Behavior of IEEE 802.15.4 Channel Models on Implant Body Area Network

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Abstract. With recent developments in the wireless networking technologies Wireless Body Area Networks (WBANs) have enabled the scope for building cost-effective and non-invasive health monitoring system. Electromagnetic wave propagation and characterization of the physical layer are important to design a suitable channel model for WBANs. Most of the radios used in WBANs are based on IEEE 802.15.4 compliant chip set. In this paper, we modified channel model of IEEE 802.15.4 in NS-2 to study the performance of channel model CM1 (implant to implant) and channel model CM2 (between an implant device and an on or out-of body device) with different sets of simulation experiments. The simulation results successfully confirmed that the modified IEEE 802.15.4 protocol could be used in WBANs.

Keywords: Implant WBANs · Channel model · NS-2 implementation

1 Introduction

Wireless communication is now considered as a never-ending growing technology. With the advances in the miniaturization of electronic devices, especially the sizes of the microcontroller, the wireless chip, intelligent biosensors, longer-life battery remote health monitoring has become an important research issue now-a-days. At the end of 2007, the IEEE launched a new task group of IEEE 802.15.6 [1] known as Wireless Body Area Network (WBAN) [1, 2] to provide short range low power and highly reliable wireless communications for use in close proximity to or inside the human body. Depending on whether it operates outside or inside a human body, WBANs can be divided into wearable WBANs and implant WBANs [3]. While wearable WBANs are considered for both medical and non-medical applications, implant WBANs are mainly considered for medical and healthcare applications. In implant WBANs the characteristics of the radio propagation channel are mainly influenced by body tissues, whereas, in wearable WBANs radio signals propagate through air. The human body is a challenging medium for radio wave transmission. It is partially conductive and consists of materials of different dielectric constants, thickness, and characteristic

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impedance. Radio propagation through a human body depends on losses caused by power absorption, radiation pattern destruction and central frequency shift [7]. The power budget [15] of a WBAN node is affected by the antenna used on such a node. The radiation pattern of an antenna will also influence the link delay budget. The link budget depends on the radio propagation conditions and packet transmission and reception techniques. As per federal communications commission (FCC) regulations, implanted medical devices operate in 402–405 MHz frequency band. In this paper we analyze performance of implant communication channel models for 402–405 MHz band with NS-2 simulations [6].

This paper is organized as follows. Section 2 provides background and related works Sect. 3 focuses on link budget calculations. Section 4 investigates the impact of IEEE 802.15.4 channel models' effects on implant WBANs through various simulations. Finally, this paper is concluded in Sect. 5.

2 Backgrounds and Related Work

Radio propagation models are used to predict the received signal power of a packet. When a packet is received with the signal power below the threshold it is dropped by the node. The major factors which influence the radio propagation are path loss and fading. Pathloss describes the loss in power as the radio signal propagates in space. It is caused by the dissipation of the power radiated by the transmitter and also by the propagation channel. On the other hand, fading occurs because of the obstacles between the transmitter and the receiver which attenuate the signal strength or due to signals taking multiple paths to reach the receiver.

In recent years a number of channel models have been proposed in the literature [8–12] especially for implant WBANs. In [9], the authors have applied the compressed sensing theory as a new sampling method to multipath fading channels to minimize packet loss and bit error rate. In [10] authors have considered statistical path loss model for MICS channels. They constructed a visualization environment in order to characterize RF propagation from medical implants.

The channel modeling subgroup [8] has released the possible communication links for WBANs based on the location of the sensor nodes which is shown in Fig. 1 [8]. The scenarios are grouped into classes that can be represented by the same Channel Models

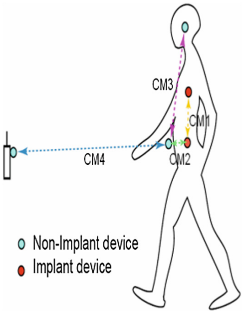

Fig. 1. Communication links for WBAN.

(CM). CM1 represents the communication link between implant devices and CM2 is between an implant device and an on or out-of body device. CM3 and CM4 are related to wearable devices.

3 Link Budget

Link budget is an important property in a wireless network in order to understand the successful packet reception rate. The link budget depends on the radio propagation conditions and packet transmission and reception techniques. Research shows that the induced pathloss in a channel near the human body is higher than free space, with the path loss exponent ranging from 2.18 to 3.3 and higher [11]. It is concluded that the path loss in WBANs is very high that, compared to the free space propagation, an additional 30–35 dB at small distances (i.e. 140 ~ 150 mm) is noticed [2]. With the help of article [4], the total path loss between a WBAN transmitter and receiver can be calculated by using Eqs. (1) and (2):

$$PL(d) = PL(d_0) + 10n \log 10\left(\frac{d}{d_0}\right) + S \tag{1}$$

$$S \sim N(0, \sigma_s) \tag{2}$$

where PL(d0) is the path loss at a reference distance d0 (50 mm). d is the distance between transmitter and receiver, n is the path loss exponent, and S is loss due to shadow fading. Shadowing effects are modelled by a random variable with a normal distribution with zero mean and standard deviation i.e., $N(0, \sigma_s^2)$.

The parameters corresponding to CM1 and CM2 are shown in the Tables 1 and 2. Details of the model derivation can be found in [4].

Table 1. Parameters for CM1 - implant to implant for 402–405 MHz.

Implant to implant	$PL(d_0)(dB)$	n	$\sigma_s(dB)$
Deep tissue	35.04	6.26	8.18
Near surface	40.94	4.99	9.05

Table 2. Parameters for CM2: implant to body surface for 402–405 MHz.

Implant to body surface	$PL(d_0)(dB)$	n	$\sigma_s(dB)$
Deep tissue	47.14	4.26	7.85
Near surface	49.81	4.22	6.81

The calculation of path loss is very important to determine the minimum reception power required by a receiver so that the packet can be received successfully. As shown in [15] the relationship between minimum reception power PRx(min) and path loss can be expressed as the following equation:

$$P_{Rx}(\min) = P_{Tx} - PL(d) \tag{3}$$

Here PTx, is the transmission power. Both PTx and path loss PL(d) are expressed in dB. This minimum reception power will depend on the receiver's sensitivity which is related to SNR. The value of SNR can be calculated by the following Eq. (4):

$$SNR = 10\,\log\left(\frac{P_{Rx}}{Noise}\right) \tag{4}$$

The minimum receiver sensitivity numbers for the highest data rate at each operating frequency band are listed in Table 3.

Table 3. Receiver sensitivity numbers

Frequency band (MHz)	Information data rate (kbps)	Minimum sensitivity (dBm)
402–405	75.9	−98
	151.8	−95
	303.6	−92
	455.4	−86

The power level at which the packet was received at the MAC [1, 2] layer is compared with the receiving threshold and the carrier-sense threshold. If the power level falls below the carrier sense threshold, the packet is discarded as noise. If the received power level is above the carrier sense threshold but below the receive threshold, the packet is marked as a packet in error before being passed to the MAC layer. Otherwise, the packet is simply handed up to the MAC layer.

4 Simulation Results

In this section we investigate the performance of a beacon-enabled IEEE 802.15.4 for in-body communications. Normally IEEE 802.15.4 protocol is not suitable for implant WBANs in its unmodified form. We have tested IEEE 802.15.4 protocol [16] with the correct channel model for implant WBANs to understand its performance. We implemented the IEEE 802.15.6 communication link channel model CM1 (implant to implant) and channel model CM2 (between an implant device and an on or out-of body device) in NS-2 and changed the power parameters of IEEE 802.15.4 so that it can be compatible for IEEE 802.15.6. The wireless physical layer parameters are considered according to a low-power Zarlink MICS Radio Platform, ZL70102 [17]. This radio transceiver operates in the 402–405 MHz band with an optimum transmission power of −16 dBm. We used the CM1 and CM2 propagation models throughout the simulation. We used multiple nodes (up to 7), which were connected with a coordinator in a star topology. The transport agent is UDP protocol, CBR traffic is considered as the traffic pattern.

To characterize the path loss and received signal strength within an implant to implant and implant to body surface area, we analysed 9 different distances ranging from 50 mm to 250 mm in our experiment. We have considered only two nodes: one transmitter and one receiver in our simulation. In Figs. 3 and 4 we characterize the result of average path loss for CM1 and CM2 as a function of transmitter-receiver separation. The deep tissue implant scenarios consider endoscopy capsule applications for upper stomach (95 mm below body surface) and lower stomach (118 mm below body surface) [13]. The near-surface scenarios include applications such as Implantable Cardioverter-Defibrillator and Pacemaker.

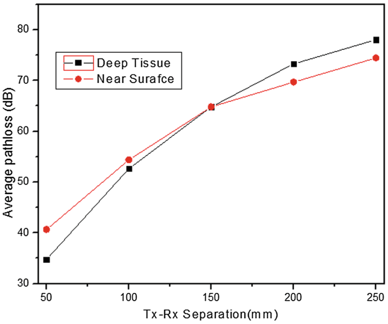

Fig. 2. Pathloss for CM1.

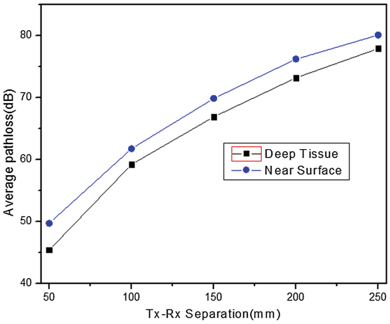

Fig. 3. Pathloss for CM2.

We represent the average path loss for CM1 in Fig. 2. for both type of scenarios with the increase of transmitter- receiver separation. Although the average path loss has increased over the transmitter-receiver separation but after 140 mm distance we see that path loss for deep tissue is larger than for the body surface scenario. Again, in Fig. 3, we show the path loss for CM2 for both of the cases where value of path loss for deep tissue scenario is always higher than near surface scenario in any point. From these figures this is evident that path loss for deep tissue scenario in CM1 is always lower than CM2 up to 200 mm and after that pathloss for CM2 slightly increased over CM1.

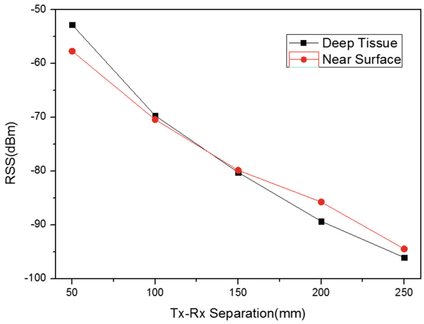

Fig. 4. RSS for CM1

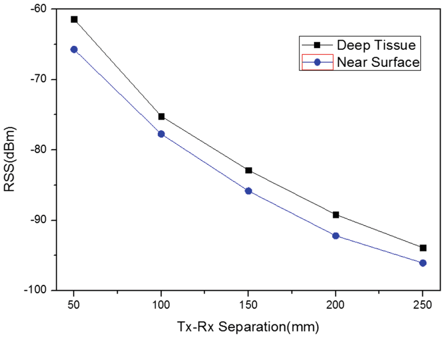

Fig. 5. RSS for CM2

In Figs. 4 and 5 we show the corresponding Received Signal Strength (RSS) for the same transmitter-receiver separation considered in Figs. 2 and 3. The maximum transmission power (−16 dBm) is considered for both channel models. We can see that in 250 mm distance the RSS value becomes marginal with the RxThresh's value (−95 dBm).

From the above figures, it is evident that the path loss has increased with the separation of the transmitter and receiver with a corresponding decrease in the RSS which was expected. The simulated path loss graphs shown in Figs. 2 and 3 are very identical with those who used MATLAB and other tools in literature [5, 14]. This dependency of RSS on the path loss is well established in the well-known channel modelling schemes and has been verified for a few threshold values of RSS mentioned in the draft.

5 Conclusion and Future Work

The main objective of this paper was to investigate IEEE 802.15.4's suitability for WBANs implant applications. The main contributions of this paper are as follows: We analyzed the performance of IEEE 802.15.4 MAC with the help of proper in-body communication channel models using NS-2 simulations. IEEE 802.15.6 communication link channel model CM1 and channel model CM2 have been implemented in NS-2. Due to space limitations we could not include all the simulation results. In our future work we want to elaborate more on implementation details of NS-2 module. We also want to apply this channel model to investigate various packet level performances such as end to end delay, energy consumption, packet delivery ratio etc. for low and heavily congested scenarios.

References

1. IEEE standard for local and metropolitan area networks part 15.6: wireless body area networks. In: IEEE Std 802.15.6-2012, pp. 1–271, 29 Feb 2012
2. Latre, B., Braem, B., Moerman, I., Blondia, C., Demeester, P.: A survey on wireless body area networks. Wireless Netw. **17**(1), 1–18 (2010). doi:10.1007/s11276-010-0252-4. Springer, Netherlands
3. Ullah, S., Higgins, H., Shen, B., Kwak, K.S.: On the implant communication and MAC protocols for WBAN. Int. J. Commun. Syst. **23**, 982–999 (2010)
4. Hagedorn, J., Terrill, J., Yang, W., Sayrafian, K., Yazdandoost, K., Kohno, R.: MICS channel characteristics; preliminary results. In: IEEE 802.15-08-0351-00-0006, September 2008
5. Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LRWPANs), IEEE 802.15.4-2003 Std
6. The network simulator - ns-2. http://www.isi.edu/nsnam/ns/
7. Yazdandoost, K.Y.: A radio channel model for in-body wireless communications. In: Wireless Mobile Communication and Healthcare: Second International ICST Conference, MobiHealth 2011, Kos Island, Greece, 5–7 October 2011

8. Yazdandoost, K., et al.: Channel model for body area network (BAN). In: IEEE 802.15.6 Technical Contribution, Document ID:15-08-0780-10-0006-tg6- Channel-model, July 2010
9. Balouchestani, M., Raahemifar, K., Krishnan, S.: New channel model for wireless body area network with compressed sensing theory. Wireless Sens. Syst. IET **3**(2), 85–92 (2013)
10. Ntouni, G.D., Lioumpas, A.S., Nikita, K.S.: Reliable and energy-efficient communications for wireless biomedical implant systems. Biomed. Health Inf. IEEE J. **18**(6), 1848–1856 (2014)
11. Li, H.-B., Kohno, R.: Body area network and its standardization at IEEE 802.15.BAN. In: István, F., Bitó, J., Bakki, P. (eds.) Advances in Mobile and Wireless Communications, pp. 223–238. Springer, Heidelberg (2008). doi:10.1007/978-3-540-79041-9_12
12. Kim, T.H., Oh, J.H., Yoo, J.H., Pack, J.K.: Channel modelling of WBAN system and human exposure due to WPT. In: Asia-Pacific Symposium on Electromagnetic Compatibility (APEMC), pp. 29–32 (2010)
13. Sayrafian-Poue, K., Yang, W.-B., Hagedorn, J., Terrill, J.: A statistical path loss model for medical implant communication channels. In: 2009 IEEE 20th International Symposium on Personal, Indoor and Mobile Radio Communication (PIMRC) (2009)
14. Yang, Y., Shen, D., Xie, Y.: A review of the implant channel modelling for WBAN. In: NSWCTC 2011, April 2011
15. Khan, J.Y., Yuce, M.R.: Wireless body area network (WBAN) for medical applications. In: New Developments in Biomedical Engineering, January 2010
16. Samsung/CUNY: Ns2 simulator for 802.15.4. http://www-ee.ccny.cuny.edu/zheng/pub
17. Xiao, Z., He, C., Jiang, L.: Slot-based model for IEEE 802.15.4 MAC with sleep mechanism. IEEE Commun. Lett. **14**(2), 154–156 (2010)