REQUIREMENTS AND SYSTEM ARCHITECTURE FOR A HEALTHCARE WIRELESS BODY AREA NETWORK

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Abstract: Wireless body area networks enable new opportunities for personal healthcare monitoring and personal healthcare applications. This paper presents a comprehensive set of requirements and challenges for building a wireless body area network to support diverse user groups and a corresponding set of healthcare applications. Based on the identified requirements, the paper presents an architecture for a wireless body area network and describes how this architecture is connected to an existing it-infrastructure supporting healthcare at home. Finally the paper presents our on-going research with development of an ASE-BAN test bed. The major goal for this test bed is to be a platform for research and experiments with development of an ultra-low power body area network including sensor, communication nodes, communication protocols and a body gateway component.

1 INTRODUCTION AND BACKGROUND

There is a rising need for personal home healthcare due to a growing population of elderly people (Patel et. al., 2010) and (Wagner et. al., 2009). To support the health problems of the elderly population wireless communication technologies have enabled new types of applications for monitoring and controlling people's physical parameters.

The first generation of e-healthcare solutions were more or less replacement of a wire with a wireless communication channel i.e. another set of protocols on top of the new physical communication media. In the second generation the devices communicated wireless with a local system host, which relayed alarms and possible also data to remote sites. In the third generation the measuring devices are wireless connected to a mobile body area network along with other sensors and actuator.

The development of successful body area network (BAN) infrastructure, sensors and the supporting applications involves specifying a set of requirement based on real-life problems of the elderly. The current work in this field is mainly dominated by a technology driven perspective but as the success of these body near technologies depends very much on user acceptance of the technologies we suggest, to use a much more user focused and user driven innovation process in the future research including practical testing with real users using these new inventions.

In this paper we will present a comprehensive set of requirements for a BAN-system and the individual BAN components.

The proposed requirement are based on our current work with architecture and network infrastructure for home healthcare in scope of the OpenCare project (Wagner et. al., 2009). The focus has initially been to create an it-infrastructure for connecting single wireless healthcare sensors typically based on Bluetooth. In this paper we extend the OpenCare project with the description of development of a test bed for a body area network called ASE-BAN.

The paper will first present a definition of ASE-BAN requirements and based on these develop a supporting ASE-BAN architecture.

This paper takes the perspective of the user, in defining the functional requirement as well as the non-functional system requirements.

More technical requirements are currently being defined by the IEEE 802.15 WPAN Task Group 6. (IEEE P802.15, 2008), which defines the requirements for a Wireless Personal Area Networks (WPAN). A short overview of these requirements,

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current challenges and wireless technologies for BANs are presented by Patel (Patel et. al., 2010).

A supplementary proposal for technical requirements is presented by Drude (Drude, 2007).

2 APPLICATION SCENARIOS

There are numerous user scenarios for healthcare applications (Drude, 2007). In this Section we will present the four user scenarios we found most interesting in relation to development of a BAN.

2.1 Health Monitoring

Health monitoring is about using technology to monitor a person remotely and is one of the most common usages of healthcare applications. An example could be for heart diseases, where a sensor will monitor the person's ECG signal for detecting heart arrhythmias, heart attach or for monitoring of a person's heart rate variability (HRV). Another typical scenario includes blood pressure measurements with remote registration of measurements.

2.2 Closed Loop Applications

In a closed loop application an automatic regulation loop is closed between a sensor and an actuator e.g. a sensor measuring glucose level and automatically controlling an insulin pump actuator. These types of applications are yet not as common, as they require very reliable systems and also a very strict approval procedure from healthcare authorities.

2.3 Rehabilitation from Accidents

In a rehabilitation process after an accident, a personal healthcare system can give instructions for exercises and monitor the performance and the progress. Users for this type of application could be of all ages. A body area network used for computer assisted rehabilitation is described by Joanov (Joanov et. al., 2005). Computer assisted home training have the opportunities to getting people quicker back to a normal life and also to save the users time and money.

2.4 Empowerment of Elderly People

With the growing number of elderly and active people, these types of application could in the future help this group be active longer, stay in their homes and thereby prevent hospitalization. It could be interactive computer games or dedicated training programs which is controlled by feedback from the BAN sensor nodes.

3 BAN REQUIREMENTS

This section presents requirements for a wireless body area network consisting of wireless network nodes (called motes in Figure 1) and a body gateway node connected to some kind of host server. The motivation for this architecture will be given in Section 4.

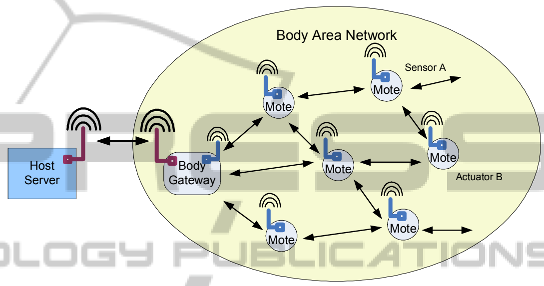

Figure 1: Wireless body area betwork topology and components: sensors/actuators, body gateway and host server.

Requirements in this section are mainly requirements which will have an influence on the system architecture for the BAN and thereby not an attempt to define a complete set of application oriented functional requirements, which normally are defined using the use case technique. First, the user related requirements are described, followed by a set of more general system requirements. Most of these requirements have an impact on both the hardware architecture and partly also on the software architecture. A subset of these requirements is also listed by Shnayder (Shnayder et. al., 2005).

3.1 User Related Requirements

3.1.1 Diverse User Group

We name the user of the BAN a *citizen* as a more inclusive term than *patient*. Users of the BAN can for example be elderly persons living at home or in a nursing home, it can be physical disabled persons at all ages, it can be persons suffering from dementia, it can be persons with chronicle diseases at all ages and it can be athletes. Some of these users have several of these characteristics e.g. an elderly physical disabled person with a chronicle disease.

We have in this way a very diverse user group spanning from young to very old and in some cases people suffering from dementia. These different types of users have very different needs and different skill levels for handling new technology, where the user group with dementia and disabled people raise the largest challenge for the healthcare developers. This leads to the first challenge:

Challenge 1: Dealing with very diverse types of users, with different application needs and different skill levels.
Requirements: Adjustable technology, user friendly, easy installation and configuration of software and hardware, easy to add new functionality and sensors.

Development of a BAN system for this diverse user group will benefit from using a user driven innovation and development process.

3.1.2 Citizen Communication

The BAN should support different ways of communicating with the user. It could be by messages, LED lamps and sounds; it could be by speech syntheses or speech recognition, by activating normal buttons or soft buttons on a touch screen. Another possibility is communication with hearing-aids or headphones. Some of these devices can be used to give reminders to the citizen e.g. a reminder to take medicine or to exercise or to measure blood pressure.

Challenge 2: User interface design for a diverse user group.
Requirements: User friendly and easy to use interfaces.

This could be obtained by conducting usability studies with different user groups and different types of interfaces supported by incorporating industrial designers in the design team and process.

3.1.3 Calling for Help

The BAN should support a "call for help" device so a citizen can call help at any time. This functionality could be supplemented with a voice-channel so the caretakers can communicate with the citizen.

Challenge 3: To offer safety and security to citizens.
Requirements: Physical design of a reliable call-device and a reliable system for transferring this event, as this could be an emergency call.

3.1.4 GPS Outdoor Positioning

The BAN should allow the connection of a GPS-device for locating people in case of an accident. It could for example be demented people who left the nursing home without supervision or a citizen getting a heart attack outside the home. As a GPS-receiver is a power demanding device, the receiver should be controlled by the BAN and the connected system so it only works on demand and therefore only use power in a short time frame.

Challenge 4: To locate a citizen in case of an accident.
Requirement: Outdoor navigation using GPS.
Ideally, indoor positioning is also relevant, however this is currently much more challenging and not part of our current research scope.

3.1.5 Fall Detection

The BAN should support a fall detection device node with the purpose of sending an automatic call for help. It could be in situations where the citizen is unconscious after a fall or it could be a person with dementia, who couldn't operate a call button or a call device.

Challenge 5: Reliable detection of a fall.
Requirement: Physical design of a tiny and reliable fall detector node integrated on the person e.g. in the cloth or in a belt.

3.1.6 Mobility

The citizen should be allowed to move freely around that means for example a heart ECG monitoring should take place indoors in a private home or at work as well as outdoors and in public places.

Challenge 6: To be continuous and everywhere connected.
Requirement: Seamless connectivity over heterogeneous networks with automatic roaming supporting indoor as well as outdoor communication over Wireless-LAN (WLAN) and WWAN.

3.1.7 Physical Constraints for BAN Components

All the BAN components are connected with wireless technology and should be as integrated as possible in the person's daily life. This raises specific requirements for the physical design i.e. it should have a very small form factor and be lightweight and have a smart design.

Some of these devices requires skin contact and could be integrated in a plaster; some could be integrated in the cloth as an intelligent textile and some should be visible e.g. a device with user interaction for example integrated in the body gateway.

Challenge 7: Obtaining user acceptance of healthcare technology devices and wearing.
Requirements: Low form factor, low weight and easy installation, wearing and a nice-looking design.

3.1.8 Power Consumption

With the diverse user group in mind it is difficult for these users to handle battery exchange and charging of a number of sensor nodes. For general convenience the devices should be developed as ultra-low powered devices with either long battery life or utilizing some kind of energy harvesting energy neutral technique. This leads to the architectural design with only a single demanding unit – the body gateway.

Challenge 8: Low powered devices with low power communication cost.
Requirements: There is a demand for ultra-low powered devices (nodes) and communication protocols.

The body gateway requires more power and could be charged e.g. by an inductive way or by a normal power charger with the inconvenience for the user and problems with being offline.

3.1.9 Economics for a BAN

The technology can help reducing the workload with care giving, but of course with a price – the cost of the new healthcare technology. With the high volume of users there are strict requirements to the solutions to be as cheap as possible both in buying, installation and operation.

Challenge 9: Obtaining low total system cost and operation cost.
Requirements: Low system costs, low communication costs, specific for the mobile communication part, which currently can be quite expensive.

3.2 General System Requirements

3.2.1 Security and Safety Issues

It is very important that both the BAN and the rest of the infrastructure are both safe and secure. Personal related information is normally regulated by national laws and should be transferred in a safe and secure manner. Another problem could be external hackers which could threaten for example a close-looped application connected to a medicine injection pump. Personal related information is very sensitive and confidential and a BAN sets strict requirements to the handling of this information.

Challenges 10: Obtaining a safe and secure system.
Requirements: Use of standard encryption techniques and authentication protocols.

3.2.2 Healthcare Application Flexibility

The BAN should support the possibility to place the application or business logic code on different places in the architecture. It could be on a sensor node, on the gateway or on one of the connected servers. Implementing an application on a sensor node doing pre-processing of the signal can reduce the communication bandwidth and thereby save power, but at the cost of a more expensive sensor node.

Challenge 11: Obtaining a flexible software and hardware architecture with different processing capabilities.
Requirements: An adjustable SW-framework or structure for application code and a flexible component oriented hardware architecture.

An automatic configuration of the application and sensor node software is a clear goal.

3.2.3. Monitoring Data Types

Data types can be real-time life-critical application data: ECG data as well as sporadic event data for example alarms and emergency call for help.

Challenge 12: Very diverse requirements for signal monitoring.
Requirements: Support for continuous real-time monitoring as well as for sporadic events. See (Patel et.al., 2010) and (IEEE P802.15, 2008) for a list of technical requirements for different applications with bitrates from less than 1 kBit/s for drug dosage and up to 10 MBit/s for video imaging.

3.2.4. Citizen Identification

The BAN should support an identification mean so the citizen can be unambiguous identified by supporting systems and the identification can be send with the collected data to remote servers.

Challenge 13: To obtain an unambiguous and secure identification.
Requirement: A secure identification of the citizen is required for the BAN system

3.2.5 Node and Person Matching

The BAN should support a mean for unambiguous identification of sensor- and actuator nodes on a given person and connect these devices with the citizen's identification code. In this way the sensor data can be linked to a given person. The problem occurs when a sensor node connects to nodes on other persons BAN in near vicinity of the person.

Challenge 14: Matching nodes with the person wearing the wireless node.
Requirement: For a secure and easy identification method.

This could for example be obtained by using Body-coupled communication (BCC) where the BCC is used to discover an identify sensor nodes on the same body as presented in (Falck et. al, 2007).

3.2.6 Open Standards and Open Source

The BAN should be based on open international standards for supporting as many BAN devices as possible from different vendors and with different types of functionality. The Continua Health Alliance, a non profit coalition of more than 200 member companies, has defined interoperability goals for wireless systems (Continua Alliance, 2010) and the (IEEE P802.15, 2008) group is working on an IEEE standard for wireless personal area networks. The Continua Alliance material and software are mainly openly available for members of the alliance.

Challenge 15: Development of open standards for the BAN.
Requirements: Open standards free to everyone and optionally also open source software solutions for BAN components.

3.2.7 Network Topology & Communication

The BAN should work with any kind of network topology from a star network with bidirectional communication between gateway and sensors or actuators, to a meshed network that allows communication between all nodes. It is critical to have a network infrastructure and related communication protocols that minimize the power consumption of this part of the BAN too.

Challenge 16: Design a network with ultra-low power, secure and reliable communication.
Requirements: Support for star and mesh topology.

4 SYSTEM ARCHITECTURE AND ON-GOING RESEARCH

The overall design guideline for the ASE-BAN is to have a powerful body gateway node acting as the link to external systems i.e. the host server in Figure 1. and the Central Server or Home Base Station in Figure 2. This body gateway should be the only power demanding component with a longer communication range supporting both wireless LAN and WWAN communication and with a seamless hand-over between the two.

The other BAN-nodes should be ultra-low power sensor or actuator nodes with a limited communication range less than one meter, where the communication power level can be adjusted to the minimum required for getting a reliable on-body communication.

Figure 2 shows a proposal for a domain model for a complete healthcare system showing the BAN system which is mounted on the indicated citizen. When the citizen is at home the communication will be over WLAN from the body gateway and it can typically send both alarms and monitored data from the BAN to the home base station component, e.g. a touch screen based computer.

If the citizen leaves his or her home the BAN will automatically stop sending real-time monitoring data and store them locally on the BAN gateway component and only communicate alarms and keep alive signals over the WWAN (e.g. GSM or UMTS).

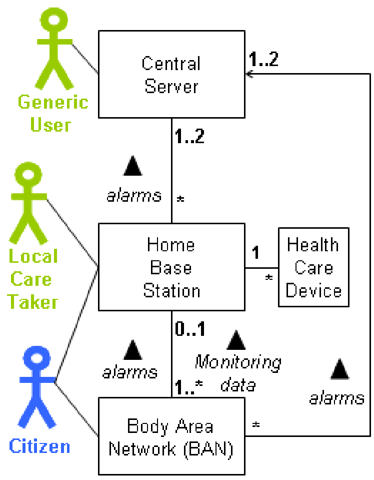

Figure 2: System domain model including BAN.

This solution is previously proposed in (Saadaoui et.al, 2007), as it saves communication cost i.e. both power and money. The principle of having a Central Server and a Home Base Station is implemented in the OpenCare project described in (Wagner et.al., 2009), where the BAN is described as a Mobile Tier component for communicating a single physical value from a citizen and not as being a part of a body area network.

The idea of having a powerful gateway for the body area network is also described in the work by Janov (Janov et. al., 2005) and Otto (Otto et.al., 2006), where they describe a three tier system consisting of tier 1. WBAN nodes, tier 2. a Personal Server and tier 3. Central Systems. On their WBAN each node communicates in a star network with the personal server i.e. the gateway. In our work we have both a star and a mesh network as possible solutions as a mesh configuration enables ultra-low power communication. Another important difference, in relation to the work described in (Saadaoui et. al., 2007), is the introduction of the home base station component, which gives another level of service to the citizens living in a private home; for elderly people normally one or two persons. The home base station collects monitoring data from the BANs for the people living in the house and it also supports shared and non-personal related healthcare devices in the home, which assist the residents with staying healthy. This could be a medicine dispenser automaton, a blood pressure meter or a weight, which can have one or more users. Using a home base station enables development of healthcare applications which takes decisions based on inputs from several different input sources i.e. BAN sensors or from the shared devices.

Another advantage with the WWAN enabled body gateway is the extra security obtained by having a backup channel for alarms in case of malfunctions in the normal data flow from BAN, to home base station to central server.

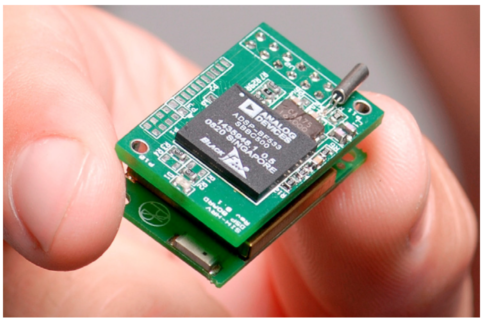

Figure 3: The ASE-BAN ECG Sensor module. The size is 13 mm x 18 mm x 30 mm. The weight is 6 g.

Figure 3 shows an example of a sensor node used in the ASE-BAN test bed (Madsen et. al., 2010) consisting of a sensor print with a digital signal processer connected in a sandwich structure with a wireless radio print. This gives the flexibility to experiment with different radio technologies and components. In our further work we plan to develop these modules in even smaller scales. Other examples of ASE-BAN sensor nodes under development are a fluid balance sensor node for detecting dehydration of elderly people and a fall detector node. BAN nodes can be body worn sensors or actuators as well as implantable medical devices (IMD) e.g. a pacemaker.

5 FUTURE WORK AND CONCLUSIONS

Our future research will experiment with different Wireless radio technologies, mesh networks with power efficient communication protocols and building a flexible hardware and software architecture for both the body gateway and the sensor nodes. Currently we are developing a generic and flexible sensor node platform, where different types of sensors can be mounted together with different processor types and radios. We are currently investigating the body gateway platform, where we are looking on the possibility of using a standard smartphone or alternatively develop an embedded body gateway.

This paper has defined a set of research challenges and corresponding set of relevant requirements for a BAN system to be used in healthcare application. Based on these requirements a system architecture proposal for an ASE-BAN has been presented which is integrated with an infrastructure in the home and with central servers.

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