Chapter 2
Body Sensors and Healthcare Monitoring:
Design and Optimization of a Wireless Communication Protocol

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ABSTRACT

The aging population and the high expectations towards quality of life in our society lead to the need of more efficient and affordable medical systems and monitoring solutions. The development of wireless Body Sensor Networks (BSNs) offers a platform to establish such a healthcare monitoring systems. However, BSNs in the healthcare domain operate under conflicting requirements. These are the maintenance of the desired reliability and message latency of data transmissions (i.e. quality of service), while simultaneously maximizing battery lifetime of individual body sensors. In doing so, the characteristics of the entire system, especially the Medium Access Control (MAC) layer, have to be considered. For this reason, this chapter aims for the optimization of the MAC layer by using energy-saving techniques for BSNs. The fact that the IEEE 802.15.4 MAC does not fully satisfy BSNs requirements highlights the need for the design of new scalable MAC solutions, which guarantee low-power consumption to the maximum number of body sensors in high density areas (i.e., in saturation conditions). In order to emphasize IEEE 802.15.4 MAC limitations, this chapter presents a detailed overview of this de facto standard for Wireless Sensor Networks (WSNs), which serves as a link for the introduction and description of the

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here proposed Distributed Queuing (DQ) MAC protocol for BSN scenarios. Within this framework, an extensive DQ MAC energy-consumption analysis in saturation conditions is presented to be able to evaluate its performance in relation to IEEE 802.5.4 MAC in highly dense BSNs. The obtained results show that the proposed scheme outperforms IEEE 802.15.4 MAC in average energy consumption per information bit, thus providing a better overall performance that scales appropriately to BSNs under high traffic conditions. These benefits are obtained by eliminating back-off periods and collisions in data packet transmissions, while minimizing the control overhead.

INTRODUCTION

Wireless Sensor Networks (WSNs) and Body Sensor Networks (BSNs) are enabling technologies for the application domain of unobtrusive medical monitoring. This field includes continuous cable-free monitoring of vital signs in intensive care units (Ragil, 2005), remote monitoring of chronically ill patients (BASUMA Project, 2006; MobiHealth Project, 2004; HealthService24 Project, 2009; Lo & Yang, 2005), monitoring of patients in mass casualty situations (Anliker, Ward, Lukowicz, Tröster, Dolveck, & Baer, 2004), monitoring people in their everyday lives to provide early detection and intervention for various types of disease (Malan, Fulford-Jones, Welsh, & Moulton, 2004), computer-assisted physical rehabilitation in ambulatory settings (MyHeart Project, 2006), and assisted living of elderly at home (Jovanov, Milenkovic, Otto, & de Groen, 2005; Eklund, Hansen, Sprinkle, & Sastry, 2005). In these scenarios, the sensors range from on-body sensors, to ambient sensors like positioning devices, to mobile devices such as cellular phones or PDAs. Depending on the application scenario BSNs are employed stand-alone or in combination with mobile phones or ambient WSNs. In order to have a better overview of potential new medical and personal healthcare applications, we will analyse and further study this field.

Like other wireless data networks, BSNs are formed by nodes (body sensors), which dynamically establish and break radio links among them in order to deliver an effective and trustworthy communication. The radio channel is common and shared by all body sensors that belong to the BSN. The Medium Access Control (MAC) layer is responsible for coordinating channel accesses, by avoiding collisions and scheduling data transmissions, to maximize throughput efficiency at an acceptable packet delay and minimal energy consumption. Therefore, it is required to define proper MAC protocols with a number of rules that guarantee the efficient use of the radio channel, and take stringent medical requirements into account (IEEE, 2003).

Bear in mind that considerable research efforts have been put into improving the efficiency of individual layers. For example, at the Physical layer (PHY), advanced signal processing techniques have been devised to face problems such as noise, interference and unwanted signal replicas caused by the random and time-varying nature of radio channels. Besides, a great variety of MAC schemes have been developed for wireless systems. However, advances attained in the different layers had barely taken into account those achieved in other layers. Actually, since a few years ago, each layer research has widely ignored the other layers. It seems clear that system performance improvements could arise from some communications between different layers, having in mind in the system design certain smart interaction among them. This foresight has led to a new paradigm: cross-layer optimization, where for instance, different layers will actuate accordingly to adapt to the actual channel conditions, performing the cross-layer interaction. Some research has been