormal distribution for both scenarios under investigation for different human body activities [6] based on actual measurements. Figure 2 shows the placement of the Tx and Rx nodes on the human body for the two studied scenarios assuming the chest as a central hub that receives data from the right wrist or the back.

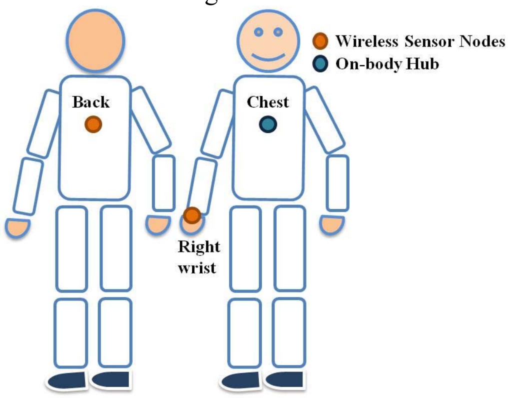



**Figure 2.** The placement of the transmitters and the receiver for the cases studied.

Maximum data throughput is then studied for the two cases assuming different body activities according to equation given in [2]:

$$R_{b,max} = \frac{1}{E_b} P_t (\frac{\lambda_c}{4\pi d})^n \quad (2)$$

where $P_t$ is the transmitter power, which is equal to 1 mW. It was selected based on the maximum allowable radiated power as mentioned in an earlier section, $f_c$= 2390 MHz, which is the maximum carrier frequency, $\lambda_c = 3 \times 10^8 / f_c$ is the wavelength, $d$ is the distance in meter between Tx to Rx, $E_b$ is the bit energy at the target BER, and $n$ is the path loss exponent, which is equal to 2. The target BER was chosen to 1e-3.

Figure 3 shows the BER performance for a BPSK modulated data sent from the right wrist to the chest (central hub) assuming different body activities. As can be seen, there are big differences in the achieved $E_b/N_0$ depending on the activity. These values range from 11 – 38.5 dB at the target BER.

The corresponding maximum data throughputs are shown in Figures 4 (a) and (b). The change in the achieved $E_b/N_0$ is also reflected on the data throughputs, which range from 0.097 - 218.29 Mbps for running and walking activities, respectively.

The second scenario considered, is the Tx node placed at the back and the Rx node is at the chest (central hub). Figure 5 shows the BER performance of the standing, walking, and running activities for this scenario. The case here is different from the changes in the achieved $E_b/N_0$ point of view. In this scenario, the achieved $E_b/N_0$ ranges from 12.2 – 16.9 dB. The reason for this slight change, from the authors' opinion, is due to that both Tx and Rx nodes are relatively in slower motion as compared to the wrist to chest case. This also justifies the reason for the major change in the walking and running activities.

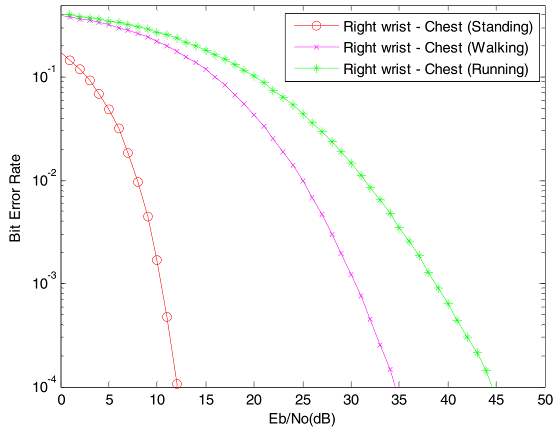
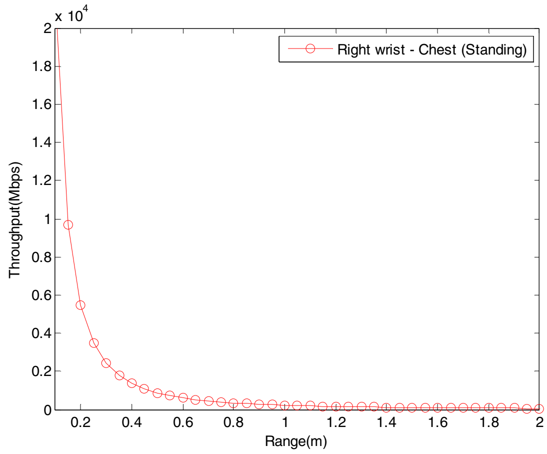
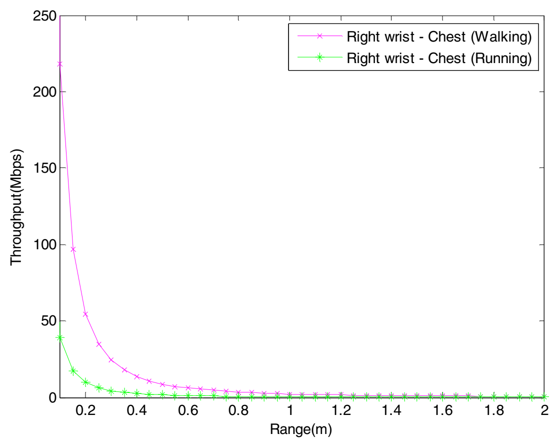



**Figure 3.** BER performance of MBAN in CM3 assuming link between right wrist and chest for standing, walking and running activities




(a)




(b)

**Figure 4.** Data throughput of right wrist to chest link of MBAN in CM3 channel at a target BER = 1e-3 (a) Standing activity and (b) Walking and running activities

Whereas, in the standing activity, the wrist to chest link achieves better results compared to the back to chest link. As the latter link is a NLOS link as compared to a LOS link for the wrist to chest scenario. However, in the walking and running activates, the effect of body movement dominates, and highly affects the achieved $E_b/N_o$ and data throughput. So, this causes the range of change to decrease for the back to chest link, and they exhibit a relatively slower movement compared to the wrist to chest scenario. Figure 6 shows the corresponding maximum data throughput for the back to chest link. In this scenario data throughput ranges from 44.57 Mbps to 165. 59 Mbps which is relatively higher than the wrist to chest link scenario. Table 2 summarizes the achieved $E_b/N_o$ assuming different body activities for the two investigated scenarios. Also, Table 3 summarizes the corresponding data throughput achieved for different human body activities for CM3 communication channel at distance = 1 m.

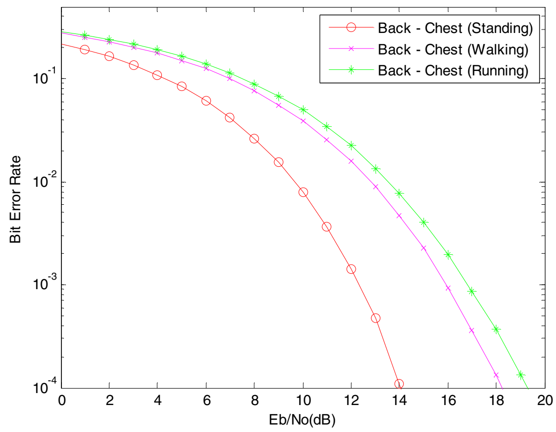



**Figure 5.** BER performance of MBAN in CM3 channel assuming link between back and chest link for standing, walking and running activities

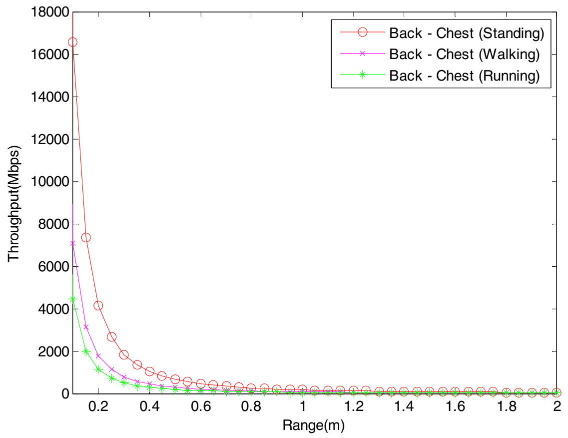



**Figure 6.** Data throughput of back to chest link of MBAN in CM3 channel assuming standing, walking and running activities at target BER = 1e-3.

**Table 2.** Achieved $E_b/N_o$ for the right wrist–chest and back-chest links for standing, walking and running activities at BER 1e-3

| Activity | $E_b/N_o$ for Right Wrist to Chest | $E_b/N_o$ for Back to Chest |
|---|---|---|
| Standing | 11 dB | 12.2 dB |
| Walking | 31 dB | 15.9 dB |
| Running | 38.5 dB | 16.9 dB |

**Table 3.** Achieved $R_{b,max}$ for the right wrist–chest and back-chest links for standing, walking and running activities at BER 1e-3

| Activity | $R_{b,max}$ for Right Wrist to Chest | $R_{b,max}$ for Back to Chest |
|---|---|---|
| Standing | 218.29 Mbps | 165.59 Mbps |
| Walking | 0.55 Mbps | 70.64 Mbps |
| Running | 0.097 Mbps | 44.57 Mbps |

## 5. Conclusion

This paper studied the BER performance and data throughput of on-body MBANs assuming two different node placements, and different body activities including standing, walking, and running. Numerical results showed that at the standing activity, the on-body MBAN achieves a very high data rate for the two considered scenarios which ranged from 165.59 – 218.2 Mbps. It was also shown that increasing the human body movement, decreases the achievable data rate. Finally, it was shown that the back Tx position outperformed the wrist Tx node position in the walking and running activities.

## 6. References

1. K. S. Kwak, S. Ullah and N. Ullah, "An overview of IEEE 802.15.6 standard," *3rd International Symposium on Applied Sciences in Biomedical and Communication Technologies (ISABEL 2010),* 07 Nov - 10 Nov 2010, pp. 1-6, 10.1109/ISABEL.2010.5702867.

2. H. Shaban and V. Tech, "A Framework for the power consumption and BER performance of ultra-low power wireless wearable healthcare and human locomotion tracking systems via UWB radios," *2009 IEEE International Symposium on Signal Processing and Information Technology (ISSPIT)*, 14-17 Dec. 2009, pp. 322–327, 10.1109/ISSPIT.2009.5407535.

3. Federal Communications Commission, "Medical Body Area Networks," May 2015, DA 15-547, pp. 4627 – 4632.

4. K. Yazdandoost, K. Sayrafian-Pour, "Channel model for body area network (BAN)," *IEEE p802.15-08-0780-12-0006*, November 2010.

5. D. Smith, D. Miniutti, T. Lamahewa, L. Hanlen, "Propagation models for body-area networks: a survey and new outlook," *IEEE Antennas Propagation. Magazine,* **55**, 5, February 2010, pp. 97–117, doi:10.1109/MAP.2013.6735479.

6. D. Smith, Et.all, "Statistical Characterization of the Dynamic Narrowband Body Area Channel," *1st International Symposium on Applied Sciences in Biomedical and Communication Technologies*, 25-28 Oct. 2008, doi:10.11094712618.