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ORIGINAL PAPER

Body Area Networks for Ubiquitous Healthcare Applications: Opportunities and Challenges

Emil Jovanov · Aleksandar Milenkovic

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Abstract Body Area Networks integrated into mHealth systems are becoming a mature technology with unprecedented opportunities for personalized health monitoring and management. Potential applications include early detection of abnormal conditions, supervised rehabilitation, and wellness management. Such integrated mHealth systems can provide patients with increased confidence and a better quality of life, and promote healthy behavior and health awareness. Automatic integration of collected information and user's inputs into research databases can provide medical community with opportunity to search for personalized trends and group patterns, allowing insights into disease evolution, the rehabilitation process, and the effects of drug therapy. A new generation of personalized monitoring systems will allow users to customize their systems and user interfaces and to interact with their social networks. With emergence of first commercial body area network systems, a number of system design issues are still to be resolved, such as seamless integration of information and ad-hoc interaction with ambient sensors and other networks, to enable their wider acceptance. In this paper we present state of technology, discuss promising new trends, opportunities and challenges of body area networks for ubiquitous health monitoring applications.

Keywords Wireless body area networks · Body sensor networks · Ubiquitous monitoring

E. Jovanov (✉) · A. Milenkovic
Electrical and Computer Engineering Department,
University of Alabama in Huntsville,
Huntsville, AL, USA
e-mail: emil.jovanov@uah.edu

Abbreviations

BAN	Body Area Network
WBAN	Wireless Body Area Network
BSN	Body Sensor Network
mHealth	Mobile Health System
ASIC	Application Specific Integrated Circuit
PAN	Personal Area Network
WAN	Wide Area Network

Introduction

Body Area Networks (BANs) emerge as a key component in building personal health monitoring systems. A BAN consists of one or more miniaturized network nodes, each of them capable of sensing, sampling, processing, and communicating one or more physiological signals (e.g., body temperature, heart rate, blood pressure, blood oxygen saturation, blood glucose level), physical activity (e.g., body posture, type and level of activity), and environmental parameters (location, temperature, humidity, light, atmospheric pressure). These nodes are typically placed strategically on the human body as tiny patches or hidden in users' clothes or even implanted in the human body. If nodes communicate wirelessly, the system is called Wireless Body Area Network or WBAN. BANs enable continual monitoring of health status, physical activity, and environmental conditions unobtrusively during normal daily activities. Data collected on BAN nodes can be merged, analyzed, and recorded on a personal server. The personal server plays a role of the BAN network coordinator and can be implemented either on a dedicated device or on a smart phone. The data recorded on the personal server can be timely forwarded to the cloud and made available for inspection to users, authorized healthcare providers, or informal caregivers.

Such a multi-tier integrated health monitoring system enables a wide range of healthcare applications, from health to fitness management of healthy individuals to preventive healthcare, assisted living, and supervised ambulatory rehabilitation. For example, a smart phone application integrated with a BAN enables a user to closely monitor changes in her or his vital signs during daily activities and can provide feedback to help maintain an optimal health status. Moreover, the personal server application may alert the user about insufficient level of physical activity or elevated body mass index based on the data from the WBAN, the user's personal data (age, gender, height), and recommended values for these parameters. The BAN and the personal server can be integrated into a broader telemedical system that includes medical personnel. The data collected for extended periods of time on a medical server can be mined for uncovering long-term trends and markers that may indicate significant changes in the health status (e.g., deteriorating or improving health status). These markers can alert authorized healthcare professionals to follow up with the user. In addition, the BAN health status information can be used (a) to monitor progress of patients undergoing rehabilitation in ambulatory settings (e.g., cardiac patients), (b) to monitor patients' adherence to treatment guidelines (e.g., whether they exercise regularly), or (c) to monitor user's compliance and effects of drug therapy.

The first academic research papers advocating the use of wireless body area networks for health monitoring applications were published a decade ago [1]. They recognized that then emerging new short range Personal Area Networks (PANs) [2] and continual advances in sensors, semiconductors, and mobile communications could be utilized for building new affordable and wearable health monitoring systems.

We have witnessed tremendous growth in capabilities of enabling technologies as well as their proliferation driven by consumer markets and large-scale wireless sensor network technologies in the last decade [3][4][5][6][7][8]. For example, new sensors have been introduced (e.g., MEMS-based accelerometers, gyroscopes, integrated front-ends for electrocardiogram) enabling reliable and unobtrusive sensing of vital signs and accurate tracking of user's physical activity. Next, continual advances in semiconductors have enabled systems-on-a-chip (SoCs) that integrate processors, memories, analog and digital peripherals on a single chip. SOCs continue to scale toward smaller, cheaper, and faster devices that consume less energy. These trends enable building energy-efficient BAN nodes that can perform digital signal processing to extract useful information and reduce amount of data that needs to be communicated to the personal server. New short range wireless radio standards have emerged (e.g., low-power Bluetooth [9], Zigbee [10], Ant [11]) and a number of radio chips have been introduced [12][13]. New radios enable building wearable nodes that can operate for long periods of time without battery replacement or recharging. Thanks to proliferation of portable devices such as music players, new battery technologies have emerged and proliferated enabling smaller and lighter batteries with increased capacity. Mobile communications have advanced providing more reliable and higher bandwidth services. Smart phones emerged as a dominant computing platform with performance and storage capabilities to match those of personal computers a decade ago (e.g., an Apple iPhone or Nokia N95) [14]. Smart phones support development of sophisticated custom applications, messaging, e-mails, full-fledged Internet access, intuitive user interfaces. They also include sensors (e.g. accelerometers), built-in cameras, location services (GPS or cell-based triangulation), and multi-standard connectivity (Bluetooth, WiFi). Finally cloud computing and Internet-based services matured and became widespread.

Convergence of all these enabling technologies creates great new opportunities for better healthcare and improved quality of living. To cite Dr. Eric Topol, General Co-Chair of Wireless Health 2010 [15]:

> "We are in the midst of a great inflection point in medicine as powerful wireless technologies will enable the continuous observation of a person's physiology, and significant medical advances in genomics will give us a clear understanding of each person's biology. This extraordinary convergence of information potentiates our ability to truly render individualized medicine."

Following first academic prototypes of WBANs [1][5][6][16], a number of commercial systems based on WBAN have emerged recently [17][18][19][20]. Typical applications include monitoring of cardiac patients, such as systems by Corventis [17] and Cardio Net [18]. They employ patch-like ECG sensor for data acquisition of ECG (e.g. PiiX from Corventis [17]) and a portable device (zLink) that receives data wirelessly from the sensor and communicates with the monitoring center to help diagnose cardiac arrhythmias. Some systems employ multiple sensors to assist with the monitoring of elderly, such as Halo Monitoring [19]. In addition to heart activity, this system monitors breathing, posture, and potential falls of the elderly. A new generation of consumer oriented health monitoring systems is also emerging; Zeo uses a WBAN to monitor movement and brain electrical activity during sleep to assess the quality of sleep [20]. Although it is not a diagnostic device, the system empowers the user to monitor patterns of activity. However, these systems are often custom-designed and optimized for a given application. To spur innovation and ensure interoperability more will need to be done on standardization.

As technological advances make WBAN systems practical, a number of economic, social, ethical issues that arise from such technology need to be resolved. Typical examples include covering costs of sensors and monitoring, liability issues, problems with poor coverage in rural areas, adherence reminders, and similar issues [21].

In this paper we present typical system architecture of a WBAN-based system for ubiquitous health monitoring and possible applications and describe current challenges.

Technology and applications

Prolonged unobtrusive monitoring requires careful design and implementation of ubiquitous monitoring systems. To ensure minimal form-factor, long operating times, and wearability, most BAN sensor platforms work in resource-constrained conditions, thus requiring highly specialized or custom component implementation.

The most efficient system implementation assumes a hierarchical multi-tier organization as presented in Fig. 1. A typical BAN system integrates several miniature sensor platforms located on the body as tiny intelligent patches, integrated into clothing, implanted below the skin or embedded deeply in tissues. Each sensor platform features one or more physiological sensors, such as temperature sensors, electrocardiograms (ECG), photoplethysmograms (SpO2 sensors), breathing sensors, blood pressure sensors, electromyograms (EMG), electro-encephalograms (EEG), and blood glucose sensors; inertial sensors based on accelerometers or gyroscopes for tracking body posture (seating, standing, supine position), as well as type and level of user's activity (e.g., slow walking, fast walking, running). Sensors could be wired to the platform or reside on the sensor platform itself. The exact arrangement depends on type of application, the number of sensor platforms in the BAN, their packaging and placement on the human body. For example, a heart activity platform usually resides on a patch with ECG electrodes [17]. Alternatively, the ECG electrodes can be connected using a flexible wire to the heart activity platform. Next, the heart activity platform may also interface a three-dimensional accelerometer for determining upper body position.

The system integrates several hierarchically organized networks:

- *Sensor Area Network* (*SAN*) integrates several sensors S_{ij} to a single sensor platform SP_i using wired or wireless interface (e.g. implanted blood glucose sensor).

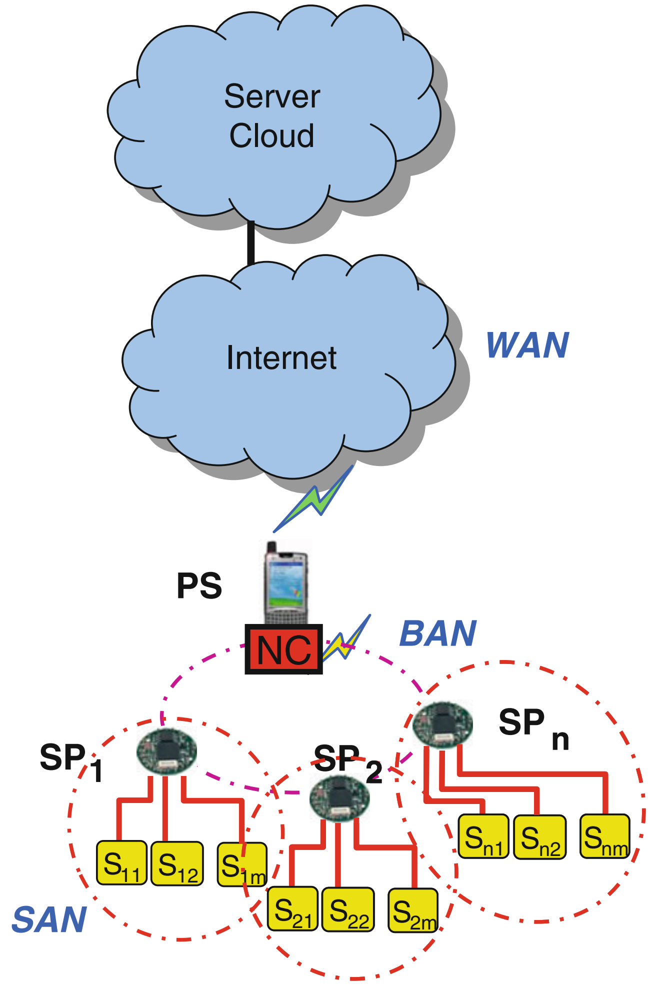

Fig. 1 System architecture of ubiquitous health monitoring systems

Typical example of a sensor platform is presented in Fig. 2. *iSense* is an inertial motion sensor platform for real-time wearable monitoring applications that integrates two sensors: accelerometer and gyroscope [22].

- *Body Area Network* (*BAN*) integrates sensor platforms (SP_i) into a single monitoring system controlled by the Personal Server (*PS*). The personal server also serves as a Network Controller (*NC*). The BAN communication can be wired in clothing or implemented using short range wireless communication [23]. Recent developments, such as ingestible microchips allow temporary associations and data collected inside the body [24][25]. Some BAN systems use home servers/gateways to integrate information from individual sensors to users. This is particularly interesting solution for hospitals and assisted living facilities [26].
- *Wide Area Network (WAN)* integrates multiple monitoring systems, typically implemented through a cellular network into a mobile health or *mHealth* system [4]. Ubiquitous monitoring systems rely on WAN for connectivity, using local area networks such as WiFi

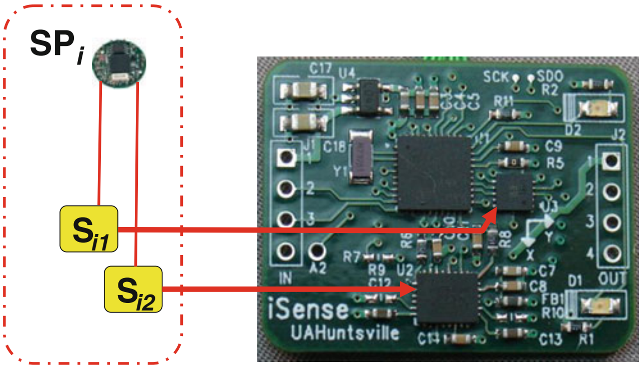

Fig. 2 *iSense*, an example of the sensor platform integrating two sensors, accelerometer (S_{i1}) and gyroscope (S_{i2}) [22]

when available. Alternative modes of communication, if supported by the Personal Server, can significantly reduce power consumption. Server cloud contains multiple servers, such as Medical Server containing user's personal medical record, information servers (e.g. weather forecast), social network servers, and other servers [5].

Current challenges

Ubiquitous health monitoring systems benefited from the fact that basic technologies are driven by consumer markets, particularly cell phone technology to portable communication platforms (e.g. smart phones, laptops, tablets). This is evident by significant improvement of power efficiency of processors and microcontrollers; parameters such as MIPS/mW significantly improved in the last two decades. This trend will continue as basic technologies continue to mature.

Acceptance of ubiquitous health monitoring systems is and will continue to be determined primarily by:

- Wearability
- Ease of use
- Meaningful feedback to the users
- Price
- Privacy & Security

Recent research studies demonstrate the need to quantify user's satisfaction and provide analysis of factors contributing to the acceptance of wireless body area networks [27]. New research and clinical studies are needed to further evaluate the new BAN systems; will users see a value proposition to wear them, will they be widely adopted, can we utilize them in early detection of disease and preventive healthcare, are some of questions that will need to be answered. A strong candidate application is using an ECG based BAN system for arrhythmia diagnostics [27]. Cardiac monitoring is still the most important application of ubiquitous health monitoring. Coronary heart disease is the single leading cause of death in America today [28][29], and WBAN offers an unobtrusive solution for continuous ambulatory monitoring.

As wearable monitoring technology progresses from academic prototypes to commercial products, it is important to understand current challenges and interaction of human and technological factors.

The most critical technical issues for the wider acceptance of ubiquitous health monitoring applications include:

- Low-power operation
- Sensor integration
- System integration
- User localization and identification

Mapping of technical issues to user factors is presented in Fig. 3. The most important relations are presented below.

- *Low power operation* enables further miniaturization by allowing smaller batteries, which improves wearability and ease of use eliminating the need for frequent battery changes (re-charges).
- *Sensor integration* also decreases size and weight of sensors which improves wearability, provides additional functionality that improves ease of use. In addition, technology scaling and increased integration enable smaller systems reducing manufacturing and maintenance cost.
- *System integration* allows context sensing that improves ease of use; access to publicly available resources that reduces operating costs; and use of standard Internet methods for authentication and secure communication that improves privacy and security. System integration also facilitates dynamic creation of social networks that play an increasingly important role in health and wellness management [30][31].
- *User localization and identification* may provide significant context sensing which may provide meaningful feedback to the user; however, user's privacy might be exposed in the process.

Low power operation

Power consumption and expected system operation time determine size and weight of battery, that typically represents

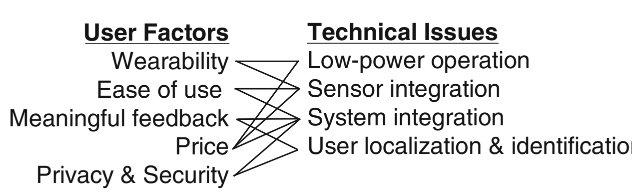

Fig. 3 Interaction between user factors and technical issues for BAN systems

more than 80% of the size and weight of wearable sensors. This is particularly critical for implantable sensors where battery replacement requires surgical intervention.

System designers must consider two critical issues:

- *Average Power Supply Current* (I_{ave}) determines system operation time that can be calculated by dividing battery capacity with average current. Average power supply current is determined by the duty cycle, or ratio of active and idle times in a typical system operation cycle [32].
- *Maximum Power Supply Current* (I_{max}) determines type of battery that can be used, since each battery type has limited maximum current it can provide.

It is important to note that upper levels of the system hierarchy presented in Fig. 1. have lower duty cycles and higher average and maximum power consumption, as well as higher processing power and communication capabilities. We believe that optimal solutions must take into account this hierarchy and distribute processing and communication along the levels of hierarchy for the most power efficient processing that still satisfy application-specific system requirements (e.g. latency and reliability).

Power efficient communication

Two important components of communication in ubiquitous health monitoring systems are BAN and WAN communication. WAN communication relies on standard wide area network, typically cellular technologies, such as WLAN, GSM, GPRS, UMTS, and WiMAX. They offer wide coverage and ubiquitous network access and demonstrate ever increasing speed and reduced price and power consumption, driven by commercial mobile phone market. Ubiquitous health monitoring benefited, and will continue to benefit, from this trend. Therefore, we will not elaborate specific issues of WAN communication in this paper. Service providers, such as Qualcomm, aggressively pursue healthcare applications as potentially very important future segment of their business [15].

The most frequently used standard for wireless BAN communication include:

- Bluetooth [9]
- Zigbee [10]
- Ant [11]
- MICS [33]
- Ultra Wide Band UWB [24]
- Custom protocols [34][35]

Bluetooth is commonly used for implementation of research prototypes and commercial sensors [9]. It features high bandwidth, low latency, and support on many mobile platforms. However, power consumption is high for most ubiquitous monitoring applications (~200 mW for commercially available modules and ~50 mW for low-power modules scheduled for release this year). Configuration features only up to 8 devices in a personal area network, inefficient idle modes, and long start up times, which is not good match for wearable health monitoring applications. New generation of low-power Bluetooth devices targets health applications, although their performance may not be sufficient for the commercially successful BAN applications. Bluetooth is still used whenever high bandwidth and low latency are required [22].

The Zigbee standard was initially developed for smart home applications [10]. It features low-cost, very low power (~60 mW), low data-rate (250 kbps) communication with very low power idle modes and collision avoidance schemes. Most Zigbee controllers feature hardware support for 128-bit AES encryption that can effectively protect BAN transmissions.

Ant protocol is an example of emerging standard for wellness and health monitoring applications [11]. It is supported by several sensor manufacturers, such as Suunto and Garmin [36][37]. It is a low speed, low power protocol. The main issue of Ant based systems is lack of support for Ant communication on standard mobile platforms. However, recently companies such as Spectec started to provide micro SD card with Ant wireless interface [38].

Ultra Wide Band (UWB) features high bandwidth and possible spatial localization of transmitters. High bandwidth is particularly important for applications that require transmission of video stream, for example transmission of video from swallowable camera pill [24] with data rate of 100 Mbps. Localization of users is particularly important for indoor localization in assisted living facilities and hospitals. Although most commercial systems provide certain level of location capabilities using strength of the received signal, the only reliable method of localization is provided by ultra wide band technology. However, the drawback is significant complexity, particularly complexity of receivers that limits its suitability for wearable applications.

All standard protocols feature significant overhead by requiring transmission of protocol-specific information. Therefore, custom protocols can provide significantly more efficient operation in application specific systems [35]. Application specific processors can even implement part of network protocol in hardware to further reduce power consumption [35]. However, the drawback of such systems is their inability to communicate with other sensors/ systems, leaving them in a very limited niche market.

Wireless communication typically consumes at least an order of magnitude more power than active processing on sensors. Therefore, power efficient communication is still a very important research topic. Current challenges and research trends include:

- *Low power operation of network controller.* Mobile platforms are not designed for continuous operation. If the main processor on a mobile platform (i.e. personal server) is used to control WBAN, the system will have a very short operation time. This is the main obstacle for wider adoption of WBAN systems.
- *Alternative wireless interfaces on mobile platforms.* Mobile platforms are optimized for low price, therefore limiting additional on-platform wireless interfaces and even standard system interfaces (e.g. USB host interface). The only standard interface commonly found on mobile platforms is SD card or micro SD card, supported on most mobile phones. As a result, many systems use that SD/micro SD interface for unsupported wireless interfaces, such as Zigbee and Ant wireless controllers from Spectec [38].
- *New wireless protocols* are proposed to reduce protocol overhead and may represent a solution if accepted as a new standard [39]. They can also provide further reduction of power consumption through implementation of network functions in hardware [35]. However, that makes changes in the protocol much harder to implement and support in future versions [40].
- *Wakeup radio* is another promising direction for low-power operation. Although some protocols (e.g. Zigbee) provide collision avoidance through scheduled transmissions, it is still necessary to wake the sensor periodically to maintain time synchronization between sensor and network controller. Those periodic synchronizations still consume significant power, particularly if the sensor transmits data only couple of times a day. The concept of wakeup radio allows transmissions without synchronizations, the transmission itself wakes up the radio on transmitter and allows power efficient operation [41].

Power sources

In spite of many developments in the last two decades, battery technology remains the main obstacle for wider adoption of wearable health monitoring. While the processing power continues to increase at a fast rate, battery capacity was increasing at a much slower rate of approximately 11% per year. Ever increasing gap between battery capacity and processor performance significantly influences possible applications and system design.

Exciting new developments for wearable monitoring applications is introduction of printed batteries [42]. Although featuring very limited capacity, they allow very low profile of sensors and intelligent patch implementations.

Promising opportunity for wider deployment of wireless sensors is energy harvesting [43]. Reduced power consumption made feasible autonomous monitoring systems that can be powered entirely or mostly by harvesting energy from environment. Typical energy generators use vibration, thermal, or ambient electro-magnetic fields. Laboratory prototypes already demonstrated energy independence of wearable physiological sensors [43].

Sensor integration

Integration of multiple sensors on sensor platform reduces the number of components, and consequently size, weight, and price of the platform. Typical functional blocks of a WBAN sensor platform are shown in Fig. 4.

All integrations are driven by the economy of scale and market opportunities. Therefore, it is not surprising that several integrations are driven by the automotive market. As an example, Bosch automotive accelerometers integrate MEMS accelerometer (signal transducer), signal conditioning circuit, and processing core in a single small ASIC (3x3mm) [44]. This is represented as option a) in Fig. 4. However, the same technology can be used in BAN sensors for monitoring of user's activity and motion [22], resulting in a very small, power efficient, and inexpensive sensor for health monitoring application. Custom signal conditioning circuits (ASICs) feature high performance and extremely low power consumption [45]. They can be efficiently integrated into wearable health monitors [46][47][48].

Integration of microcontroller and wireless controller is the next important step, represented as option b) in Fig. 4. As an example, Texas Instruments (TI) as a leader in low power microcontrollers recently acquired Chipcon as a leader in the design of power efficient wireless controllers. As a result, TI introduced CC430 family, a microcontroller-based radio-frequency system-on-a-chip [49]. CC430 is based around a low-power MSP430 microcontroller with a radio-frequency transceiver operating in a sub-1GHZ ISM

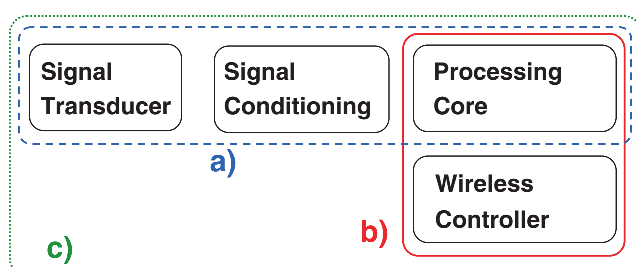

Fig. 4 Sensor integration options; **a**) integration of processing and signal conditioning circuits [44], **b**) integration of microcontroller and wireless controller [49], **c**) single chip sensor implementation [35]

(Industrial, Scientific, Medical) band. It integrates the following components on a single chip:

- a powerful clock and power-management block that supports multiple low-power operating modes;
- a processor/memory block,
- a number of digital I/O peripherals including timers, I/O ports, LCD controllers, serial communication interfaces, an encryption block,
- high-performance analog interfaces (analog-to-digital converters and comparators), and
- radio-frequency transceiver.

With increased level of integration CC430 enables lower power, flexibility in designing RF applications, smaller products and lower systems cost, as well as faster time-to-market.

Ultimate goal of sensor integration is integration of all components on a single chip, represented as option c) in Fig. 4. As an example, Toumaz introduced Sensium Life Platform as a single chip solution for ECG monitoring that integrates bioamplifier, processor, and wireless controller [34][35]. A single chip solution allows extremely small and power efficient sensors for the given application, which in turn allows very small power sources with improved wearability. Sensium supports up to 8 sensor nodes and a USB/UART based gateway.

Nearly all the electronics and firmware for Sensium life platform sensor nodes or base stations are integrated on to a system-on-a-chip called the TZ1030. The TZ1030 operates at ultra low power (the circuitry operates in so-called sub threshold region where transistors are barely turned on, resulting in extremely low-power consumption) and includes a highly flexible sensor interface, digital block with 8051 processor and 64 kbyte of RAM and a custom RF transceiver.

The sensor interface includes all circuitry for sensor interfacing and calibration, including analogue front-end for signal amplification, filtering, sampling, and feature extraction. Coupled with appropriate external sensors, the TZ1030 can provide ultra low power monitoring of ECG, heart rate, temperature, respiration and physical activity. It also includes the flexibility to interface to sensors with analog or digital outputs.

On chip microcontroller with program and data memory enables local processing of signals at the sensor node extracting information such as heart rate from the raw sensor data. This capability can significantly reduce the transmit data payload.

System integration

Full potential of wireless body area networks for health monitoring can be realized by integrating individual on-body systems into ubiquitous real-time *mHealth* systems. Personalized body area networks can dynamically exchange the information with the environment, interact with social networks and tap into a vast knowledge base of the server cloud. Collective information allows better understanding of the underlying phenomena. For example, the same increase of heart rate might be explained by physical activity (information from motion sensor), increased temperature/humidity (information from ambient sensor), social interaction (vicinity of another BAN), or cognitive stress (EEG sensor).

It has been demonstrated that social networks influence health and behavior, as obesity appears to spread through social ties [50]. WBANs can naturally facilitate exchange of information within trusted social network, encouraging healthy behavior and lifestyle changes. All interventions are most likely to succeed if they modify the person's social network. This approach is more cost-effective since health improvements in one person might spread to others in their social network.

The main technical challenges for system integration include interoperability and security. Although common wireless interface may allow exchange of messages, it is necessary to define rules of engagement for smart, interoperable components that operate within a distributed medical monitoring environment that consists of WBANs and environmental sensors [51].

Environmental intelligence

Environmental sensors can provide significant information about the type of activity and context of user's activity. For example, sensors embedded in the carpet can quantify activity of a user, number of visits to the restroom, and other information. Wireless sensor networks are becoming part of our environment. Objects in our environment will represent network nodes, creating a dynamic network—"web of things" [53]. By providing common protocols, we can exchange information with ambient sensors [54]. As an example, personal BAN can automatically associate body weight measurement with a person taking measurement and seamlessly integrated that information into personal medical record. In-home sensors can assess health status and cognitive decline of users by estimating gait velocity [52].

Smart textiles

Integration of sensors into clothes has the potential to significantly improve user's compliance and wearability of sensors. Several projects demonstrated usability of smart textiles for integration of sensors and continuous health monitoring [55][56]. Reebok and MC10 are developing sportswear that incorporates electronics to monitor athletes' health and performance during training and rehabilitation [57].

Smart phones as gateways

Smart phones are natural information gateways and personal servers in ubiquitous health monitoring systems. They can be used to control and collect data from the BAN sensors to the environment. They also provide universal user interface for collection of subjective information and wellness diary [58]. Commonly used platforms allow development of custom applications in iOS, Android, and Windows Mobile development environment. High resolution displays and audio, as well as on-platform sensors make possible high performance personalized user interfaces suitable for long-term use.

The most critical issue is power efficient control of the wireless body area network. The main processor on the smart phone is not power efficient for continuous operation, while small form factor (typically micro SD card [38]) of wireless interface card restricts application of intelligent wireless controllers with power efficient processors. Ideal solution would be integration of the low power wireless interface on standard phone platforms, or implementation of intelligent wireless interfaces with on-board power efficient microcontrollers.

User localization and identification

User localization is important feature necessary for context discovery. Outdoor localization can be accessed through GPS available on smart phone. Indoor localization is much harder to implement, although very important for some applications, such as monitoring in hospitals and assisted living facilities. Depending on application requirements, the system can use strength of the received wireless signal to determine approximate location. Some wireless controllers provide that functionality automatically using the same approach (e.g. Ant [11]). Reliable indoor localization can be achieved as a by-product of use of ultra wide band (UWB) transceivers. However, current generation of transceivers has prohibitive power consumption for wearable applications.

Some health monitoring applications require reliable localization in a very small range, for example, association of measurements from shared sensors, such as blood pressure sensor. Possible solutions include use of passive RFIDs or near field communication [59]. Near field communication controllers are implemented in some mobile phones to support secure exchange of information at small distances (5–10 cm). The same approach can be used to identify the user and associate measurements.

Identification of wearer is another open issue, significant for health monitoring applications. This will be particularly important for the closed-loop systems, such as BAN with integrated drug pumps. Several research projects are evaluating possible use of biometrics methods to identify the user and secure transmissions in wireless body area sensor network [60].

Conclusion

WBAN based m-Health technologies demonstrated great potential for ubiquitous health monitoring during activities of daily living. Potential applications include early detection of abnormal conditions, supervised rehabilitation, and wellness management. They can provide patients with increased confidence and a better quality of life, and promote healthy behavior and health awareness. Automatic integration of collected information and user's inputs into research databases can provide medical community with opportunity to search for personalized trends and group patterns, allowing insights into disease evolution, the rehabilitation process, and the effects of drug therapy.

This paper reviewed the opportunities and challenges of wearable ubiquitous health systems that can increase acceptance of WBAN technology and lower the cost by shifting the focus to prevention and early detection of health conditions. A new generation of personalized monitoring systems will allow users to configure their systems and user interface, interact with their social network and improve their quality of living.

References

1. Jovanov, E., Price, J., Raskovic, D., Kavi, K., Martin, T., and Adhami, R., "Wireless Personal Area Networks in Telemedical Environment", *Third IEEE EMBS Information Technology Applications in Biomedicine—Workshop of the International Telemedical Information Society ITAB ITIS 2000*, Arlington, Virginia:22–27, November 2000.
2. Heile, B., Gifford, I., and Siep, T., "The IEEE P802.15 working group for wireless personal area networks." *IEEE Netw.* 13(4):4–5, Jul. 1999.
3. Raskovic, D., Martin, T., and Jovanov, E., "Medical Monitoring Applications for Wearable Computing." *Comput. J.* 47(4):495–504, July 2004.
4. Istepanian, R. S. H., Jovanov, E., and Zhang, Y. T., "Guest Editorial Introduction to the Special Section on M-Health: Beyond Seamless Mobility and Global Wireless Health-Care Connectivity." *IEEE Trans. Inf. Technol. Biomed.* 8(4):405–414, Dec. 2004.
5. Jovanov, E., Milenkovic, A., Otto, C., and de Groen, P., "A wireless body area network of intelligent motion sensors for computer assisted physical rehabilitation." *J NeuroEng Rehabilitation.* 2:6, 2005, March 1, 2005.
6. Yang, G-Z., *Body Sensor Networks*, Ed. Springer, 2006.

7. Jovanov, E., Poon, C. Y., Yang, G. Z., and Zhang, Y. T., "Guest Editorial Body Sensor Networks: From Theory to Emerging Applications." *IEEE Trans. Inf. Technol. Biomed*. 13(6):859–864, November 2009.
8. Bonato, P.,"Wearable Sensors and Systems." *IEEE Eng. Med. Biol. Mag*. 29(3):25–36, May–June 2010.
9. Blueooth Alliance, http://www.bluetooth.com (Dec 2010)
10. Zigbee Alliance, http://www.zigbee.org (Dec 2010)
11. Ant, http://www.thisisant.com (Dec 2010)
12. TI+Chipcon Low Power RF Guide, http://focus.ti.com/lit/sg/slab052b/slab052b.pdf (Dec 2010)
13. Nordic Semiconductors, http://www.nordicsemi.com/ (Dec 2010).
14. Kalil, T., *"Harnessing the Mobile Revolution," Innovation, Vol. 4, No. 1*, MIT Press, Winter 2009:9–23.
15. Wireless Health 2010, http://www.wirelesshealth2010.org/ (Dec 2010).
16. Shnayder, V., Chen, B. R., Lorincz, K., Fulford-Jones, T. R. F., and Welsh, M., *"Sensor networks for medical care." Division Eng. Appl. Sci.*, Harvard Univ., Cambridge, MA, Tech. Rep. TR-08-05, 2005.
17. Corventis PiiX, http://www.corventis.com/US/medprof.asp (Dec 2010).
18. CardioNet, http://www.cardionet.com/ (Dec 2010)
19. Halo Monitoring, http://www.halomonitoring.com/ (Dec 2010)
20. Zeo, http://www.myzeo.com/ (Dec 2010)
21. Seto, E., Istepanian, R. S. H., Cafazzo, J. A., Logan, A., and Sungoor, A., "UK and Canadian perspectives of the effectiveness of mobile diabetes management systems." *Annu. Int. Conf IEEE Eng. Med Bio Soc, EMBC*:6584–6587, 3–6 Sept. 2009.
22. Jovanov, E., Hanish, N., Courson, V., Stidham, J., Stinson, H., Webb, C., and Denny, K., *"Avatar—a Multi-sensory System for Real Time Body Position Monitoring." Proc. of the 31th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, Minneapolis, USA:2462–2465, September 2–6, 2009.
23. Yan, L., Zhong, L., and Jha, N., "Energy comparison and optimization of wireless body-area network technologies," in *Proc. Int. Conf. Body Area Networks (BodyNets)*, June 2007.
24. Yuce, M. R., Dissanayake, T., and Keong, H. C., "Wireless telemetry for electronic pill technology." *IEEE Sens.*:1433–1438, 25–28 Oct. 2009.
25. Proteus Biomedical Digital Pill, http://www.proteusbiomed.com/ (Dec 2010).
26. Jovanov, E., "Wireless Technology and System Integration in Body Area Networks for m—Health Applications." *Proc. 27th Ann. Int. Conf. IEEE Eng Med. Biol. Soc.* Shanghai, China:7158–7160, September 2005.
27. Fensli, R., Dale, J. G., O'Reilly, P., O'Donoghue, J., Sammon, D., and Gundersen, T., "Towards Improved Healthcare Performance: Examining Technological Possibilities and Patient Satisfaction with Wireless Body Area Networks." *J. Med. Syst.* 34(4):767–775.
28. AHA (2010) American Heart Association, Cardiovascular Disease Statistics, http://www.americanheart.org/presenter.jhtml?identifier=4478
29. Lloyd-Jones, D., and Members, W. G., "Heart Disease and Stroke Statistics 2009 Update: A report from the American Heart Association Statistics Committee and Statistics Subcommittee." *Circulation.* 119:e21–e181, 2009.
30. Rahman, M. A., Alhamid, M. F., El Saddik, A., and Gueaieb, W., "A Framework to bridge social network and body sensor network: An e-Health perspective." *IEEE Int. Conf. Multimedia Expo. ICME*:1724–1727, June 28 2009–July 3 2009.
31. Xuning Tang, Yang and Christopher, C., "Identifying influential users in an online healthcare social network." *Intelligence and Security Informatics (ISI), 2010 IEEE International Conference on*, vol., no.:43–48, 23–26 May 2010
32. Milenkovic, A., Otto, C., and Jovanov, E., "Wireless Sensor Networks for Personal Health Monitoring: Issues and an Implementation," *Computer Communications* (Special issue: Wireless Sensor Networks: Performance, Reliability, Security, and Beyond). 29(13–14):2521–2533, August 2006.
33. Yuce, M. R., Ng, S.W. P., Myo, N. L., Lee, C. H., Khan, J. Y., and Liu, W., "A MICS band wireless body sensor network," in Proc. IEEE WCNC.:2473–2478, 2007.
34. Sensium Toumaz, http://www.toumaz.com/page.php?page=sensium_life_platform
35. Wong, A. C. W., McDonagh, D., Omeni, O., Nunn, C., Hernandez-Silveira, M., and Burdett, A. J., "Sensium: An Ultra-Low-Power Wireless Body Sensor Network Platform: Design & Application Challenges," in Proc. IEEE EMBC.:6576–6579, 2009.
36. Suunto, http://www.suunto.com/ (Dec 2010)
37. Garmin, http://www.garmin.com/garmin/cms/site/us/intosports/ (Dec 2010)
38. Spectec Ant, htpp://www.spectec.com.tw/sdant.html (Dec 2010)
39. Yseboodt, L., Nil, M., Huisken, J., Berekovic, M., Zhao, Q., Bouwens, F., Hulzink, J., and Meerbergen, J., "Design of 100 μW wireless sensor nodes for biomedical monitoring." *J. Signal Process. Syst.* 57(1):107–119, 2009.
40. Ullah, S., and Kwak, K. S., "Performance study of low-power MAC protocols for Wireless Body Area Networks," *2010 IEEE 21st International Symposium on Personal, Indoor and Mobile Radio Communications Workshops (PIMRC Workshops).*:112–116, 26–30 Sept. 2010.
41. Zhang, Y., Huang, L., Dolmans, G., and de Groot, H., "An analytical model for energy efficiency analysis of different wakeup radio schemes." *2009 IEEE 20th International Symposium on Personal, Indoor and Mobile Radio Communications*.:1148–1152, 13–16 Sept. 2009.
42. Printed Batteries—Market Analysis on the Future of Printable Batteries, http://www.azom.com/Details.asp?ArticleID=4951 (Dec 2010)
43. Vullers, R. J. M., Schaijk, R. V., Visser, H. J., Penders, J., and Hoof, C.V., "Energy Harvesting for Autonomous Wireless Sensor Networks." *IEEE Solid-State Circuits Magazine*. 2(2):29–38, Spring 2010.
44. Bosch Sensortec Acceleration Sensors, http://www.bosch-sensortec.com/content/language1/html/4377.htm (Dec 2010)
45. Yazicioglu, R. F., Yazicioglu, R. F., Merken, P., Puers, R., and Van Hoof, C., "A 60 μW 60 nV/√Hz readout front-end for portable biopotential acquisition systems." *IEEE J. Solid-State Circuits.* 42 (5):1100–1110, 2007.
46. Grundlehner, B., Brown, L., Penders, J., Gyselinckx, B., "The Design and Analysis of a Real-Time, Continuous Arousal Monitor," Proc. 6th Int. Workshop on Wearable and Implantable Body Sensor Networks, BSN 2009, June 2009:156–161.
47. Yazicioglu, R., Torfs, T., Penders, J., Romero, I., Kim, H., Merken, P., Gyselinckx, B., Yoo, H., and Van Hoof, C., "Ultra-low-power wearable biopotential sensor nodes." *Proc. EMBS.*:3205–3208, Sept 2009.
48. Brown, L., van de Molengraft, J., Yazicioglu, R. F., Torfs, T., Penders, J., and Van Hoof, C., "A low-power, wireless, 8-channel EEG monitoring headset," in Proc. IEEE EMBC.:4197–4200, 2010.
49. TI CC430, http://www.ti.com/cc430 (Dec 2010)
50. Christakis, N. A., and Fowler, J. H., "The Spread of Obesity in a Large Social Network over 32 Years." *N. Engl. J. Med.*:357:370–379, July 26, 2007.
51. Warren, S., and Jovanov, E., "The Need for Rules of Engagement Applied to Wireless Body Area Networks," IEEE *Consumer Communications and Networking Conference CCNC2006*, Las Vegas, Nevada:979–983, January 2006.

52. Hagler, S., Austin, D., Hayes, T. L., Kaye, J., and Pavel, M., "Unobtrusive and Ubiquitous In-Home Monitoring: A Methodology for Continuous Assessment of Gait Velocity in Elders," *IEEE Trans. Biomed. Eng.* 57(4):813–820, April 2010.
53. Web of Things, http://www.webofthings.com/wot/2010/ (Dec 2010)
54. Gupta, V., Poursohi, A., and Udupi, P., "Sensor. Network: An open data exchange for the web of things," *8th IEEE International Conference on Pervasive Computing and Communications Workshops (PERCOM Workshops)*:753–755, March 29 2010–April 2 2010.
55. Boulos, M. N. K., Lou, R. C., Anastasiou, A., Nugent, C. D., Alexandersson, J., Zimmermann, G., Cortes, U., and Casas, R., "Connectivity for Healthcare and Well-Being Management: Examples from Six European Projects," *Int. J. Environ. Res. Public Health*. 6:1947–1971, 2009.
56. Coyle, S., Lau, K. T., Moyna, N., Diamond, D., di Francesco, F., Costanzo, D., Salvo, P., Trivella, M. G., De Rossi, D., Taccini, N., Paradiso, R., Porchet, J. A., Ridolfi, A., Luprano, J., Chuzel, C., Lanier, T., Revol-Cavalier, F., Schoumaker, S., Mourier, V., Chartier, I., Convert, R., De-Monquit, H., and Bini, C., "BIOTEX—Biosensing textiles for personalised healthcare management." *IEEE Trans. Inf. Technol. Biomed.* 14(2):364–370, 2010.
57. K. Bourzac, "Stretchable Silicon Could Make Sports Apparel Smarter," MIT Technology Review, Dec 9, 2010, http://www.technologyreview.com/computing/26872/
58. Mattila, E., Korhonen, I., Salminen, J., Ahtinen, A., Koskinen, E., Sarela, A., Parkka, J., and Lappalainen, R., "Empowering citizens for wellbeing and chronic disease management with wellness diary." *IEEE Trans. Inf. Technol. Biomed.* 14(2):456–463, 2010.
59. Dohr, A., Modre-Opsrian, R., Drobics, M., Hayn, D., and Schreier, G., "The Internet of Things for Ambient Assisted Living." *Seventh International Conference on Information Technology: New Generations (ITNG).*:804–809, 2010.
60. Poon, C. C. Y., Zhang, Y. T., and Di Bao, S. D., "A novel biometrics method to secure wireless body area sensor networks for telemedicine and m-health." *IEEE Commun. Mag.* 44(4):73–81, April 2006.