ASE-BAN, a Wireless Body Area Network Testbed

Jens Kargaard Madsen
Aarhus School of Engineering
Aarhus University
Aarhus, Denmark
jkm@iha.dk

Henrik Karstoft
Aarhus School of Engineering
Aarhus University
Aarhus, Denmark
hka@iha.dk

Finn Overgaard Hansen
Aarhus School of Engineering
Aarhus University
Aarhus, Denmark
foh@iha.dk

Thomas Skjødeberg Toftegaard
Aarhus School of Engineering
Aarhus University
Aarhus, Denmark
tst@cs.au.dk

***Abstract*— Miniature Body Area Networks used in health care support greater mobility to patients and reduces actual hospitalization. This paper presents the preliminary implementation of a wireless body area network gateway. It is designed to implement the gateway functionality between sensors/actuators attached to the body and a host server application. The gateway uses the BlackFin BF533 processor from Analog Devices, and uses Bluetooth for wireless communication. Two types of sensors are attached to the network: an electro-cardio-gram sensor and an oximeter sensor. The testbed has been successfully tested for electro-cardio-gram data collection, and using wireless communication in a battery powered configuration.**

Keywords-component; low power wireless sensor network; healthcare; ECG sensor; body area network; testbed; ASE-BAN

I. INTRODUCTION

The demand for health-related services in Europe is expected to grow in the near future, partly because of the relative increase in number of elders in the European region. Some demands will be on highly patient-centric and prevention-based health-related services. Technologies to cope with these demands are cheap real-time systems to monitor body functions of patients [1]. A ubiquitous computing network can be set up, where wireless technologies are applied to communicate accurate patient medical data to medical practitioners around the clock from the comfort of home; hence letting patients experience greater mobility and reduce hospitalization. This brings electronic health care support, known as m-Health in the literature [2], one step further.

A wireless real-time monitoring system can be organized in a wireless body area network (BAN) first coined by Van Dam et al. in 2001 [3]. The BAN in Fig. 1 consists of a number of different sensors and actuators connected using wireless communications to the intelligent personal node (body gateway). The sensors could e.g. be an electro-cardio-gram (ECG) sensor monitoring cardiovascular activity, a beat-to-beat sensor monitoring continuous blood pressure or an oximeter sensor observing the pulse and blood oxygen levels. An actuator could be a device stimulation muscle activator. The gateway communicates via a wireless link with a local or remote host application at a remote server. Such as system can provide ease in information-flow from the patient to the medical practitioners, in a convenient and secure way for the patient.

BAN's can acquire large quantities of patient medical information in real-time from the sensors. Such data should be communicated to the medical practitioners, in a suitable manner and data must be offloaded to the host for storage or post-processing from time to time.

Since wireless transmission is relatively energy costly, the gateway should only transmit context relevant data when needed, to minimize energy consumption. This give rise to several technical challenges such as, how should the sensors communicate wirelessly with the gateway? When should the gateway communicate data to the host? What data should be communicated to the host? How should the data be communicated to the host? This paper addresses some of these challenges.

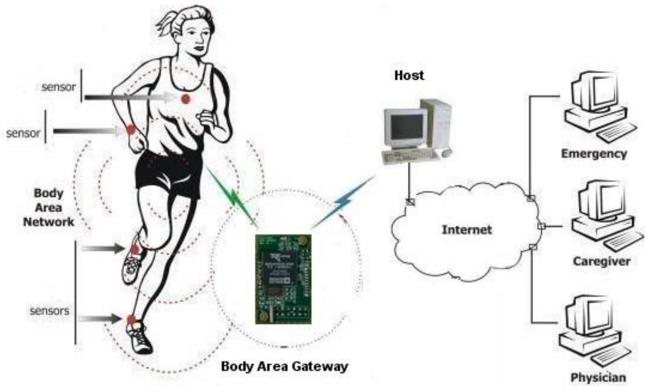

Figure 1. The wireless body area network.

A number of research groups have worked on implementing a BAN platform, typically for dedicated purposes. One example is the Human++ UniNode from the Netherlands [13] monitoring the autonomic nervous system. Here the network is build from a number of sensors communicating directly and the body area network is not connected to a separate gateway. In the same manner the MIT Media Lab [14] and the Fraunhofer Institute [15] have studied emotions using different portable monitoring systems. Additionally in [16] a prototype bio-potential sensor node is presented for monitoring a multitude of bio-potential signals. A system consisting of three of these nodes packaged in a headband enables wireless sleep stage monitoring. What we try to do with ASE-BAN is to create a flexible platform that can be use in designing dedicated low power sensor nodes, more complex and resource demanding nodes e.g. including a signaling processor directly well as the gateway node itself where the protocol translation and connectivity of the BAN to the outside takes place.

Section II gives a brief discussion of BAN architectures with focus on design requirements/constraints.

Section III describes the low-cost Aarhus School of Engineering BAN (ASE-BAN) gateway prototype testbed, initially designed to monitor ECG signal and other patient medical signals over long time spans with no user intervention. This is work in progress.

The paper finalizes with a description of the future work of the ASE-BAN testbed.

II. THE BAN ARCHITECTURE

The network outlined in Fig. 2 illustrates a BAN consisting of a number of sensors/actuators nodes (motes), a body gateway and a host.

The motes and the body gateway are connected wirelessly within the body zone in a star or mesh network topology and relaying data (packets) to or from each other. Most (bi-directional) communication is between the gateway and the motes, but two motes could also communicate directly, e.g. in a sensor actuator setup where a measured parameter by sensor-mote-A (drop of glucose level) implies a consequent action to be performed real-time by actuator-mote-B (injection of insulin). Likewise, the gateway is connected wirelessly to the host in a bi-directional point-2-point connection.

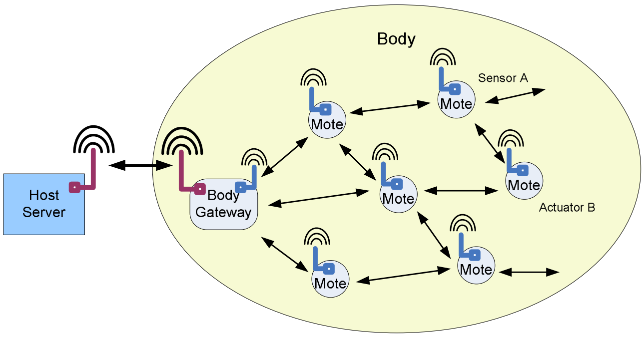

Figure 2. Wireless body area network topology and components such as sensors/actuators (motes), body gateway and host server.

A. The BAN Communication Protocol

Challenges with the design of a BAN communication protocol are issues like: noisy environment (RF noise and interference), variable traffic loads (dynamic bandwidth allocation), alarm situations (data priority/interruption), secure and accurate transmission (privacy and trustable), simple installation and service (plug and play), effortless adding/removing of motes and long time operation with minimal intervention (weeks/months/years). Therefore, key attributes for the BAN are: Reliability, scalability, security, power efficient, and easy of use and configure.

Since, single-hop communication (star topology) not always can be guaranteed (e.g. from front to back) and at the same time be power efficient, multi-hop communication (mesh topology) might be used to obtain optimized power efficient connectivity [4]. Interoperability meaning standard based protocols is also important to enable mote products from several vendors in the BAN.

An example of a protocol satisfying these requirements is the Time Synchronized Mesh Protocol (TSMP) proposed in [5], now being integrated into the emerging IEEE 802.15.4E standard. Key components of TSMP are:

- Time synchronized communication
- Frequency hopping
- Automatic mode joining and network formation
- Fully-redundant mesh routing
- Secure message transfer

In TSMP each transmission, transacted in a synchronized specific timeslot, contains a single packet and acknowledgements which are generated when a packet has been received unaltered and complete. Use of frequency hopping reduces the impact of interferences and increases the effective bandwidth. Aggressive use of duty-cycle and time-slot based principles makes the protocol very power efficient. A key attribute of TSMP is its self-organization mesh routing that makes it easy to add/remove motes. Finally, TSMP support encryption, authorization and integrity with regards to secure message transfer.

B. The BAN Gateway

A gateway (optionally two in case of redundancy) per BAN performs the following major tasks:

- Configuration and synchronization of the BAN
- Controlling and monitoring of the motes
- Collection and further processing of the sensors data
- Forwarding of processed and aggregated data wirelessly to the host for further processing and interpretation
- Reception of commands from the host

This requires hardware that includes: a transceiver supporting the communication within the BAN (motes), a transceiver supporting the communication with the Host, a powerful processor including memory and storage, and a power supply unit including a (rechargeable) battery. Optional, a display could be added for “on-site” monitoring.

The form factor and weight of the gateway should be tailored to be wearable with minimal impact on the body comfort, e.g. like a modern Smartphone or smaller.

Like most portable devices, the design should be optimized with low power consumption in mind. Weeks of operation without the need of recharging/replacing the battery would be acceptable.

C. *The BAN Sensors*

Sensors can be tiny patches worn on or implanted in the human body. The number and types of sensors in a BAN depends on the application. Examples of typical ones are:

- ECG sensor for monitoring heart activity
- Blood pressure sensor
- Oximeter sensor

The key functions of a BAN sensor are: physiological measurement and data collection, (optional) processing and forwarding wirelessly to the gateway. This requires specific physiological sensor hardware, a processor including memory, a transceiver (bi-directional communication) and a power supply source.

Small form factor, light in weight, and ultra low energy consumption are required with respect to physical comfort and minimal service. The latter one is with regards to extended battery lifetime (months or even years) without the need of intervention.

Therefore, sensor hardware should be designed and implemented with ultra low power consumption in mind, and with support for communication protocol supporting such operations. E.g. sensors kept in sleep mode when not performing any active tasks.

Integrated energy harvesting is another possibility to extend the rechargeable battery lifetime, potentially ‘forever’ in case the harvested energy is larger than the consumed energy over time. In body area networks body heat and body vibrations are obvious sources for energy harvesting. In [6] an example of using body heat is described that with proper energy management may eliminate the use of a battery.

III. IMPLEMENTATION & RESULTS

This section describes the low-cost BAN prototype testbed. This is work in progress and only preliminary results will be presented.

A. *The ASE-BAN Testbed Model Overview*

Fig. 3 illustrates the ASE-BAN functional diagram. Here one module describes the actual ASE-BAN gateway and two additional modules implement the ECG and the oximeter sensors.

In this initial version the wireless connection between the gateway and the host is implemented using Bluetooth whereas the connections (wired in this prototype) to the two sensor modules is only emulating the wireless channel. In the next version of the testbed the wireless ASE-BAN connections will be implemented proprietary low power radio communication modules.

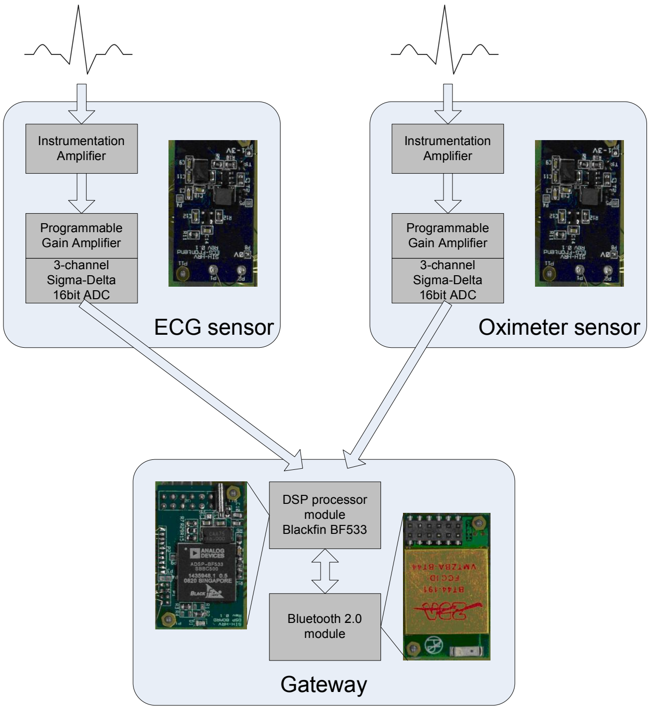

Figure 3. Block diagram of the ASE-BAN gateway with an ECG and an oximeter sensor module.

B. *The ASE-BAN Gateway*

The testbed prototype gateway consists of two modules, the processor module and the communication module, as illustrated in the lower part of Fig. 3. The modules are assembled to form a sandwich structure as show in Fig. 4.

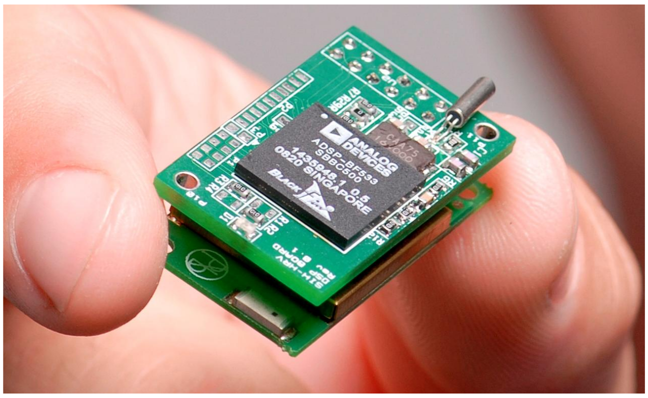

Figure 4. The physical ASE-BAN gateway module. The size is 13 mm x 18 mm x 30 mm. The weight is approximately 6 g.

The processor module is a small foot-print Digital Signal Processor platform equipped with a BlackFin BF533 signal processor from Analog Devices [7]. This signal processor is a high-performance fix-point processor with two 16 bits multiply-and-accumulate units, capable of parallel processing. The processor is capable of handle clock-speeds up to 600 MHz. The on-chip real-time-clock is connected to a 32 kHz crystal. The module also includes a M25P10-A serial 1 MBit data flash for program storage and a secure digital memory card for on-board local data storage. On reset the processor boots the program form the flash. The processor may transfer data to the SD-card using the serial peripheral interface.

The wireless communication module, consist of a Bluetooth 2.0 module of class 2. The RF range is up to 100 meter. It supports data transfer rates up to 3 Mbits/s. The module is connected to the processor module trough a UART interface. The module facilitates connectivity to sensors in the ASE-BAN and to the host, in this setup a PC or cell phones. The module is easy to use, but costly in terms of energy consumption, especially in relation to the rather low bandwidth need for the current set of sensors (< 500 Hz @ 16 bit). The next generation will have a more energy efficient communication module.

The processor platform is used to process the signals from the sensors. Current software runs standard adaptive noise removing techniques to remove hum in the ECG. The R-peak in the ECG signal is calculated using the Pan Thomkins algorithm [8] and finally classic pNN50 Heart Rate Variability [9] is calculated for diagnostic purposes.

C. The ASE-BAN Sensors

The current prototype supports 2 types of sensors: an ECG sensor and an oximeter sensor.

The ECG sensor module measures 2 lead ECG signal on patients. The module includes an ECG amplifier, an analog-to-digital converter and a power supply unit.

Since ECG signal typically has peak to peak amplitude of approximately 2 mV amplification is needed prior to the analog to digital conversion. The amplification is done using the AD620 instrumentation amplifier from Analog Devices [10]. This amplifier has high bandwidth, low noise and providing high common-mode rejection, as such offers high quality amplification of the ECG signal.

The AD conversion is implemented, using the AD770 3-channel 16 bit ΣΔ-converter from Analog Devices [11]. The sampling rate for the ECG signal is set to 500 Hz.

The current power supply unit accepts input voltages in the range 0.8 – 3 V and enables warning on low battery.

The sensor is intended to be worn for a longer time span without intervention; hence appropriate electrodes must be selected, to provide for high signal quality and patient comfort. The prototype uses 2 lead insulated bio-electrodes which provide good signal quality and reduced risk for skin irritation [12]. Fig. 5 shows a recorded ECG on the host server. The power consumption can be as small as 500 µW, this means a battery on 0.5 Wh will operate a couple of weeks given continuous operation.

The oximeter measures the oxygen saturation in the patient blood. The module is being implemented in a similar way as the ECG module (same size etc.), but since the module is in the design phase no measurement results are at this point in time available.

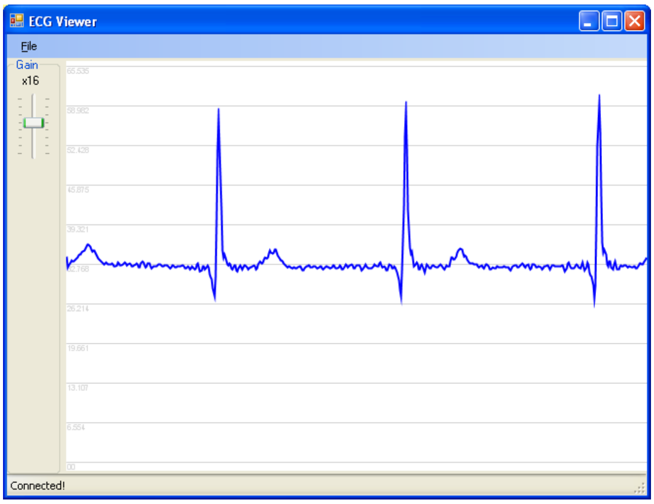

Figure 5. A real-life ASE-BAN ECG mesurement.

IV. CONCLUSION & FUTURE WORK

In this paper an initial prototype body area network testbed for measuring ECG and oxygen level in blood has been presented. The testbed has been implemented and successfully tested for ECG data collection. The oximeter module is in the design phase so no measurement results are available at this point in time.

Since this paper presents the initial implementation of the ASE-BAN testbed a larger number of activities have been postponed to further work in the near future. This work can be categorized in two levels, short term and long term. The immediate short of to implement and test the oximeter sensor. Additionally the short term issues are to work with power efficient signal processing techniques for robust detection of the R-peaks and accurate estimation of the heart rate variability for diagnostic purposes including compression of sensor data. In the longer term new sensor hardware for the body area network will be implemented to create low power solutions with little or no battery power. A number of energy harvesting techniques are being investigated. Additionally the gateway hardware itself will be optimized in terms of energy consumption. This includes the radio module as well as the software implementation which in the future will offer mechanisms to put the device to sleep when not necessary. Additionally the network communication protocol itself will be designed to reduce the power consumption of the BAN for continuous real-time monitoring. Finally the introduction of an ultra-small-scale IP stack in the gateway is being considered for connectivity to the host and further on a network infrastructure.

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