

Energy-efficient and Heterogeneous Implantable Body Sensor Network

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Abstract—Applications of body sensor networks (BSN) in health-care are growing rapidly. The number of implanted sensors used to accurately prognose and diagnose the medical-conditions are increasing. The implanted medical devices (IMD), for example pace-makers are improvised for delivering patient-centric therapies. These IMD require continuous pathological information about the disease from the implanted sensors to ensure the therapeutic value of the treatment. A reliable wireless communication between these heterogeneous medical sensors and devices is essential. The medical sensors and devices have dynamic requirements for wireless communication in terms of throughput, duty-cycle and latency. Fault-tolerant communication links must be devised for medical-emergencies. Wireless communication between the in-body and on-body sensor nodes should be supported. The amount of energy available to the in-body sensor nodes is very limited, which puts forth a strict requirement of ultra-low power consumption. In this work we aim to develop wireless communication protocol which will address the complex requirements of IBSN. This paper briefly explains the research problem and the focus of the research. Preliminary results obtained from the initial work including the characteristics of in-body radio channel and performance of MAC protocols are presented. This paper will identify the research challenges and discuss the planned research approach.

Keywords—*Cyber Physical Systems, Medium Access Control, Implantable Body Sensor Networks, Closed Loop Medical Devices.*

I. INTRODUCTION

Medical devices are capable of delivering patient centric therapies. However, different therapeutic settings should be frequently updated to the device according to the physiological status of the patient. For example, let us consider the deep brain stimulation (DBS) device for epileptic patients. Although the DBS can be used to reduce seizures in certain epileptic patients, there is no effective mechanism to predict the onset of seizures using only the electro-encephelogram(EEG) signals [1]. In this case, real-time monitoring of physiological signals such as breathing-pattern, sweat, heart rate, etc. can be used together with EEG signals to predict the onset of epileptic seizure [1].

In such medical scenarios we envision a closed-loop operation of the DBS as shown in Fig. 1 to improve its therapeutic value in epileptic patients. In the proposed closed-loop operation of the DBS, implantable and wearable medical sensors will sense and record the physiological signals, and implanted brain electrodes will sense EEG signals. The bio-signals are analyzed in an powerful external node (e.g. smart-phone) for predicting the onset of seizure. If the onset of seizure is

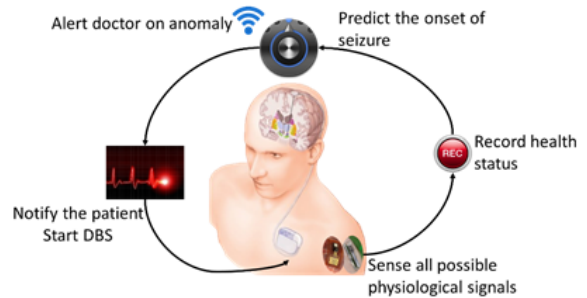


Fig. 1. Closed loop operation of pacemaker using IBSN – An Illustration

predicted, the patient is notified and treated with DBS. The whole process will take place in real-time ensuring the patient's life is not threatened by seizures. If an anomaly is detected in the bio-signals, the doctor will be alerted immediately.

Closed-loop operation of DBS is an immediate application of IBSN which can improve patient safety, quality-of-life of the patient, accuracy of treatment delivered and greatly reduce the fatalities caused by human errors.

II. FOCUS OF THE RESEARCH

The focus of the research will be on the design of wireless communication strategies for IBSN. New network protocols enabling energy-efficient communication among the implantable sensor nodes, and between the implantable and wearable sensor nodes will be designed. The design will support heterogeneity, in terms of application/use-case requirements, sensors/devices, network topology and dynamicity, in terms of characteristics of the communication channel, quality of service requirements

III. PRELIMINARY WORK

The design of wireless communication strategies is done in three parallel phases as shown in Fig. 2. Each phase has sub-tasks which will be completed chronologically.

A. First phase - Wireless channel model

The design of the network protocol stack requires the physical layer characteristics including the channel model. Currently, there is no unique channel model available for implant communication inside body. Various measurement

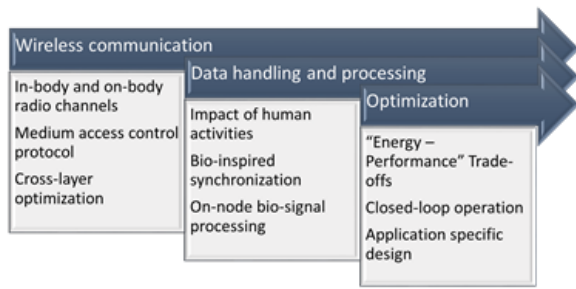


Fig. 2. Parallel research phases

PL parameters	CM1		CM2	
	simulation	empirical	simulation	empirical
$PL(d_0)$ dB	40.94	56.65	49.81	61.32
n	4.99	6.18	4.22	6.06
σ_n	9.05	10.65	6.81	9.56

Fig. 3. Path-loss parameters of human body as wireless medium

campaigns of channel characteristics are underway. The channel model characteristics depends on the hardware components used such as antenna and matching circuit as well as the operating frequency, which are not taken into account by the existing channel models for implant communication. Moreover, hardware losses and different tissue characteristics have not been taken into account in the link budget of the existing channel models. The characterization of human body as a channel model is required to develop network protocols.

Wireless communication in IBSN must be extremely reliable and energy-efficient in order to provide a long-term safe operability. The underlying MAC protocol in a wireless communication is an important feature which directly affects reliability and energy-efficiency. To reduce the energy wastage due to idle-listening, collision, and over-hearing, a new concept of low power wake-up radio was introduced. Some MAC protocols that can make use of wake-up radio have been proposed. We evaluated three of the existing MAC protocols with and without the wake-up feature, using the developed channel model.

In this phase we conducted various experiments as mentioned in [2], [3], to develop a channel model using animal tissue and evaluated the model using the existing MAC protocols.

B. First phase - Results

The experiments conducted resulted in a channel model [2] with path-loss parameters as shown in Fig. 3. From the results of [2], it is shown that the attenuation of radio communication is very high inside the tissue. The path loss exponent inside the animal tissue deviates from that of the IEEE 802.15.6 results. Moreover, additional path loss has to be accounted for the in-body to off-body communication which includes the indoor propagation losses. To compensate for the losses induced by the animal tissue, the settings of PHY parameters can be adjusted such as transmission power, antenna orientation and transmission distance.

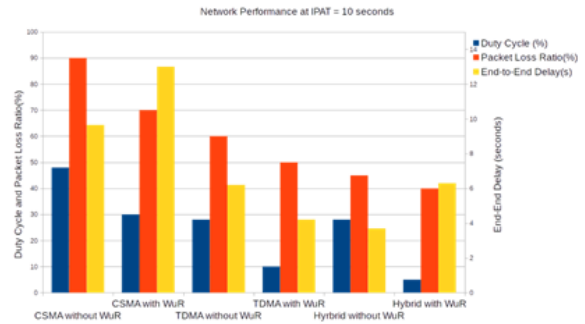


Fig. 4. Performance of MAC protocols in in-body channel model

We analyzed the performance of wake-up radio technology with commonly used MAC protocols and evaluated them with the channel model developed in [2]. It is found that the MAC protocols using wake-up radio has the lowest energy consumption in IBSN scenario as shown in Fig. 4.

IV. FUTURE WORK

The bio-signals will be analyzed in the second phase, which involves characterizing the heterogeneity of different medical sensors and devices. Based on the characteristics of different medical sensor nodes, the communication strategies (e.g. the adaptive topology, routing and data handling) will be developed. Cross layer optimization of PHY and MAC layer will be implemented.

The human activities such as walking, running etc. have a periodic impact on the radio channel which could be used to synchronize sensor nodes. Some of the bio-signals such as heart-rate and breathing-pattern are also periodic and will be used to improve synchronization in IBSN. Further analysis of bio-signals is required to improve the performance of the IBSN. Adaptive design of MAC protocol will be carried out based on the results obtained.

In third phase, the wireless protocols developed will be optimized for a selected use-case such as pace-maker use-case. The performance and energy-efficiency trade-offs of wireless protocols will be extended for different use-cases. Upon optimizing the developed wireless protocols for different use-cases, a generic wireless protocol stack for implantable medical devices will be proposed.

REFERENCES

- [1] Carney, P.R. and Myers, S. and Geyer, J.D. Seizure prediction: Methods. *Epilepsy & Behavior, Volume 22, Supplement 1*, Pages S94-S101, December 2011.
- [2] Karupiah Ramachandran, V.R. and Meratnia, N. and Zhang, Kui and Havinga, P.J.M. Towards Implantable Body Sensor Networks - Performance of MICS Band Radio Communication in Animal Tissue. *In: Proceedings of the 10th EAI International Conference on Body Area Networks, BODYNETS 2015*, 28-30 September 2015, Sydney, Australia. ACM.
- [3] Karupiah Ramachandran, V.R. and van der Zwaag, B.J. and Meratnia, N. and Havinga, P.J.M. Implantable Body Sensor Network MAC Protocols Using Wake-up Radio Evaluation in Animal Tissue. *In: Proceedings of the 9th International Symposium on Medical Information and Communication Technology, ISMICT 2015*, 24-26 March 2015, Kamakura, Japan. IEEE Engineering in Medicine & Biology Society.