Hindawi Publishing Corporation
EURASIP Journal on Wireless Communications and Networking
Volume 2009, Article ID 479512, 7 pages
doi:10.1155/2009/479512

Research Article

On PHY and MAC Performance in Body Sensor Networks

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Received 26 January 2009; Accepted 14 May 2009

Recommended by Naveen Chilamkurti

This paper presents an empirical investigation on the performance of body implant communication using radio frequency (RF) technology. In body implant communication, the electrical properties of the body influence the signal propagation in several ways. We use a Perspex body model (30 cm diameter, 80 cm height and 0.5 cm thickness) filled with a liquid that mimics the electrical properties of the basic body tissues. This model is used to observe the effects of body tissue on the RF communication. We observe best performance at 3cm depth inside the liquid. We further present a simulation study of several low-power MAC protocols for an on-body sensor network and discuss the derived results. Also, the traditional preamble-based TMDA protocol is extended towards a beacon-based TDMA protocol in order to avoid preamble collision and to ensure low-power communication.

1. Introduction

Body Sensor Networks (BSNs) are becoming increasingly important for sporting activities, unobtrusive healthcare systems, and members of military services. They are considered as a key technology to prevent the occurrence of myocardial infarction, monitor series of events or any other life critical condition, and are used for interactive gaming and entertainment applications. Traditionally, many body functions were rarely monitored and separated by a considerable period of time. Holter monitors were used to collect cardio rhythm disturbances for offline processing but they were not used to provide real-time feedback [1]. For instance, transient abnormalities are sometimes hard to capture, for example, many cardiac diseases are episodic such as transient surges in blood pressure, paroxysmal arrhythmias or induced episodes of myocardial ischemia and their timing cannot be predicted [2]. BSNs allow continuous monitoring of patients under natural physiological states without constraining their normal activities. They are used to develop a smart and affordable health care system and can be a part of diagnostic procedure, maintenance of chronic condition, and supervised recovery from a surgical procedure. In-body sensor networks are used to restore control over paralyzed limbs, enable bladder and bowel muscle control, and maintain regular heart rhythm as well as many other functions. In-body applications include monitoring and program changes for pacemakers and implantable cardiac defibrillators, control of bladder function, and restoration of limb movement. These applications may require continuous or occasional one- or two-way transmission. Some applications require a battery where the current drain must be low, so as not to reduce the working life of the implant function.

The development of an unobtrusive ambulatory BSN induces a number of issues and challenges such as interoperability, scalability, Quality of Service (QoS), and low-power communication protocols. A number of ongoing projects such as CodeBlue, MobiHealth, and iSIM have contributed to establish a proactive and unobtrusive BSN system [3–5]. A system architecture presented in [6] performs real time analysis of sensor's data, provides real time feedback to the user, and forwards the user's information to a telemedicine server. UbiMon aims to develop a smart and affordable health care system [7]. MIT Media Lab is developing MIThril that gives a complete insight of human-machine interface [8] HIT focuses on quality interfaces and innovative wearable computers [9]. IEEE 802.15.6 aims to provide power-efficient in-body and on-body wireless communication standards for medical and nonmedical applications [10]. NASA is developing a wearable physiological monitoring system for astronauts called LifeGuard system [11]. ETRI focuses on the development of a low-power MAC protocol for a BSN [12].

In this paper, we study the performance of radio frequency (RF) communication to an implant and present a simulation study of several low-power MAC protocols for an on-body sensor network. The rest of the paper is categorized into four sections. Section 2 presents a discussion on antenna design for an in-body sensor network. Section 3 investigates the performance of RF communication between an implanted device and a base station. Section 4 provides a simulation study of several low-power MAC protocols for an on-body sensor network. This section also discusses the potential issues and challenges in the development of in-body and on-body MAC protocols. Section 5 concludes our work.

2. Antenna Design for an In-Body Sensor Network

The band designated for in-body communication is Medical Implant Communication System (MICS) band, and is around 403 MHz. Its wavelength in space is 744 mm, so a half wave dipole is 372 mm. Clearly it is not possible to include an antenna of such dimensions in a human body [13]. These constraints make the available size much smaller than the optimum.

The electrical properties of the body affect the propagation in several ways. First, the high dielectric constant increases the electrical length of E-field antennas such as a dipole. Second, body tissue, such as muscle, is partly conductive and absorbs some of the signal but it also acts as a parasitic radiator. This is significant when the physical antenna is much smaller than the optimum size. Typical dielectric constant (ε_r), conductivity (ρ), and characteristic impedance $Z_0(\Omega)$ properties of muscle and fat are shown in Table 1.

Table 1: Body electrical properties [13].

Frequency	Muscle			Fat		
	(ε_r)	$\rho(\mathrm{S.m^{-1}})$	$Z_0(\Omega)$	(ε_r)	$\rho(\mathrm{S.m^{-1}})$	$Z_0(\Omega)$
100	66.2	0.73	31.6	12.7	0.07	92.4
400	58	0.82	43.7	11.6	0.08	108
900	56	0.97	48.2	11.3	0.11	111

2.1. Dipole Antenna. For a dipole of length 10 mm, at 403 MHz, the radiation resistance is 45 mΩ in air. The electrical length of the dipole is increased when surrounded by a material of high dielectric constant such as the body.

2.2. Loop Antenna. For a loop of 10 mm diameter, the area is 78.5 mm^2. This results in a radiation resistance of 626 $\mu\Omega$. However, the loop acts as a magnetic dipole that produces more intense magnetic field than that of a dipole. The loop is of use within the body as the magnetic field is less affected by the body tissue compared to a dipole or patch and it can be more readily integrated into existing structures.

2.3. Patch Antenna. A patch antenna can be integrated into the surface of an implant. Without requiring much additional volume, the ideal patch has dimensions as shown in Figure 1 and acts as a $\lambda/2$ parallel-plate transmission line with impedance inversely proportional to the width.

The radiation occurs at the edges of the patch, as shown in Figure 2. For in-body use, a full size patch is not an option. An electrically small patch has a low real-valued impedance and therefore impaired performance compared to the ideal one. There are several other options for antenna such as Planar Inverted-F Antenna (PIFA), loaded PIFA, the bow tie, spiral and trailing wire. These antennas have properties that make them better suited for certain applications.

2.4. Impedance Measurement. The impedances of the patch and dipole are affected considerably by the surrounded body tissue. The doctor determines the position of the implant within the body. It may move within the body after fitting. Each body has a different shape with different proportions of fat and muscle that may change with time. This means that a definite measurement of the antenna impedance is of little value. Measuring it immersed in a body phantom and makes an approximation of impedance liquid [14]. Using this impedance, the antenna-matching network can be designed with the provision of software controlled trimming as can be done with variable capacitors integrated into the transceiver. The trimming routine should be run on each power up or at regular intervals to maintain optimum performance.

3. In-Body RF Communication

The requirements of RF communication for on-body and in-body sensor networks are different due to their corresponding channel characteristics. In an on-body sensor network, signals often propagate across the body surface. This propagation may be a combination of surface waves, creeping waves, diffracted waves, scattered waves, and free space propagation depending on the antenna position [15]. In an in-body sensor network, the signals propagate inside the human body where the electrical properties of a body affect the signal propagation. All existing formulas to design free-air communication are used for on-body communication systems. However, it is very difficult to calculate the performance of in-body communication systems [16]. To compound the design challenges, the location of the implant is also variable. During surgery the implant is placed in the best position to perform its primary function, with a little consideration for the wireless performance.

In-body RF communication uses MICS band that has a maximum Effective Radiated Power (ERP) of 25 μW (-16 dBm) in air. The Industrial Scientific and Medical (ISM, 2.4–2.5 GHz) band is used to transmit a wakeup signal to an implant with a power of 100 mW (+20 dBm). Once a wakeup signal is received at the implant, it powers up its circuit as given in Figure 3.

3.1. Results. It is possible to simulate the performance of RF implant using 3D simulation software but this is time consuming and is not valuable. We use a Perspex body model

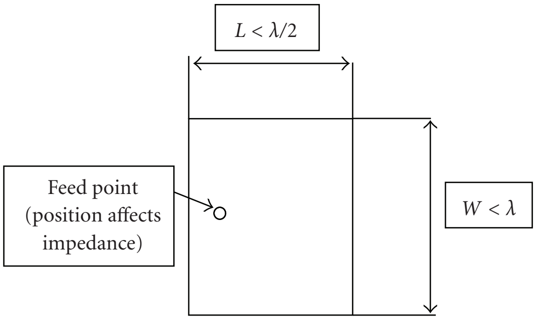

Figure 1: Patch antenna plan view.

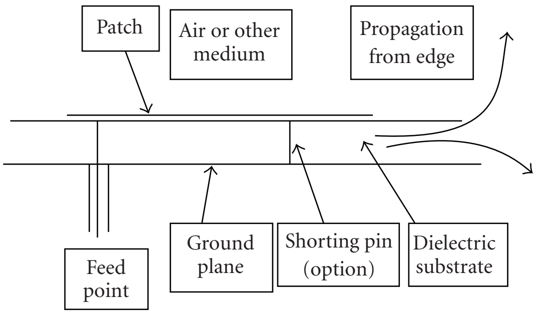

Figure 2: Patch antenna side view.

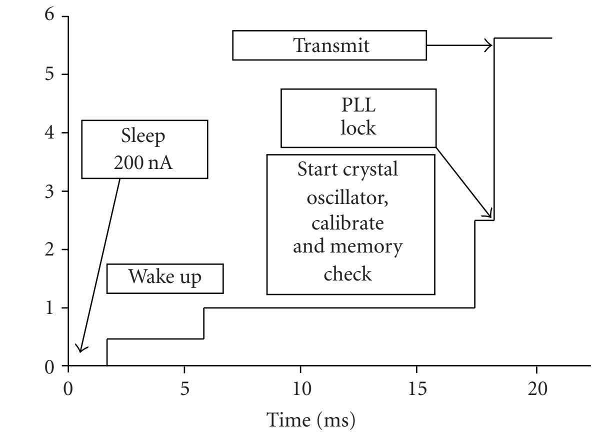

Figure 3: Implant wakeup sequence and current consumption.

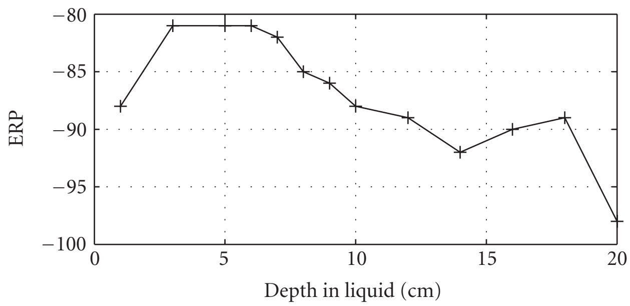

Figure 4: ERP versus Depth in liquid.

filled with a liquid that mimics the electrical properties of the basic body tissue. The liquid contains water, sodium chloride, sugar, and Hydroxyl Ethyl Cellulose (HEC), which mimics muscle or brain tissue for the frequency range from 100 MHz to 1 GHz as given in Table 2. The Perspex body is defined in standard ETSI [17]. It is a 76 cm high and has a 30 cm diameter. The Perspex tank that we use has a 30 cm diameter, an 80 cm height, and a 0.5 cm wall thickness.

Figure 4 shows the ERP from an implant immersed in a tank of body phantom liquid. The implant is transmitting a Continuous Wave (CW) signal, where the measurement is performed with a log periodic antenna and a spectrum analyzer. The environment is an anechoic chamber with a tank and a log periodic antenna separated by 3 m. Using the antenna parameters and the measured signal power, the ERP is calculated. Clearly, the ERP increases from a 1 cm depth to a maximum between 2 cm and 7 cm, thereafter it decreases. The gradual increase is due to the simulated body acting as a parasitic antenna. The implant patch is very small compared to the air wavelength and its performance is improved by contact with tissue—holding it in a hand improves the measured signal strength by about 10 dB over performance in air. There are possibilities, that is, the liquid acts as a parasitic antenna and also attenuates the signal. The reduction in signal level with depth is expected as the liquid absorbs the signal.

The implant is immersed into a tank of body phantom liquid at various depths. The base-station antenna is a dipole with a distance to the tank of 3 m. With the implant transmitting a CW signal, the Remote Signal Level Indication (RSSI) of the base-station is recorded. RSSI is a relative measure of signal strength with each point equivalent to approximately 2.5 dB. As with the signal level measurement, the RSSI increases from the initial value, then decreases with depth as illustrated in Figure 5.

Table 2: Body tissue recipes [17].

Ingredient	% of weight (100 MHz to 1 GHz)	% of weight (1.5 MHz to 2.5 GHz)
Water	52.4	45.3
Sugar	45.0	54.3
Salt (NaCl)	1.5	0.0
HEC	1.1	0.4

In Figure 6, data is exchanged between the implant and the base station. When data is exchanged between the implant and the base-station, error correction is used to ensure that reliable data is obtained. If an error is detected then it is corrected by invoking an Error Correction Code (ECC). The infrequent ECC invocation shows better link quality. As with the signal level and RSSI, the figure further shows an improvement in the link at a depth between 3 cm and 5 cm. We conclude that the implant reveals best performance at a depth of 3 cm and not close to the skin surface.

4. MAC Protocol for BSNs

MAC protocols are classified into contention-based and TDMA-based protocols. In contention-based protocols, nodes contend for the channel using CSMA mechanism. If the channel is busy, the node defers its transmission until the channel becomes idle. These protocols are scalable with no strict time synchronization constraint. However, they incur significant protocol overhead. In TDMA-based protocols, the channel is divided into time slots of fixed duration. These slots are assigned to the nodes and each node transmits during its own slot period. These protocols are energy conserving protocols. Because the duty cycle of radio is reduced and there is no contention, idle listening, and overhearing problem but these protocols require frequent synchronization.

Li and Tan proposed a novel TDMA protocol for an on-body sensor network that exploits the biosignal features to perform TDMA synchronization and improves the energy efficiency [18]. Other protocols like WASP, CICADA, and BSN-MAC are proposed in [19–21]. The performance of a nonbeacon IEEE 802.15.4 is investigated in [22], where the authors considered low upload/download rates, mostly per hour. Furthermore, the data transmission is based on periodic intervals that limit the performance to certain applications. There is no reliable support for on-demand and emergency traffic.

The BSN traffic requires sophisticated low-power techniques to ensure safe and reliable operations. Existing MAC protocols such as SMAC [23], TMAC [24], IEEE 802.15.4 [25], and WiseMAC [26] give limited answers to the heterogeneous traffic. The in-body nodes do not urge synchronized and periodic wakeup patterns due to unpredicted medical events. Medical data usually needs high priority and reliability than nonmedical data. In case of emergency events, the nodes should access the channel in less than one second [27]. The IEEE 802.15.4 can be considered for certain on-body applications but it does not achieve the required power level of in-body nodes. For critical and noncritical medical traffic, the IEEE 802.15.4 has several power consumption and QoS issues [28–31]. Also, this standard operates in 2.4 GHz band, which allows the possibilities for interference from other devices such as IEEE 802.11 and microwave. Table 3 shows the effects of microwave oven on the XBee remote module [32]. When the microwave oven is ON, the packet success rate and the standard deviation are degraded to 96.85% and 3.22%, respectively. However, there is no loss when the XBee modules are taken 2 meters away from the microwave oven.

Dave et al. studied the energy efficiency and QoS performance of IEEE 802.15.4 and IEEE 802.11e [33] MAC protocols under two generic applications: a wave-form real time stream and a real-time parameter measurement stream [34]. Table 4 shows the packet delivery ratio and the Power (in mW) for both applications. The *AC_BE* and *AC_VO* represent the access categories voice and best-effort in the IEEE 802.11e.

In a beacon-enabled IEEE 802.15.4, nodes use slotted CSMA/CA to contend for the channel. The use of CSMA/CA provides reliable solution for an on-body sensor network but it has several limitations for an in-body sensor network. The main reason is that the path loss inside the human body due to tissue heating is much higher than in the free space. The in-body nodes cannot perform Clear Channel Assessment (CCA) in a favorable way. Zhen et al. analyzed the performance of CCA by in-body and on-body nodes [35]. Figure 7 shows that for a given −85 dBm CCA threshold, the on-body nodes cannot see the activity of in-body nodes when they are away at 3 m distance from the surface of the body.

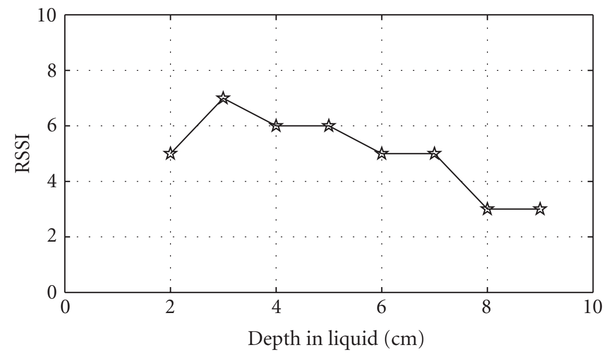

Figure 5: RSSI versus Depth in liquid.

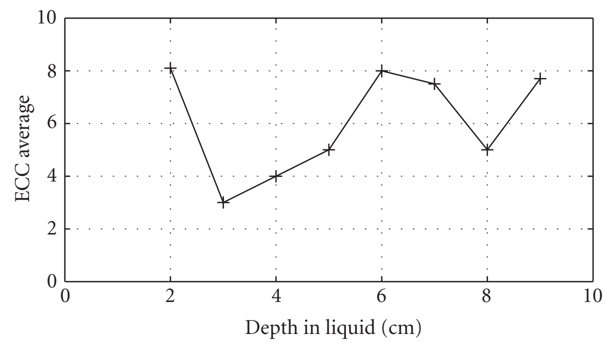

Figure 6: ECC invocation versus Depth in liquid.

Table 3: Coexistence test results between IEEE 802.15.4 and microwave oven.

Microwave status	Packet success rate	
	Mean	Std.
ON	96.85%	3.22%
OFF	100%	0%

Table 4: Packet delivery ratio and power (in mW).

Sensor nodes		IEEE 802.15.4	IEEE 802.11e (AC_BE)	IEEE 802.11e (AC_VO)
Packet delivery ratio	Wave-form	100%	100%	100%
	Parameter	99.77%	100%	100%
Power (mW)	Wave-form	1.82	4.01	3.57
	Parameter	0.26	2.88	2.77

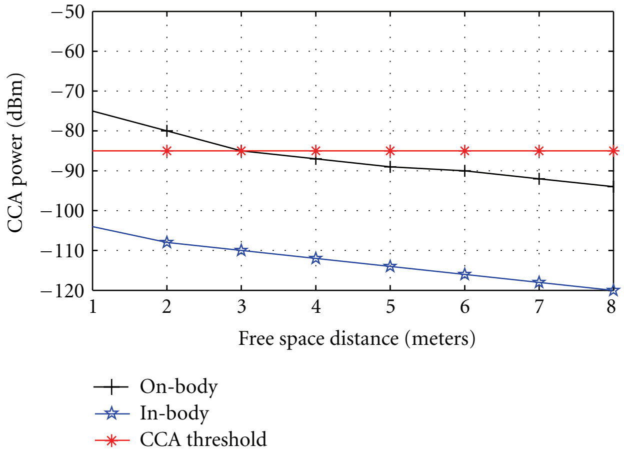

Figure 7: CCA in on-body and in-body sensor networks.

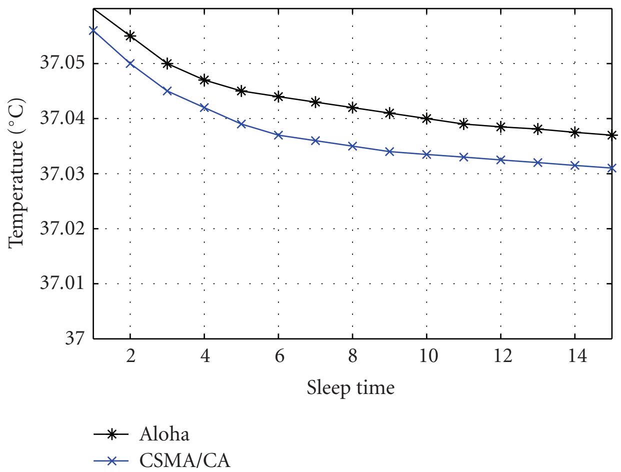

Figure 8: Saturated temperature using aloha and CSMA/CA.

The in-body nodes (MAC) should also consider the thermal influence caused by the electromagnetic wave exposure and circuit heat. Nagamine and Kohno discussed the thermal influence of the in-body nodes using different MAC protocols in [36]. Figure 8 shows the temperature of a node when ALOHA and CSMA/CA are used.

4.1. Simulation Environment. We present the performance analysis of Preamble-Based TDMA (PB-TDMA) [37], beacon-enabled IEEE 802.15.4, and S-MAC protocols for an on-body sensor network using NS-2 [38]. In case of PB-TDMA and S-MAC, the wireless physical parameters are considered according to low-power Nordic nRF2401 transceiver [39]. This radio transceiver operates in the 2.4–2.5 GHz band with an optimum transmission power of −5 dBm. However, in case of IEEE 802.15.4, Chipcon CC2420 radio interface is considered [40]. We use the shadowing propagation model throughout the simulations. The parameters in the shadowing propagation model are adjusted according to [41]. We consider 6 nodes firmly placed on the human body. The nodes are connected to the coordinator in a star topology. The initial node energy is 5 Joules. The data rate of the nodes is heterogeneous. The simulation area is 1 × 1 meter and each node generates Constant Bit Rate (CBR) traffic. The packet size is 134 bytes. The transport agent is User Datagram Protocol (UDP). For the performance analysis of IEEE 802.15.4, we use part of the results discussed in [42].

4.2. Results. In Figure 9, we present the packet delivery ratio for different transmission powers. In a beacon-enabled mode, the packet delivery ratio of IEEE 802.15.4 for all transmission powers is almost 100% with tolerable power consumption. PB-TDMA gives 90% value for −5 dBm, while S-MAC gives only 5% value.

Figure 10 considers PB-TDMA protocol to show the residual energy at ECG node for different transmission powers. There is a minor change in the residual energy for three transmission powers. This further concludes that reducing the transmission power does not ensure low-power

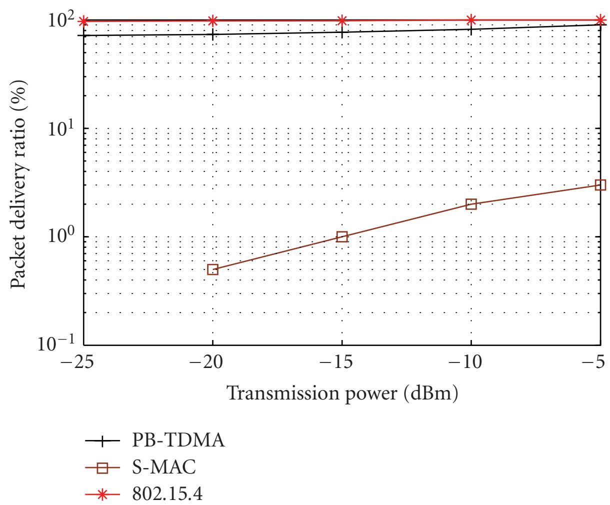

Figure 9: Packet delivery ratio.

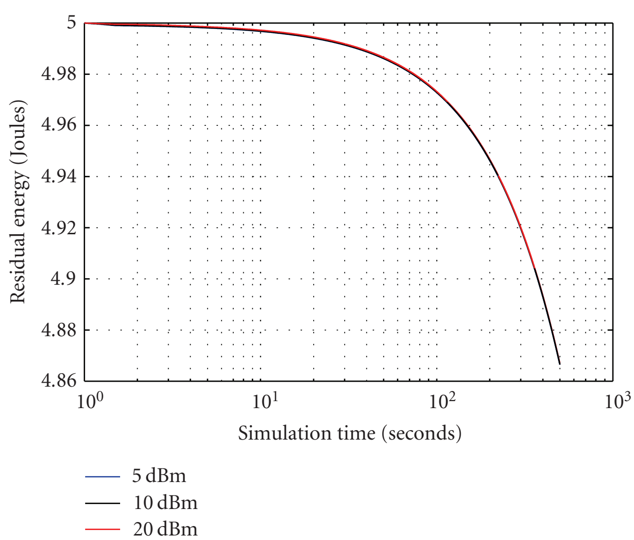

Figure 10: Residual energy at ECG node.

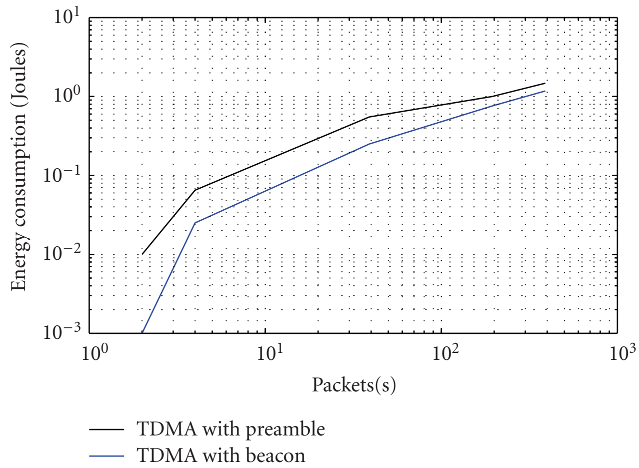

Figure 11: Power consumption of TDMA protocol with a preamble and a beacon.

communication unless supported by an efficient power management scheme.

Generally, PB-TDMA protocol uses a preamble for data slot allocation. The preamble contains a dedicated subslot for each node. These subslots are used to activate the destination node by broadcasting the destination node ID of an outgoing packet. This leads the high traffic nodes (in case, many nodes activate their destination nodes) towards a preamble collision. We propose a beacon-based TDMA protocol that provides a solution to avoid preamble contention by using a beacon (based on IEEE 802.15.4) instead of a preamble. The beacon frame is controlled and broadcasted by the coordinator and is mainly used for synchronization and resource allocation purposes. Figure 11 shows the energy consumption of a TDMA protocol with a preamble and a beacon for a 256 bytes packet size. Unlike preamble which is used by the nodes to broadcast destination ID, coordinator broadcasts the beacon frames and hence, avoids collisions. The figure also shows that a proper coordination and controlling mechanism (beacon-based TDMA protocol) at the coordinator ensures low-power communication compared with an improper coordination (preamble-based TDMA protocol) mechanism.

5. Conclusions

This paper studied the possibilities of RF communication to a device implanted under the human skin. We used a Perspex tank of a 30 cm diameter, an 80 cm height, and a 0.5 cm wall thickness for empirical investigation. The tank was filled with a liquid that mimicked the electrical properties of the human body at 400 MHz. The liquid acted as a parasitic antenna and also attenuated the signal. We concluded that the gradual increase in ERP is due to the liquid acted as a parasitic antenna. Furthermore, the signal increased to an optimum as we immersed the implant deeper into the tank. We observed best performance at 3 cm depth inside the liquid and not close to the skin surface. We further provided a simulation study of several low-power MAC protocols for an on-body sensor network. We also discussed the potential issues and challenges in the development of a novel low-power MAC protocol for a BSN.

Acknowledgment

This research was supported by the The Ministry of Knowledge Economy (MKE), Korea, under the Information Technology Research Center (ITRC) support program supervised by the Institute for Information Technology Advancement (IITA) (IITA-2009-C1090-0902-0019).

References

[1] December 2008, http://www.nyp.org/health/electrocardiogram-stresstest-holter.html.

[2] B. Lo and G. Z. Yang, "Key technical challenges and current implementations of body sensor networks," in *Proceedings of the 2nd International Workshop on Body Sensor Networks (BSN '05)*, pp. 1–5, April 2005.

[3] November 2008, http://fiji.eecs.harvard.edu/CodeBlue.

[4] January 2009, http://www.mobihealth.org.

[5] July 2008, http://www.cs.uoregon.edu/research/wearables/index.html.

[6] E. Jovanov, A. Milenkovic, C. Otto, and P. C. De Groen, "A wireless body area network of intelligent motion sensors for computer assisted physical rehabilitation," *Journal of NeuroEngineering and Rehabilitation*, vol. 2, no. 6, 2005.

[7] March 2008, http://www.ubimon.net.

[8] Febuary 2008, http://www.media.mit.edu/wearables/mithril.

[9] April 2008, http://www.hitl.washington.edu.

[10] December 2008, http://www.ieee802.org/15/pub/TG6.html.

[11] January 2009, http://lifeguard.stanford.edu.

[12] http://www.etri.re.kr/eng.

[13] G.-Z. Yang, *Body Sensor Networks*, Springer, New York, NY, USA, 2006.

[14] J. Wojclk, et al., "Tissue Recipe Calibration Requirements, SSI/DRB-TP-D01-003," Spectrum Sciences.

[15] P. Hall, "Antennas challenges for body centric communications," in *Proceedings of the International Workshop on Antenna Technology: Small and Smart Antennas Metamaterials and Applications*, 2007.

[16] S. Ullah, H. Higgins, M. Siddiqui, and K. S. Kwak, "A study of implanted and wearable BSN," vol. 4953 of *Lecture Notes in Computer Science*, pp. 464–473, 2008.

[17] Electromagnetic Compatibility and Radio Spectrum Matters (ERM), "Electromagnetic Compatibility (EMC); standard for radio equipment and services; Part 27; specific conditions for Ultra Low Power Medical Implants (ULP-AMI) and related peripheral devices(ULP-AMI-P)," Tech. Rep. ETSI EN301 489-27, V1.1.1, ETSI, Cedex, France, March 2003.

[18] H. Li and J. Tan, "Heartbeat driven medium access control for body sensor networks," in *Proceedings of the 1st ACM SIGMOBILE International Workshop on Systems and Networking Support for Healthcare and Assisted Living Environments*, pp. 25–30, 2007.

[19] B. Braem, B. Latre, I. Moerman, C. Blondia, and P. Demeester, "The wireless autonomous spanning tree protocol for multihop wireless body area networks," in *Proceedings of the 1st International Workshop on Personalized Networks*, San Jose, Calif, USA, 2006.

[20] B. Latre, B. Braem, I. Moerman, C. Blondia, E. Reusens, W. Joseph, and P. Demeester, "A low-delay protocol for multihop wireless body area networks," in *Proceedings of the 4th Annual International Conference on Mobile and Ubiquitous Systems: Computing, Networking and Services (MobiQuitous '07)*, pp. 1–8, 2007.

[21] H. Li and J. Tan, "Medium access control for body sensor networks," in *Proceedings of the 16th International Conference on Computer Communications and Networks (ICCCN '07)*, pp. 210–215, Honolulu, Hawaii, USA, August 2007.

[22] N. F. Timmons and W. G. Scanlon, "Analysis of the performance of IEEE 802.15.4 for medical sensor body area networking," in *Proceedings of the 1st Annual IEEE Communications Society Conference on Sensor and Ad Hoc Communications and Networks (SECON '04)*, Santa Clara, Calif, USA, October 2004.

[23] W. Ye, J. Heidemann, and D. Estrin, "Medium access control with coordinated adaptive sleeping for wireless sensor networks," *IEEE/ACM Transactions on Networking*, vol. 12, no. 3, pp. 493–506, 2004.

[24] T. Van Dam and K. Langendoen, "An adaptive energy-efficient MAC protocol for wireless sensor networks," in *Proceedings of the 1st International Conference on Embedded Networked Sensor Systems (SenSys '03)*, pp. 171–180, Los Angeles, Calif, USA, November 2003.

[25] IEEE Std.802.15.4, "Wireless medium access control (MAC) and physical layer (PHY) specifications for low data rate wireless personal area networks (WPAN)," 2006.

[26] A. El-Hoiydi and J.-D. Decotignie, "WiseMAC: an ultra low power MAC protocol for the downlink of infrastructure wireless sensor networks," in *Proceedings of the 9th IEEE Symposium on Computers and Communication (ISCC '04)*, pp. 244–251, Alexandria, Egypt, 2004.

[27] Technical Requirement Document, IEEE 802.15.6, January 2009.

[28] A. Sikora and V. Groza, "Coexistence of IEEE 802.15.4 with other systems in the 2.4 GHz ISM-band," in *Proceedings of IEEE Instrumentation and Measurement Technology Conference (IMTC '05)*, Ottawa, Canada, May 2005.

[29] N. Golmie, D. Cypher, and O. Rebala, "Performance analysis of low rate wireless technologies for medical applications," *Computer Communications*, vol. 28, no. 10, pp. 1266–1275, 2005.

[30] N. Chevrollier, N. Montavont, and N. Golmie, "Handovers and interference mitigation in healthcare environments," in *Proceedings of IEEE Military Communications Conference (MILCOM '05)*, Atlantic City, NJ, USA, October 2005.

[31] I. Howitt and J. Gutierrez, "IEEE 802.15.4 low rate—wireless personal area network coexistence issues," in *Proceedings of IEEE Wireless Communications and Networking Conference (WCNC '03)*, pp. 1481–1486, 2003.

[32] C. Chen and C. Pomalaza-Ráez, "Monitoring human movements at home using wearable wireless sensors," in *Proceedings of the 3rd International Symposium on Medical Information and Communication Technology (ISMICT '09)*, Montreal, Canada, February 2009.

[33] IEEE 802.11e Std, "Amendment to Part 11: "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications"," "Medium Access Control Quality of Services Enhancements" November 2005.

[34] D. Cavalcanti, R. Schmitt, and A. Soomro, "Performance analysis of 802.15.4 and 802.11e for body sensor network applications," in *Proceedings of the 4th International Workshop on Wearable and Implantable Body Sensor Networks (BSN '07)*, 2007.

[35] B. Zhen, H.-B. Li, and R. Kohno, "IEEE body area networks and medical implant communications," in *Proceedings of the ICST 3rd International Conference on Body Area Networks*, Tempe, Ariz, USA, 2008.

[36] S. Nagamine and R. Kohno, "Design of communication model suitable for implanted body area networks," in *Proceedings of the 3rd International Symposium on Medical Information and Communication Technology (ISMICT '09)*, Montreal, Canada, February 2009.

[37] S. Ullah, R. Islam, A. Nessa, Y. Zhong, and K. S. Kwak, "Performance analysis of a preamble based TDMA protocol for wireless body area network," *Journal of Communications Software and Systems*, vol. 4, no. 3, 2008.

[38] March 2008, http://www.isi.edu/nsnam/ns.

[39] July 2008, http://www.sparkfun.com/datasheets/RF/nRF2401-rev1_1.pdf.

[40] July 2008, http://www.moteiv.com.

[41] A. Fort, C. Desset, et al., "Ultra wide-band body area channel model," in *Proceedings of IEEE International Conference on Communications (ICC '05)*, Seoul, Korea, May 2005.

[42] W. Lars and S. Sana, "Architecture concept of a wireless body area sensor network for health monitoring of elderly people," in *Proceedingsof the 4th IEEE Consumer Communications and Networking Conference (CCNC '07)*, Las Vegas, Nev, USA, January 2007.