Towards Non-parametric Statistical Modeling for Low Power Radios in Body Area Networks: Analysis, Modeling, and Simulation

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ABSTRACT

Advancements in nanotechnology will soon make it possible to fabricate a Body Sensor Network (BSN) with miniature embedded sensors that monitor physiological activities occurring inside of the body and simultaneously probe the outside environment for harmful chemicals, dangerous radiation levels, and a more general score of other hostile events. In order to detect and eventually treat diseases in a body sensor network, the development of a communication system that can continuously communicate medical information from noninvasive and in-vivo biomedical sensors are needed. The continuous evaluation of vital signs can reduce the time to detect illnesses and save lives. This research has a significant intellectual merit in engineering, medicine, and nanoscience. It will initiate collaboration between computer scientists, biomedical engineers, and medical doctors with the aim of using a multidisciplinary approach for the detection and treatment of diseases using a Body Sensor Network (BSN).

1. INTRODUCTION

A new class of distributed embedded systems, body sensor networks, is rapidly evolving. Our approach will build upon our growing understanding and experience with another class of distributed embedded systems, wireless ad hoc sensor networks. Wireless sensor networks share key features with body sensor networks: 1.sensing, self-configuration, and actuation are conducted under severe communication constraints; 2. the systems are tightly coupled to the physical world; 3. and system configuration and adaptation must be self-organizing, without requiring human intervention. However, our system will differ significantly in that scalability of nodes within the body sensor network is not necessary, the system must deal with a large amount of interference from the body, the system as a whole will integrate into a larger medical infrastructure, and the system must be compatible with standards setup in the medical backbone infrastructure.

Body Area Networks (BANs) have different properties than traditional wireless sensor networks (WSN). Path loss in BANs is affected by several characteristics, such as power level, antenna design, arm motion, and if the communication travels along or across the body. Interference is particularly harmful when there is a lot of arm motion or when the communication travels around the waist [1]. WESTs plans to do two measurement studies of a 802.15.4 and Bluetooth body area network. WESTs will use statistical analysis methods to determine the loss characteristics and additional pattern within the network. WESTs will integrate patterns and sensor data on what the person is doing in order to develop routing protocols are needed that take into account the unique characteristics of a BAN. For example, if the network can determine that a person is walking from loss patterns and sensor data they can use the collaborating data to increase the throughput in the very lossy network. WESTs will also use the results of this measurement study to be used in a vision application to model how this data can be applied to people of different heights, weights, and body compositions. Due to time constraints, only preliminary results of using the measurement study within vision application will be produced within the year timeline.

Preliminary research has been conducted to investigate the feasible of using implantable sensors in applications monitoring medical conditions [3]. In collaboration with bioengineering and urology, we implanted a pressure sensor within a pig to measure the pressure in the upper urinary track. Unfortunately, there was considerable difficulty in reliable wireless transmission from within the pig to a PDA. In another project, we investigated how to quantitatively measure a patient’s body movements after a stroke or heart attack [6]. However, measurement studies on how wireless communication propagates on the body and the development of routing protocol specifically designed to operate well on the body needs to be explored. Additional research has also been done exploring how to use noninvasive biomedical sensors (ECG, blood pressure, and pulseox) to monitor patient’s vital signs in mass casualty event [4]. However, previous research lacks an in-depth analysis of how wireless communication on the body propagates and how to make this network infrastructure delay tolerant. Moreover, research needs to be done to determine how to make the ad-hoc network delay-tolerant [5]. Delay tolerance is important because one cannot predict in a ubiquitous environment when an available backbone network will be available.

Wireless embedded medical systems will allow for the efficient monitoring of physiological occurrences through noninvasive and in-vivo biomedical sensors. My research will investigate how these biomedical sensors can safely and effectively monitor the vital signs of a patient and communicate this pertinent information in a delay tolerant manner to relevant parties. The development of this system will have broad impact in basic computer science, biomedical engineering, clinical medicine, and nanoscience.

2. METHODOLOGY / APPROACH

My proposed research will focus on building components within a three tier architecture that consists of a body sensor network, personal server, and a centralized server (Figure 1). The bottom tier of the body area network will consists of MEMS technology for the sensors, embedded medical devices, and communication of these devices in a body area network. The second tier will consist of programmable lightweight systems such as cell phones, PDAs, and iPAQs that will gather this data from the body area network and transmit it to the central server.

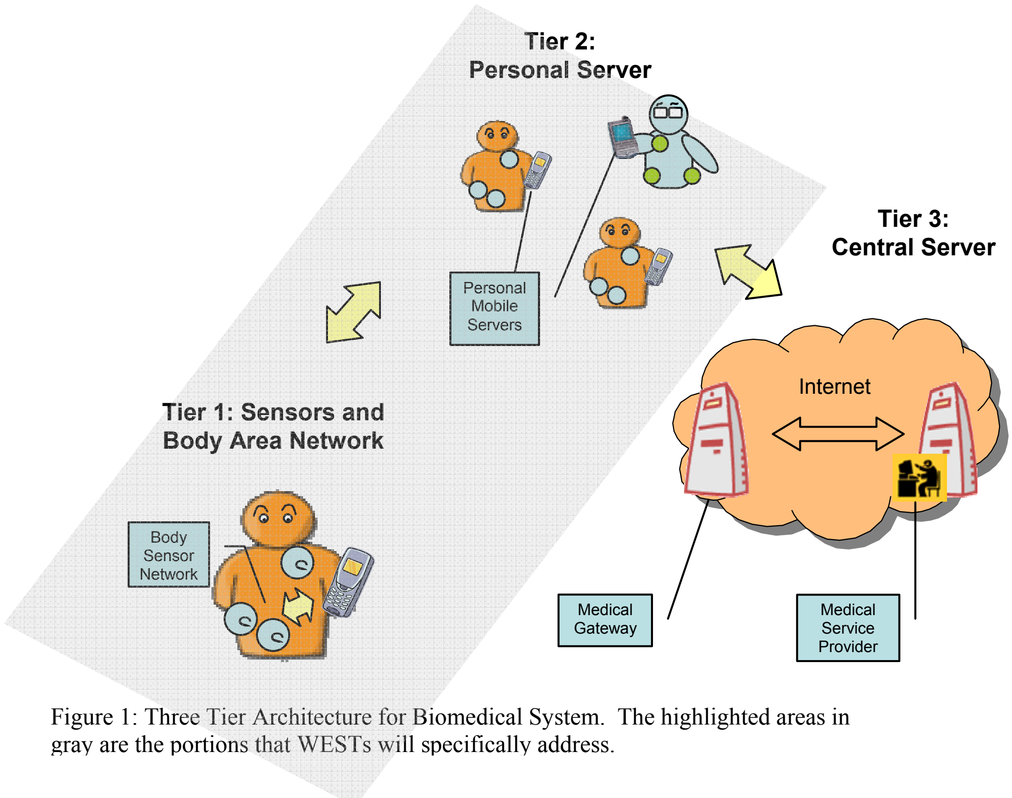

Figure 1: Three Tier Architecture for Biomedical System. The highlighted areas in gray are the portions that WESTs will specifically address.

The central server interfaces with a backbone infrastructure such as the Internet or hospital network. On this level research will go into how to process the medical data and make it usable within the hospital protocols such as HL7. Within the one year of research, WESTs will focus primarily on the first and second tier, specifically on the communication of the medical devices within the body area network and the transmission of this data in a resilient manner to the second tier.

On the first tier, a body sensor network (BSN) with miniature embedded systems that monitor physiological occurrences inside the body and simultaneously probe the outside environment for harmful chemicals, dangerous raditation levels, and other hostile events. The ubiquitous sensor network will contain several types of non-invasive and in-vivo sensors (Table 1). Multiple non-invasive biomedical sensors, such as electrocardiogram (ECG), pulse oximetry, non-invasive blood pressure will noninvasively monitor continuous, automated, real-time patient vital signs will also be investigated. Additional non-invasive sensors on the skin or clothing tha will detect hazardous chemicals will be investigated in future research. The end goal of our system is for a person's vital signs and motor activities to periodically be sent to hospitals to remotely monitor the patient's condition. In this fully built system, sensors will also monitor environmental conditions such as location, time, temperature, and pollution index.

The system can also be used for other medical awareness applications. Our system will facilitates the quantitative analysis of bio-signals, such as electromyography (EMG), respiration, periphery temperature, heart signals (ECG), and skin conductance. In case of abnormal conditions or malfunctioning, body sensors can also broadcast a request to WESTs. Due to time constraints, our system will work with medical sensors commercially available or developed in collaborating research institutions. My proposed system will build two functional body area networks with lightweight medical devices: a Bluetooth body area network and a 802.15.4 body area network. The Bluetooth body area network will have a glucose medical sensor, pulse-ox sensor, blood pressure sensor, and ECG sensor. The 802.15.4 body area network will have a pulse-ox sensor, ECG sensor, and in-vivo pressure sensor. The Embedded and Reconfigurable System lab has some equipment will need to purchase the Bluetooth ECG sensor, manufacture the 802.15.4 pulse-ox and ECG sensor from the specs from research collaborators, and use the in-vivo pressure sensor currently being developed by collaborators (Table 1).

Sensor Type
Bluetooth ECG
Bluetooth Blood Pressure
Bluetooth Glucose
Bluetooth PulseOx
Zigbee Compliant ECG
Zigbee Complaint PulseOx
Implantable Pressure Sensor

Table 1: Sensors used within the body sensor network.

The ubiquitous body sensor network (BSN) will contain several types of non-invasive and in-vivo sensors (Table 1). Multiple non-invasive biomedical sensors will monitor continuous, real-time patient vital signs. We will carry out systematic measurements of both 802.15.4 and Bluetooth body area networks. Specifically, we will use statistical analysis methods to determine path propagation patterns and loss characteristics within the network. We will analyze single link autocorrelation, global quality bandwidth, covariance of same source links, forward and reverse link correlation, packet size, temporal consistency of links, and correlation among links of the same path. In addition, our approach will analyze how user motion, propagation patterns, sensor data, and application requirements can create a model of the body sensor network and be used to design BAN routing protocols. For example, if the network can infer that a person is walking from loss patterns from sensor data, it can exploit data and path redundancy to increase the throughput in the lossy network.

Human movement can be represented as a dynamic system driven by actions, actuator forces, and joint trajectories within a vision application. [7] demonstrated how one could infer actions from remote measurements of joint angles or trajectories and how simple dynamical models can be classified into actions, such as walking. We will build on top of this model with statistical data to model how body area networks operate with people of different heights, weights, and body compositions within the vision application.

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