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Deliberation and Exertion of Wireless Body Area Networks for Exclusive Health Care Supervision

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Abstract—**Body-area networks (BANs) are wireless sensor networks (WSNs) that operate in close proximity to the human body, being used for example for distributed wireless medical body sensors. Current implementations of BANs use standardized radio frequency (RF) technologies like IEEE 802.15.4, and do not account the characteristics of the body channel, e.g. strong attenuation of high frequency radio waves. In order to provide high reliability as well as energy efficiency while communicating close to the human body, a new technology called body-coupled communication (BCC) was developed. As it uses the human body as channel, it does not suffer from shadowing and enables efficient and reliable data communication between nodes in close contact with the human body. As many applications still require transmitting some data few meters from the human body, it is essential to also have RF capabilities in a BCC-BSN. In this paper we propose a new BAN node architecture where all nodes have both a BCC and RF transceiver. We propose a protocol that enables the cooperation between the two technologies. We present the hardware and software system implementation and illustrate our concept with measurement results. We show that our dual technology solution is more efficient and reliable than classical RF solutions for BANs. This paper provides energetic security algorithm for sensing devices and multiple applications. Industries such as relevant to medicine and sport can get benefits means in plenty from the wireless body area network projects. By means of these sensor devices any one can successfully know the heartbeat, level of the glucose, and blood pressure of the patient. We can predict heart attack, diabetes, cancer and many other diseases without much of a difficulty using Wireless body area network concepts.**

Keywords: **IEEE 802.15.4, BCC, RFM WBAN, ZigBee, GPRS, WWAN, WLAN, CC2420, MIPS, ActiS**

I. INTRODUCTION

Our prototype implementation of the WBAN is best understood in the context of the motivating vision and proposed system architecture of a distributed ubiquitous health monitoring system. In the first subsection we describe this system architecture and the benefits it offers in light of the issues discussed in the introduction. In the following subsections we describe the hardware architecture of the WBAN prototype and the overview of the software architecture although primarily as a development environment. The proposed WBAN for ambulatory health monitoring is contained within a multi-tier telemedicine system as illustrated in Figure. 1.

The telemedicine system spans a network comprised of individual health monitoring systems that connect through the Internet to a medical server tier that resides at the top of this hierarchy. The system is not merely a distributed data logger, which in itself would provide great advantage over current systems, but provides distributed data processing and analysis functions. Each tier in the network is intelligent and provides some form of analysis; in some cases it may be possible for on-the-spot real-time diagnosis of conditions. The top tier, centered on a medical server, is optimized to service hundreds or thousands of individual users, and encompasses a complex network of interconnected services, medical personnel, and healthcare professionals. Each user wears a number of sensor nodes that are strategically placed on the body. The nodes are designed to unobtrusively sample vital signs and transfer the relevant data to a personal server through a wireless personal network implemented using ZigBee (802.15.4) or Bluetooth (802.15.1). The personal server, implemented on a home personal computer, handheld computer, smart phone, or residential gateway, controls the WBAN, performs sensor fusion, and preliminary analysis of physiological data. It provides graphical or audio interface to the user, and transfers captured health information to the medical server through the Internet or mobile telephone networks (e.g., GPRS, 3G).

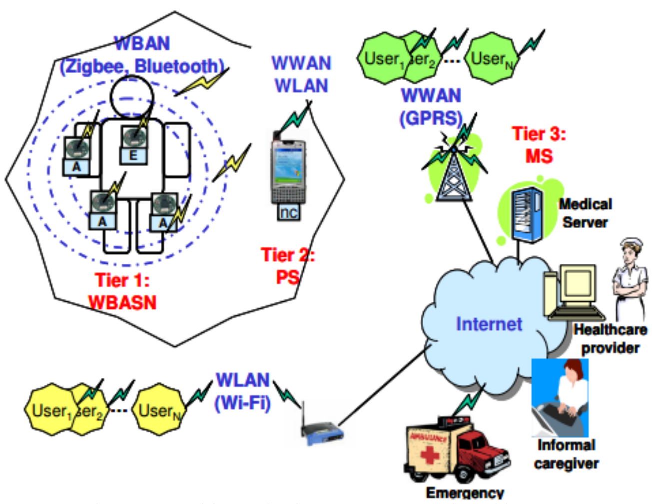

Figure 1. Health monitoring system network architecture

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II. MEDICAL SERVER

The medical server provides a variety of differing functions to WBAN users, medical personnel, and informal caregivers. The medical server stores electronic patient records in a database, provides a high availability daemon for authenticating registered WBAN users and accepting session uploads, summarizes physiological data and automatically analyzes the data to verify it is inside or outside acceptable health metrics (heart rate, blood pressure, activity) and identifies known patterns of health risks. It is the responsibility of the medical server to interface the electronic patient records and insert new session data, generate alerts to the physician and emergency health care professionals when abnormal conditions are detected, and provide physician and informal caregiver portals via the Internet for retrieving health summary reports remotely. This is especially powerful for the physician who can access the data at a convenient time to determine whether the patient is responding to a prescribed medication or exercise and make updates to those prescriptions and forward them electronically back to the patient where the user's personal server is responsible for delivering such changes to the user.The large amount of data collected through these services can also be utilized for knowledge discovery through data mining. Integration of the collected data into research databases along with quantitative analysis of conditions and patterns could prove invaluable to researchers trying to link symptoms and diagnoses with historical changes in health status, physiological data, or other parameters (e.g., gender, age, weight). In a similar way this infrastructure could significantly contribute to monitoring and studying of drug therapy effects.

III. PERSONAL SERVER

The personal server, at the second tier, is responsible for interfacing with the medical server via the Internet, interfacing the WBAN sensors and fusing sensor data, and providing an intuitive graphical and/or audio interface to the end user. The personal server application can run on a variety of platforms with a variety of wide area network (WAN) access possibilities for Internet access. Platform selection is system specific and should be selected to minimize obtrusiveness for a given user. For in-home monitoring of elderly patients, a stationary residential gateway or personal computer might be the ideal platform, but for high mobility users, it may be necessary to use a smart phone or handheld computer with GPRS capabilities [Jovanov06] [Priddy06]. The personal server requires ZigBee or Bluetooth capability for communications within the WBAN; depending on the platform, this may be integrated in the device or provided as a separate plug-in network coordinator (NC). The NC is responsible for coordinating WBAN communications and managing aspects such as time synchronization, timeslot assignment, and channel sharing.

In addition, the personal server is responsible for sensor configuration including node registration (type and number of sensors), initialization (e.g., specify sampling frequency and mode of operation), customization (e.g., run user-specific calibration or user-specific signal processing procedure upload), and setup of a secure communication (key exchange). Once the sensor nodes are configured, the personal server fuses sensor data into personalized session files. Based on synergy of information from the multiple medical sensors, the PS application should determine the user's state and his or her health status, providing user feedback through a friendly and intuitive graphical or audio user interface For interface to the medical server, the personal server requires some wireless wide area network (WWAN) or wireless local area network (WLAN) access such as GPRS or 802.11 respectively. In the case of a static residential gateway or home personal computer implementation, the personal server may be connected directly to a broadband Internet link. The personal server holds patient authentication information and is configured with IP address or domain name of the medical server so that it can access services over the Internet. The PS schedules upload of health monitoring session files at periodic intervals or defer transmission in the event an Internet connection is unavailable. In such cases, the personal server may be unable to propagate indicators of serious changes in health status. Because processing is performed on the personal server and on sensor nodes, the system should be capable of recognizing abnormalities and alerting the user to potential threatening physiological conditions.

IV. SENSOR NODES

For every personal server, a network of intelligent sensor nodes captures various physiological signals of medical interest. Each node is capable of sensing, sampling, processing, and communicating physiological signals. For example, an ECG sensor can be used for monitoring heart activity, an EMG sensor for monitoring muscle activity, an EEG sensor for monitoring brain electrical activity, a blood pressure sensor for monitoring blood pressure, a tilt sensor for monitoring trunk position, a breathing sensor for monitoring respiration, while the motion sensors can be used to discriminate the user's status and estimate her or his level of activity. Each sensor node receives initialization commands and responds to queries from the personal server. WBAN nodes must satisfy requirements for minimal weight, miniature form-factor, low-power consumption to permit prolonged ubiquitous monitoring, seamless integration into a WBAN, standards based interface protocols, and patient-specific calibration, tuning, and customization. With further development of the technology, the wireless network nodes can be implemented as tiny patches or incorporated into the user's clothes. The network nodes continuously collect and process raw information, store them locally, and send processed event notifications to the personal server.

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The type and nature of a healthcare application will determine the frequency of relevant events (sampling, processing, storing, and communicating). Ideally, sensors process data on-sensor, minimizing the number of data transmissions, therefore significantly reducing power consumption and extending battery life. When local analysis of data is inconclusive or indicates an emergency situation, the node can transfer raw signals to the next tier of the network for further processing. Patient privacy, an outstanding issue and a requirement by law, must be addressed at all tiers in the healthcare system. Data transfers between a user's personal server and
the medical server require encryption of all sensitive information related to the personal health [Warren05]. Before possible integration of the data into research databases, all records must be stripped of all information that can tie it to a particular user. The limited range of wireless WBAN communications partially addresses security; in addition, the messages can and should be encrypted using either software or hardware techniques. Some wireless sensor platforms have already provided a low power hardware encryption solution for ZigBee communications [CC2420].

V. HARDWARE ARCHITECTURE

We have designed and implemented a prototype WBAN for exploring issues and implementation details of the complete system proposed in the previous subsection. Figure 2 shows a photograph of two prototype sensors. The fully operational prototype system includes an integrated ECG and tilt sensor (eActiS), two activity sensors (ActiS), and a personal server with attached network coordinator (not shown). Each sensor node includes a custom application specific board and uses the Tmote Sky platform [Otto05] for processing and for ZigBee wireless communication. The personal server runs either on a laptop computer or a WLAN/WWAN-enabled handheld PocketPC. The network coordinator with wireless ZigBee interface is implemented on another Tmote Sky that connects to the personal server through a USB interface. Alternatively, a custom network coordinator that features the ZigBee wireless interface, an ARM processor, and a compact flash interface to the personal server is under development.

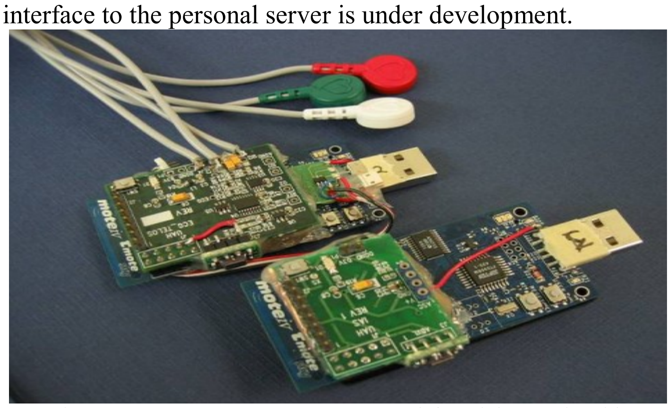

Figure 2. Prototype WBAN sensors. From left to right: eActiS with electrodes, ActiS

Wireless Sensor Platform –

Tmote Sky For the main processing board on the embedded sensor nodes, we used commercially available wireless sensor platforms from Moteiv [Moteiv]. During the course of development, we used Moteiv's original Telos rev A, its successor Telos rev B, and finally the Tmote Sky platform. Each platform is based on an MSP430 family microcontroller with integrated RAM and flash memory, a USB interface, and an integrated wireless ZigBee compliant radio with antenna. The Telos rev A utilizes the MSP430F149 microcontroller with 2KB RAM and 60KB flash memory, while the Telos rev B and Tmote Sky utilize the MSP430F1611 with 10KB of RAM and 48KB of flash memory, representing the largest capacity RAM offered in an MSP430 device. Telos rev B and Tmote Sky are 100% code compatible and can be used interchangeably [Moteiv]. The Tmote Sky platform is an ideal fit for this application due to small footprint and out of the box TinyOS support. In addition, the Tmote Sky platform includes humidity, temperature, and light sensors that might be of interest for some applications. The Tmote Sky platform features a 10-pin expansion header that allows one UART and I2C interface, two general-purpose I/O lines, and three analog inputs to be connected to a custom daughter card. It is through this expansion header that we were able to integrate the ActiS and eActiS sensor nodes. The Tmote Sky from Moteiv serves as the main processing platform of the embedded sensor node as well as the network coordinator. Each Tmote Sky board utilizes an MSP430F1611 microcontroller and Chipcon's CC2420 ZigBee radio interface.

VI. INTELLIGENT SIGNAL PROCESSING MODULES

The activity sensor, ActiS, consists of the Tmote Sky platform and an Intelligent Signal Processing Module (ISPM), implemented as a daughter card. The ISPM utilizes an on-board MSP430F1232 microcontroller for pre-processing and filtering of sampled data. The ISPM is connected via the 10-pin Tmote Sky expansion header. A general purpose digital output is connected from the Tmote Sky to the ISPM interrupt request input (connected to the MSP430F1232 microcontroller). This allows the main platform to request samples periodically by interrupting the ISPM. Raw data or partially processed data can then be transmitted using the USART configured as a UART and simple serial communication protocol. Figure 3 shows a block diagram of the ISPM daughter card.

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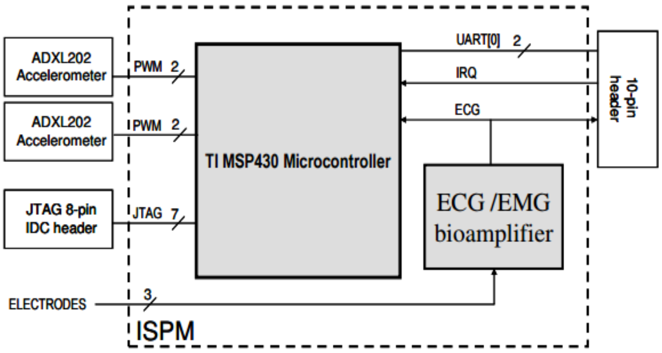

Figure 3. ISPM block diagram

The integrated ECG and tilt sensor (eActiS) consists of the Tmote Sky platform and an ISPM with a single-channel bio-amplifier for three-lead ECG/EMG. Electrodes are connected and placed on the chest for monitoring heart activity. The bioamplifier output (ECG signal) is connected directly to the expansion header for Tmote Sky processing as well as to the on-board MSP4301232 for optional pre-processing directly on the ISPM. When the ISPM is used as an ECG heart monitor and worn on the chest, the integrated accelerometers serve as an upper body tilt sensor. The ISPM monitors motion using two dual-axis ADXL202 accelerometers from Analog Devices. The ADXL202 is a low cost, low power MEMS accelerometer capable of measuring both dynamic acceleration (e.g., vibration) and static acceleration (e.g.,gravity) at magnitudes up to ±2g [ADXL202]. We measure motion in three axes by mounting the accelerometers orthogonally. One ADXL202 is mounted directly on the ISPM board and collects data for the X and Y axes as represented in Figure 4; the second ADXL202 is mounted vertically to measure motion in the Z axis. Figure 4 shows the ISPM used on an ActiS sensor node with the axes of motion sensing drawn.

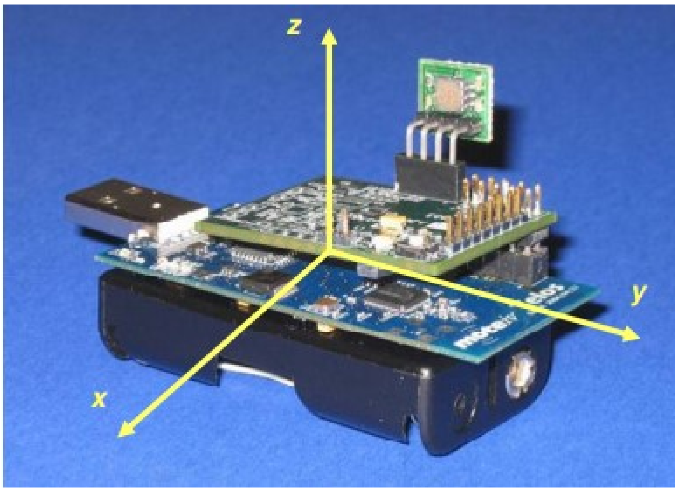

Figure 4. ActiS sensor node – Tmote Sky with ISPM motion sensing daughter card

VII. WBAN WIRELESS COMMUNICATIONS

Long-life, persistent sensor nodes require efficient power management. With highly integrated electronics, the sensor size and weight becomes dominated by battery selection. An implementation must address conflicting requirements for small size and infrequent battery maintenance, striving for a balance that will maximize user compliance. It is our challenge as designers to minimize sensor power consumption and thus maximize battery life for a given size. In designing our prototype we have held low power consumption as a primary design goal in every component of the system – in processor and technology selection, in managing sensor data, in network organization, and in efficient communications. Power consumption of the sensor node is dominated by the wireless radio. Nearly 85% can be attributed to CC2420 controller – even when not actively transmitting. The CC2420, although the lowest power of its kind, still draws 17.4mA when transmitting and 19.7mA when receiving. In contrast, the MSP430 utilizes 250µA/MIPS – typically
just over 1mA when active. As an example, the MSP430 can execute 100,000 instructions for the same cost of transmitting a single 40 byte message. With that in mind, power savings can be realized by disabling the radio when not in use as well as reducing the total quantity of transmission – even if extensive computation is required. Besides power efficiency, we were motivated to implement simple and scaleable communications, to use standards-based protocols, and to support multiple simultaneous WBANs within close proximity of one another. The resulting solution spans multiple layers, is IEEE 802.15.4 compliant and upholds the ZigBee star network topology. It leverages existing communication framework within TinyOS and addresses practical WBAN implementation issues.

IEEE 802.15.4 and ZigBee -

Our prototype WBAN utilizes the IEEE 802.15.4 compliant CC2420 radio for wireless communications. The IEEE 802.15.4 standard defines communications for nodes in a low-rate wireless personal area network (LR-WPAN) and is well suited for our prototype WBAN. The standard specifies the physical (PHY) layer and data link / media access control (MAC) layer. At the physical layer, IEEE 802.15.4 defines three frequency bands, spread spectrum chip rate, and data encoding [IEEE802.15.4]. The CC2420 radio is fully compliant and hides these details from the system designer. The CC2420 operates at the highest frequency band – 2450 MHz (2.4 GHz). The standard specifies 16 channels in the 2.4 GHz ISM band. Channel selection is exposed to the application developer through the TinyOS-based CC2420 software driver. By exploiting different 802.15.4 channels, we have been able to operate multiple simultaneous WBANs in close proximity without interference.

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At present this feature is statically assigned, but satisfies proof of concept. IEEE 802.15.4 employs a carrier sense multiple access with collision avoidance (CSMA-CA) scheme for peer-topeer communications. In the simplest form, communications are asynchronous and random access can occur. IEEE 802.1.5.4 includes specification for an optional super frame structure utilizing device timeslots which we exploit in the next section. ZigBee and IEEE 802.15.4 are cooperating protocol stacks. ZigBee is tightly coupled to 802.15.4 in that the PHY and MAC layers are specified to be IEEE 802.15.4; however, the ZigBee specification details the upper protocol layers – network, application and application sublayer, and security. It specifies network topologies, routing mechanisms and dynamic discovery and registration of nodes as they enter and

exit the network. ZigBee defines three network topologies: star, tree, and mesh. In the star topology a single node serves as the network coordinator; nodes communicate directly to the network coordinator, but not peer-to-peer. In a tree topology, nodes are arranged hierarchically so that each node communicates to a designated router node. Traffic propagates through the network by visiting router nodes. A mesh network topology allows full peer-to-peer communications [ZigBee]. Based on the human-centric WBAN model, we are able to exploit the simplified star topology. Whenever possible we upheld the spirit of the ZigBee specification, but did not restrict ourselves to conform to the ZigBee specification. At the time of writing, TinyOS does not include a ZigBee protocol implementation nor did any open source ZigBee stack exist. With price tags over $5000 this did not seem like a viable option. Instead of developing this functionality, we chose to maintain the spirit of ZigBee, but allow for a simpler implementation. By doing so, our efforts could be focused on exploring more general challenges in WBAN implementation and maintaining flexibility for future implementations that may not use ZigBee – a Bluetooth WBAN for example. Compared to Bluetooth which is primarily designed for wireless cable replacement for electronic devices, 802.15.4 / ZigBee offers lower data rates and lower power consumption. Bluetooth is limited to a relatively small number of network participants while 802.15.4 scales upward to 65,536 nodes. In addition, 802.15.4 implementations have smaller memory footprints [Bluetooth] [ZigBee].

VIII. CONCLUSION

Wireless Body Area Networks (WBANs), comprised of tiny intelligent physiological sensors, represent a promising addition to wearable systems for health monitoring. Following current trends in advances in size, low power, and dense integration (complete systems on a chip), it is expected that WBAN sensor nodes can be easily integrated into a user's clothing or worn as tiny patches on the skin. The absence of wires and small weight make them unobtrusive and allow ubiquitous, ambulatory health monitoring for extended periods.

Integration of WBANs into a broader telemedicine system empowers patients and users with continuous ambulatory monitoring, a chance for remote rehabilitation at reduced cost while adding value, and the earliest possible detection of abnormal health indicators. This thesis presents a WBAN implementation which consists of multiple sensor nodes, a personal server, and a network coordinator. The sensor boards and network coordinator were built from off-the-shelf wireless sensor platforms with custom-designed intelligent physiological sensor boards for ECG and activity monitoring. The nodes communicate wirelessly using standards-based IEEE 802.15.4 and a novel, health monitoring specific, power-efficient TDMA scheme. In addition, we introduced novel techniques for time synchronization including an original hybrid convergence scheme and an event management scheme motivated by power efficiency.

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