Architecture Concept of a Wireless Body Area Sensor Network for Health Monitoring of Elderly People

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Abstract— *Emerging Wireless Body Area Sensor Networks are a promising technology which enables health monitoring of elderly people and enhances their independent living. In this paper, we propose the system architecture and protocol stack of a Wireless Body Area Sensor Network for health monitoring of elderly people. The architecture can be deployed in both indoor and outdoor environments and enables transmission of both routine and emergency vital signs.*

Key words: *Body Area Sensor Networks, health monitoring, architecture, protocol stack.*

1. Introduction

Recent advances in wireless networking, microelectronics and wireless sensors help to cope with the imminent problems and social challenges of a growing aging population.

The number of elderly is expected to grow very rapidly in Germany and many other countries during the coming decades. Between 1998 and 2080, the total population of Germany is expected to decline by 35.5% from 82.1 million to 53.1 million. At the same time, the number of elderly will increase by 21.1% [1]. The trend is global. In 2002 the globe held 440 million people age 65 or over. The worldwide aging population is projected to increase rapidly, almost doubling by 2020 and more than tripling by 2050 [2].

Simultaneously with this constantly increasing number of elderly people, health costs are also increasing demanding for novel technological solutions that enhance elderly independence, address health monitoring and lower healthcare bill. In Germany, the overall hospital expenditure will increase from about 24.7 billion Euros in 2000 to more than 46 billion Euros in 2041 [3].

How can we deliver better and less expensive healthcare services to this growing population of seniors? One possible solution could be to shift health monitoring from hospital systems to those places where elderly people live and move. This solution allows seniors to stay longer at home. In recent years, there has been increasing interests in researches investigating elderly health monitoring systems. Wireless Body Area Sensor Networks (WBASN) is an emerging technology area which utilizes wireless sensors to build a complete wearable health monitoring system.

In this paper we describe an architectural concept of a WBASN for health monitoring of elderly people. The application of this ongoing work is the monitoring of elderly people with cardiac arrhythmia. The WBASN consists of a pulse oximeter sensor which monitors the blood oxygen saturation (SpO_2) and heart rate (HR) and an Electrocardiogram sensor (ECG) for monitoring heart activity. We are interested in transmission of both routine and emergency vital signs and we propose a solution that can fit both indoor and outdoor environments. While it is mainly deployed at home, our system remains operational if the elderly leaves his/her home. At home both routine and emergency vital signs are transmitted over a WLAN network. In outdoor environments, only emergency vital signs measurements are transmitted over a GPRS network. Routine vital signs are stored locally and uploaded when the person gets back home. This choice minimizes communication costs over the GPRS network.

The remainder of this paper is structured as follows: In section 2, we review related work. Section 3 and 4 outline the architectural requirements and describe the proposed system architecture. The protocol stack is presented in section 5. In section 6, we discuss simulations and evaluations results. Finally, section 7 concludes the paper.

2. Relate Work

A number of recent projects have focused on WBASN and wearable health devices. They can be classified according to their deployment environment (Indoor/outdoor) or the type of health data they transmit (routine/ emergency vital signs)

In [4] the hardware and software architecture of a WBAN for ambulatory health status monitoring is discussed. A prototype including two activity sensors and an ECG sensor, a Personal Server and a Network

Coordinator has been developed; integrating the WBAN into a broader multi-tier telemedicine system and using Zigbee as wireless technology. The deployment environment of their application is indoors.

The MobiHealth project [5] developed a customisable vital signals monitoring system based on a Body Area Network (BAN) and an m-health service platform utilizing UMTS and GPRS networks. The BAN prototype was tested in clinical trials with different healthcare states. Tests included transmission of both routine and emergency vital sign Wireless technologies such as Bluetooth and Zigbee were used for intra-BAN communication whereas GPRS and UMTS for external communication. During the validation phase of the project, it was concluded that a major issue in the development of new medical services, is the communication costs. According to the validation tests, continuous monitoring of vital signs generates data in the order of magnitude of 10MB per day per user and an application communication cost of around 1 Euro per MB.

A scenario from the Ubimon project [6] developed at the department of Computing, Imperial College London, aimed at investigating Healthcare delivery by combining wearable and implantable sensors. The project proposed monitoring patients under natural physiological state in their daily life. The described scenario monitored routine vital signs.

HealthGear, a wearable real-time health system for monitoring and analysing physiological signals [7] developed at Microsoft Research Department, consists of a set of physiological sensors connected via Bluetooth to a cell phone. It is used with an oximeter to constantly monitor and analyse the user's blood oxygen level SpO_2 and heart rate. An exemplary HealthGear application is monitoring users in their sleep in order to detect sleep apnea events. The proposed architecture deals with routine vital signs and is deployed in an indoor environment.

CodeBlue is a research project at Harvard University. It integrates sensor nodes and other wireless devices into a disaster response setting [8] [9]. This project developed a pulse oximeter sensor, two lead electro-cardiogram and a specialized motion-analysis sensor. CodeBlue comprises a suite of protocols and services that let heterogeneous devices such as wireless sensors, location beacons, PDAs (Personal Digital Assistants) and laptops coordinate their activities. It outfits patients in emergency and disaster environments with wearable wireless sensors and allows care givers to continuously monitor the status of their patients. The sensors use ad-hoc networks to transmit emergency vital signs.

While the mentioned projects led to interesting results, they can not fulfil all requirements of the mentioned scenario. Our ongoing work focuses on the development of a novel architecture which moreover enhances patient mobility and deals with both indoor and outdoor environments. It enables monitoring and transmission of both routine and emergency vital signs. Furthermore, it takes into account communication costs, an issue which was also raised in the MobiHealth project [5]. It can be addressed by limiting the transmission over the GPRS network in outdoor environments to emergency vital signs only. Routine vital signs can be stored locally and uploaded later at home. To the best of our knowledge, no one proposed the storage of vital signs in outdoor environments to reduce communication costs and combined the transmission of health data over a WLAN at home and a GPRS network outdoor.

3. System Requirements

In order to make a WBASN useful and practical, some requirements have to be fulfilled. These requirements are closely related to the specific application. In our case study, the WBASN architecture must satisfy the following requirements:

Length of monitoring: The cardiac activity needs to be monitored for an extended period especially for elderly people suffering from cardiac arrhythmia. Long-term analyses on ECGs are required to predict eventual heart attacks. The application must allow continuous monitoring.

Reliability: The reliability of measurements and message delivery to healthcare professionals is essential, due to potentially life-threatening episodes.

*Power Management: Senso*r nodes have low power capacity and are assumed to be dead when they are out of battery. The system must conserve energy especially when the elderly subject is outside.

Time synchronization: Each sensor runs at its own clock and has a different sample frequency. Consequently time synchronization between sensors is needed.

Message delivery: vital signs are delivered within a certain time determined by the level of emergency. The architecture should allow real-time delivery of emergency vital signs for both indoor and outdoor environments. Messages carrying emergency vital signs require minimal delays.

Frequency of signal transmission and the amount of information: Important questions are how

often data has to be transmitted and how much data. In our application the physiological data is acquired for an extended period (8 hours for example) and downloaded to the base station in real time. The system ensures periodic transmission of routine vital signs and immediate transmission of emergency messages. The application data traffic is determined by the sample frequency and digitization method.

Buffer management: In the outdoor environment, the routine vital signs are stored. Buffering data may result in a buffer overflow due to capacity limitations. This may lead to data loss or temporal application termination.

Scalability: The architecture should scale well in terms of the number of patients and the number of sensors on each patient.

4. System Architecture

A. *Choice of the wireless technology*

The candidate wireless technologies are based on the standards IEEE 802.11b, IEEE 802.15.1 and IEEE 802.15.4. Several considerations are taken into account to match the medical application with the wireless technology [10] *The application data traffic:* In most cases the sampling frequency of the physiological signals is configurable. In our case study, The ECG signal is sampled at a rate of 500 samples per second with a sample size of 16 bits. The oxygenation as well as the heart rate are sampled at a rate of 1 sample per second with a sample size of 16 bits. The application data traffic is 500*16+1*16+1*16=8032bits/s.

The standards IEEE 802.15.4, IEEE 802.15.1 and IEEE 802.11b offer respectively 0.25 Mb/s, 1 Mb/s and 11 Mb/s data rates. Considering the application data traffic requirements, IEEE 802.15.4 appears more appropriate than the two other standards.

Coverage area: Coverage areas vary from the body area (<1m), personal area (<10m), local area (<100m) to wide area (>100m). Since the healthcare application communicating devices are in close proximity to each other, IEEE 802.15.4 is an appropriate choice for communication in the personal area while the IEEE 802.11b covers the local area.

Network architecture: IEEE 802.15.4 uses an ad hoc mode. This mode is appropriate for our application where the sensors are communicating with the base station in an ad hoc manner.

Power management: The amount of power used to generate the wireless signal affects the power consumption of the wireless device. IEEE 802.15.4 targets low power and low data rate applications.

B. *Proposed architecture*

The proposed Wireless Body Area Sensor Network for elderly healthcare monitoring is illustrated in figure 1. The health status of the elderly subject is remotely monitored to detect sudden changes or predict possible heart attacks. ECG, blood oxygen saturation and heart rate are required for such predictions of life threatening episodes. The doctor or caregiver receives both the long-term trend data and possible automatic alarms in emergency cases.

When the elderly is at home, sensor nodes sense and process the physiological data and send them to the patient-carried base station. The latter analyses the collected data. It ensures real time transmission of emergency vital signs and periodic transmission of routine vital signs (data within a normal range). The base station uploads the data it collects to the central server which is located in a hospital or a healthcare centre. When the elderly leaves home, the base station stores routine vital signs and transmits only emergency data over a GPRS network.

The proposed architecture facilitates monitoring and assessment of seniors' health without the prohibitive costs of existing structures. Elderly people can send from home detailed and accurate vital signs measurements. The doctor or caregiver can access the data from his/her office and checks the patient health status. Remote medical databases allow long-term analysis on historical data and help healthcare professionals to track every prescribed drug over a patient's health.

The system has a three-level hierarchy comprised of sensor nodes, a base station and a central server.
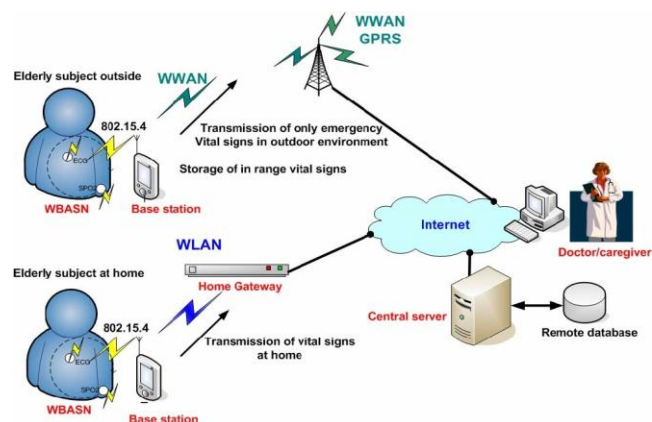
The sensor nodes: Sensor nodes sense, process and communicate vital signs. They store acquired data and transmit them to the base station before their memory fills. In our case study, the sensors consist of an ECG and a pulse oximeter. The ECG sensor monitors the heart electrical activity. Pulse oximetry accesses blood oxygen saturation and heart rate. These parameters are critical information in emergencies. In such situations, a reduction in blood oxygenation or sudden change in heart rate can indicate a need for urgent intervention [7]. A GPS sensor can also be used outdoor to track the elderly subject location in emergency cases.

The base station: The base station is a Personal Digital Assistant PDA. It is carried by the patient and communicates with sensor nodes via a Network Coordinator. The wireless communication is based on the IEEE 802.15.4 standard which is promoted by the Zigbee Alliance [11] [12] and the Network Coordinator is attached to the base station.

To communicate with the central server, the base station employs a WLAN to reach an Internet access point (e.g., a home gateway). The base station acts as a local processor: It allows collecting, present and analyzes sensor signals. It can store the collected data before uploading it to the central server. It must ensure periodic transmission of routine physiological data and immediate transmission of emergency data.

When the patient leaves home, the base station detects the absence of WLAN beacons and switches to the outdoor environment operation mode. In such environments, it analyses the collected physiological data, stores the in-range vital signs locally, and initiates uploads when the subject is back within the home network coverage. If an abnormal condition is

Detected, it sends immediately the emergency vital signs to the central server over a GPRS network. The level of emergency is determined by comparing the current values of vital signs to the patient specific thresholds.

The central server: The central server performs central data storage. It receives the sampled physiological data and stores it to the database. As mentioned above, this enables doctors to do long-term analysis and predict heart attacks or other life threatening conditions. The central server keeps also electronic medical records of patients and contacts emergency caregivers if a serious health anomaly is recognized. Furthermore, it forwards doctors and caregivers instructions to patients.

5. Protocol Stack

Given the previous system requirements and architecture, the proposed protocol stack is

illustrated in figure 2. The left side represents the Zigbee protocol stack [12]. The WBASN application consists of the sensor nodes and the network coordinator Application Objects. When deployed, sensor nodes must join the network, collect and sample health data and transmit it to the base station. The network coordinator tasks include network configuration and management.

The proposed WBASN operates in a star network topology. All communications are established between the sensors and the network coordinator. The coordinator operates in a beaconed mode and uses a Superframe structure [11].

As shown in figure 2, two important helper protocols are to be taken into account in this ongoing work. Time Synchronization is a crucial issue in WBASN. Wireless sensor nodes distributed on the body measure time using local clocks and have different sample frequencies. Local time readings of sensors can easily mismatch because of random phase shifts and drift rates of clock oscillators. The error is cumulative as the sensors operate for long periods and they can loose synchronization if we do not address this issue by a time synchronization protocol.

Efficient Power Management Scheme is considered because power consumption is a major concern as sensor nodes should operate for extended periods in this application. Wireless sensors are battery powered and elderly people should not be bothered by regular battery replacement or recharging.
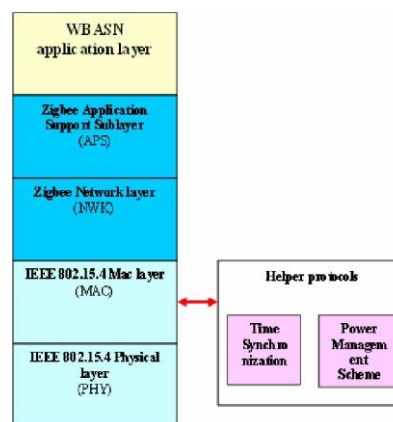

Figure 2. WBASN Protocol stack

Power consumption must be particularly reduced if the patient is outside. Furthermore, sensor nodes must not be out of battery in emergency situations. In order to conserve energy, nodes should be put into sleep modes whenever possible. This can be achieved by a judicious choice of a power management scheme.

6. Simulation Scenario

We are currently simulating the proposed architecture in an indoor environment. Simulations are carried out with the NS2 network simulator [13]. When the elderly subject wearing the sensors moves, only a hardly noticeable movement between the sensor nodes and the "on-body"-base station occurs. Thus, the sensors and the base station can be seen in a fixed topology. The studied area is a lateral surface (1m*1m) and Constant Bit Rate CBR traffic sources are used. We inject for each sensor, the appropriate traffic rate (8kb/s for the ECG sensor and 32bits/s for the pulse oximeter sensor). The transport agent is the User Datagram Protocol UDP. The NS2 shadowing propagation model is used as the propagation model. The wireless physical layer parameters are adjusted according to those of the Tmote Sky Platform which utilizes the Chipcon CC2420 radio interface [14]. The CC2420 is IEEE 802.15.4 compliant and has a programmable output power ranging from -25 to 0 dBm. The initial energy of all nodes is 3 Joules and the he simulation running time is 200s.

The coordinator initiates the network formation and sends periodic beacons. Sensor nodes join the network and start the transmission of physiological samples. We define the following metrics for studying the performance of the proposed architecture.

- o Packet delivery fraction: The ratio of packets successfully received to packets generated by the CBR sources.

- o Energy flow: The energy remaining at each node during the simulation running time.

A. Simulation Results

We determine the packet delivery fraction for different transmission power values. IEEE 802.15.4 supports two types of data services: acknowledged and unacknowledged. We display the packet delivery fraction for each type.

The energy flow is determined for the ECG sensor because it has the greatest data rate. It looses more energy than the pulse oximeter which has a small data rate of 32bits/s. The remaining energy is displayed for three transmission power values 0dBm, -10dBm and -25 dBm.

B. Discussion

The results obtained for the packet delivery fraction show that the acknowledged data service performs better. This comes from the fact that it

uses a retransmisson mechanism in case of non successful packet delivery. As shown in figure 3, the acknowledged data service offers a packet delivery fraction of 100% for a transmission power greater than or equal to -10 dBm. However we still notice a small packet loss of nearly 3% below this value. This can be explained by the fact that IEEE 802.15.4 drops a packet when three transmissions fail to receive a proper acknowledgement. At -25dBm, the packet delivery fraction drops from 97% in an acknowledged service to 83% in an unacknowledged service which means a loss of nearly 20% of packets for the latter. This cannot be accepted in case of emergency scenarios. We opt for the acknowledged data service.

For the energy flow, as shown in figure 4, a very slight difference is noticeable between the slopes corresponding to the three transmission power values. The remaining energy values show that reducing the transmission power does very little to save energy. It can only be conserved by a power management scheme. This justifies the helper power management scheme introduced in our proposed protocol stack.
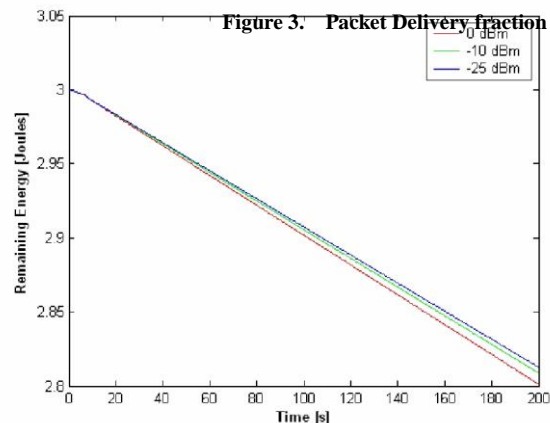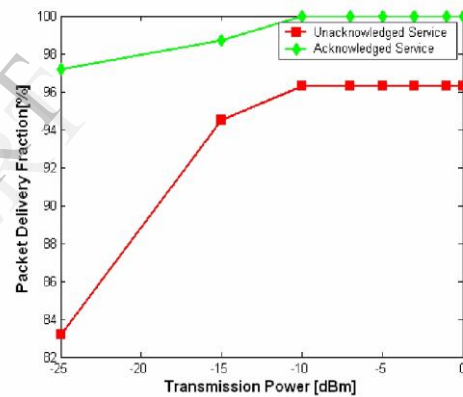

Figure 3. Packet Delivery fraction

Figure 4. Remaining Energy of the ECG sensor

7. Conclusion

In this paper, we have presented an architecture concept and a protocol stack of a Wireless Body Area Sensor Network for health monitoring of elderly people. The architecture can be deployed in both indoor and outdoor environments. We derived the requirements of the application, argued its pairing with the appropriate wireless technology and described the system architecture and protocol stack. Simulations of the proposed Architecture show that the acknowledged data service of the IEEE 802.15.4 performs particularly well offering a packet delivery fraction greater than 97% for all transmission power values. Reducing the transmission power does not really save energy. This can be achieved by a power management scheme.

The project is ongoing and future work includes increasing the number of wireless sensors in the architecture, simulation of the power management scheme, simulation of the proposed architecture in an outdoor environment and evaluation of the handover between the WLAN network indoor and the GPRS network outdoor.

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