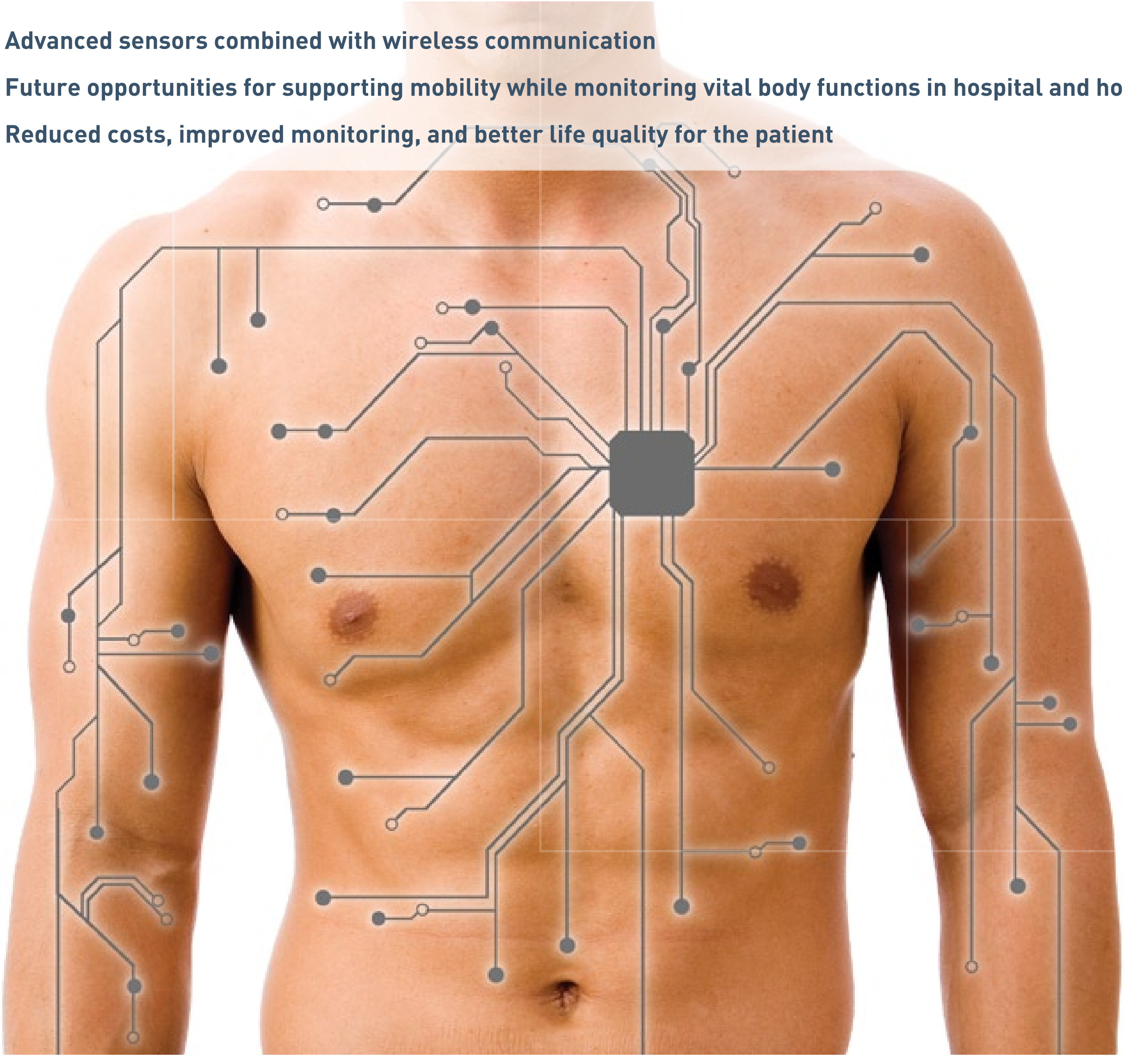
Nordic Innovation Centre

December 2007

Biomedical Wireless Sensor Network

- **Advanced sensors combined with wireless communication**
- **Future opportunities for supporting mobility while monitoring vital body functions in hospital and home care**
- **Reduced costs, improved monitoring, and better life quality for the patient**



Author: Eirik Næss-Ulseth with support from all partners

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Biomedical Wireless Sensor Network - BWSN

MEMSCAP The Power of a Small World™ · Millicore · Novosense · VTT
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Rikshospitalet - Radiumhospitalet HF The Interventional Centre

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Nordic Innovation Centre

Title: Biomediucal Wireless Sensor Network (BWSN)		
Nordic Innovation Centre project number: 06259		
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Abstract: There is a critical need for more cost efficient solutions for supervision/monitoring patients during and after surgery, as well as when the patient is at home. Advanced sensors combined with wireless communication will give reduced costs, improved monitoring, and better life quality for the patient. This project developed, implemented and tested a first version of a biomedical sensor network for the future wireless hospital and home care. The sensor network comprised four different sensors, and was tested in a hospital environment. The project was carried out by a consortium representing a unique trans-national value chain, crossing Finland, Norway and Sweden's borders. The project was funded by the Nordic Innovation Centre (NICe) and Svensk-Norsk Næringslivssamarbeid (SNN). The main conclusion is that the BWSN shows the future opportunities for supporting mobility while monitoring vital body functions in hospital and home care. The BWSN is a first version solution where important technical barriers have been solved. The BWSN needs to be further developed in order to cover security handling, improved signal integration and visualization, achieve extended mobility outside the surgery room, monitoring of several patients/persons at the same time, and further adaptations to medical experts needs for information included integration with other patient systems. The BWSN and the collaboration form an important platform for further technical development and business development in order to penetrate a market expected to increase a lot in the future. Based on the results from the BWSN project, the project partners extended with SINTEF Norway, have suggested a BWSN project phase 2 (BWSN-II), to be performed in 2008-2009.		
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Executive Summary

Within the hospital or extended care environment, there is an overwhelming need for constant and invisible monitoring of more and more vital body functions. Today's biomedical sensor solutions are effective for an individual measurement (for example ECG), but are not integrated into a complete body area network, where many simultaneous sensors are working at the same time on an individual patient. Also there is a need for increasing patient mobility, and in many cases, sensors for biomedical monitoring are not yet wireless. This creates the need for the implementation of new biomedical personal wireless networks with a common architecture and the capacity to handle multiple sensors monitoring different body signals.

The purpose of the project was to develop, implement and test a biomedical wireless sensor network (BWSN) comprising body sensors that communicate wirelessly with the patients control device for monitoring and external communication. The project focused especially on wireless communication and multi-sensor signal integration. Further, the purpose was to create a basis for collaboration on product and services opportunities, including spin off projects.

The project was funded by the Nordic Innovation Centre (NICe) and Svensk-Norsk Næringslivssamarbeid (SNN).

Method/implementation:
The project objective was obtained by performing the following activities:

- Sensor requirements to communication, included evaluation of basic communication alternatives. We divided the requirements into the following parts:
    - The different sensors overall requirements to communication
    - Common sensor communication protocol
    - Physical layer requirements
    - Detailed radio module requirements: voltage 3 V, electrical connector, sub modules; radio, power control, antenna, AD converter
- Software platform for signal visualisation and storage. A common software platform was developed included user interface from application layer (API) and upwards on PDA/PC
- A common sensor message format or communication protocol was developed due to the lack of standard protocols on the market.
- Customization of the WSN communication chip solutions were performed included electrical connectors, power control, antenna, and AD converter.
- Sensor specific communication integration where each sensor company performed customizations of their interface using the common communication protocol.
- A test bed was developed including test protocol/procedures, “Gold Standards”, supporting:
    - Testing of all the sensors monitored at the same time using the same communication solution. Stationary environment.
    - More in-depth domain specific testing of the each sensor and its wireless solution. Stationary environment.
    - Sensors in a multi sensor and mobile user environment.
- Testing of the BWSN was done in user environment (IVS)

The work has partly been done in small teams focusing on solving particular challenges, e.g. the common communication protocol. A team with technical experts from all the partners has worked intensively performing the final integration and testing of the sensors in a wireless network.

Concrete results and conclusions:
The biomedical wireless sensor network (BWSN) was developed, implemented and tested at the Interventional Centre at the Norwegian National Hospital. The BWSN shows monitoring of all wireless sensors at the same time. Four different sensors were integrated:

- Memscap Wireless Pressure Transducer
- Millicore DigiVent Pulmonary Air Leakage
- Novosense CardioPatch ECG sensor
- VTT Heart Monitoring Accelerator

A BWSN website is established www.bwsn.net for internal communication, document archiving, and also external communication. The project results will be presented at an open meeting February 8th, 2008 at the Norwegian National Hospital.

The main conclusion is that the BWSN shows the future opportunities for supporting mobility while monitoring vital body functions in hospital and home care. The BWSN is a first version solution where important technical barriers have been solved. The BWSN needs to be further developed in order to cover security handling, improved signal integration and visualization, achieve extended mobility outside the surgery room, monitoring of several patients/persons at the same time, and further adaptations to medical experts needs for information included integration with other patient systems. Even though we developed a comprehensive test bed and test procedures, “Gold Standards”, we were only able to perform limited testing within the scope of the project.

Recommendations:
The BWSN project comprises a unique collaboration covering both sensors, communication solutions, sensor network development and testing in user environments. The BWSN and the collaboration form an important platform for further technical development and business development in order to penetrate a market expected to grow significantly in the future. Based on the results from the BWSN project, the project partners extended with SINTEF Norway, have suggested a BWSN project phase 2 (BWSN-II), to be performed in 2008-2009. In the project phase 2 we propose to extend the BWSN focusing on the following topics:

- Reliability in the monitoring of patient vital signals from sensors, specifically investigating:
    - Electromagnetic interference
    - Stability
    - Security
    - Artifacts during movements
    - Network robustness
- Alarm functions
- Reliability with multiple wireless network link technologies
    - Patient or body PAN communication

  - Global communication with UMTS/GPRS or similar
  - Seamless integration with reliable network/sensor protocols
  - Network architecture development to support mobility (ie handover), high and low data rate sensors, changing data rates, sensor failure, sensor changing.
  - Integration with a central hospital database and decision support systems.
- System Integration
  - Modular solutions (improve the plug in functionality): components with standard interfaces at the sensor and network protocol levels
  - Possibility for the ”hot” changing/implementation of sensors from multiple suppliers
  - Implementation of standard open operating system (Tiny OS) and sensor application software

The strategic value and impact of the project will be multi-faceted. Firstly, the individual sensor companies will achieve wireless sensor solutions at product quality that will make these SMEs competitive on the open market. They will be able to further test their sensor solutions within real hospital and home care environment. In addition these results will have strategic marketing importance to the sensor companies.

Secondly, a component supplier (Novelda) will improve a new radio technology based on UWB impulse radio. This will have strategic impact for Europe in the ability to test this technology and highlight its potential within a biomedical environment. UWB technology is currently being led by U.S. companies assisted by the FCC which has passed a ruling allowing UWB transmission within specific frequency bands. It is of importance that European companies have access to this technology.

Thirdly, the IVS, National Hospital of Norway will gain an advanced test bed using “Gold Standard” procedures for testing biomedical wireless sensor networks. This will be make it possible for the sensor and communication suppliers to achieve documented verification and approval supporting market penetration of their products. Further, the BWSN test bed will be a showcase of the wireless hospital and home care of the future. Financing and organizing implementation and use of biomedical sensor networks are critical, and it is important to build up knowledge about the opportunities among key interest groups, e.g. politicians, health care administration, patient groups.

And fourthly, the public R&D enterprises (VTT, Acreo, Imego, SINTEF) will build practical competence in ICT, sensors and networks for biomedical applications, strategically important areas for future Nordic R&D. This will contribute to a strong network of R&D enterprises to allow for cooperation and participation in the European Framework programs in the specific area of ICT for the elderly, a specific challenge for the European 7th Framework program. The maintenance and development of strong public R&D entities within the Nordic countries is necessary to keep the region competitive with other geographical areas such as the rest of Europe, U.S. and the Far East which have strong public research institute funding in the area of ICT.

Table of Content

Preface

This report describes the major developments in the Biomedical Wireless Sensor Network (BWSN) project. We started in September 2006 and the first version of the BWSN was ready in the end of 2007. We aim at continuing the collaboration in a project BWSN-II planned to be performed in 2008 and 2009. We acknowledge the support from Nordic Innovation Centre (NICe) and Svensk-Norsk Næringslivssamarbeid (SNN).

BWSN project partners

December 18th, 2007

1. Introduction

Within the hospital or extended care environment, there is an overwhelming need for constant and invisible monitoring of more and more vital body functions. Today's biomedical sensor solutions are effective for an individual measurement (for example ECG), but are not integrated into a complete body area network, where many simultaneous sensors are working at the same time on an individual patient. Also there is a need for increasing patient mobility, and in many cases sensors for biomedical monitoring are not yet wireless. This creates the need for the implementation of new biomedical personal wireless networks with a common architecture and the capacity to handle multiple sensors, monitoring different body signals, with different requirements.

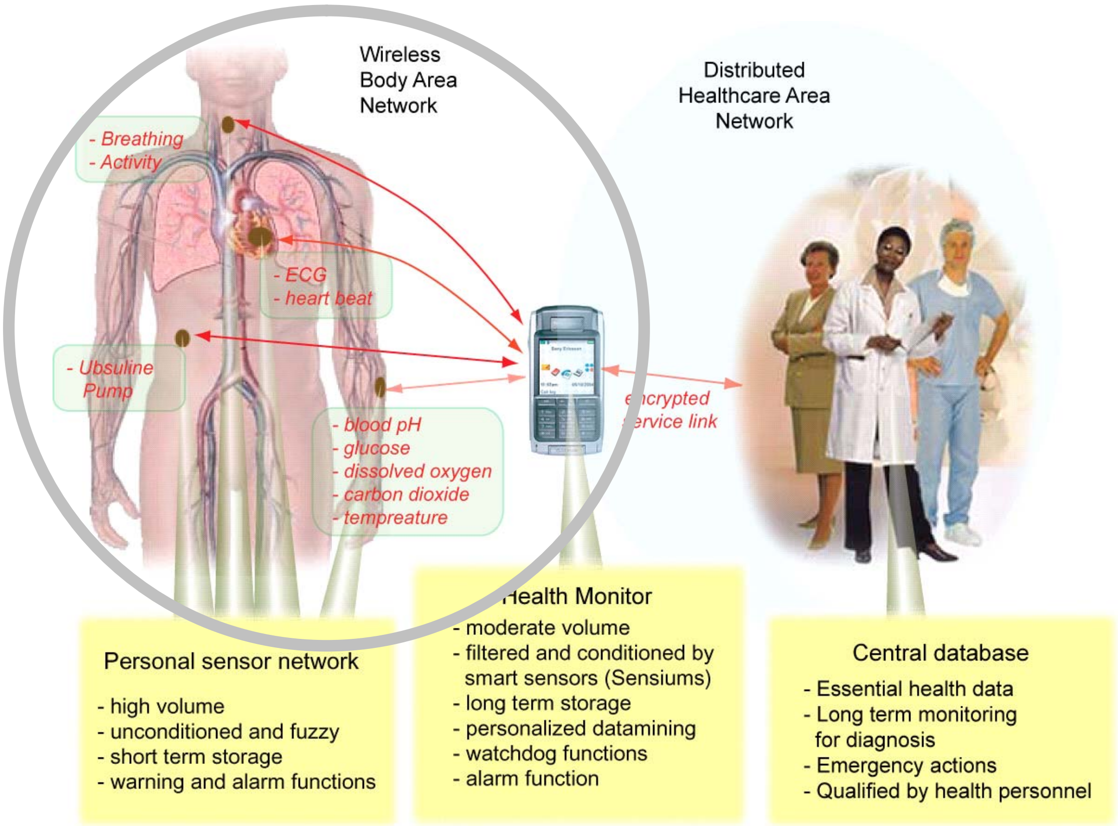
The benefit of using wireless sensor technology in health care can be divided into two areas. One area is the use of new technological solutions for individually based, multi-parameter monitoring at home. Patients with chronic diseases, as well as a constantly growing number of seniors, will profit on treatment and medical monitoring in their own environment (e.g. at work or at home). These monitoring systems are linked to individuals rather than places. Almost unlimited freedom of movement implies use of wireless and even implanted sensors that will greatly enhance home monitoring and follow-up.

The second area of benefit lies within increasing the efficiency of treatments at hospitals. The cost of continuous monitoring and surveillance is already high and growing dramatically. This goes for both prior to treatment monitoring, and internally at the hospital, as well as post-monitoring. The biomedical sensors of today are mostly based on hard wiring, in addition to being based on proprietary solutions. Multi-parameter analysis produces new data that can enhance information quality. The implementation of more flexible wireless technology will lead to reduced hospitalization time due to more rapid mobilization, as well as improved documentation by stored, digitalized signals. The result will be enhanced decision making for diagnostics, observation and patient treatment.

Improvements within sensor technology, data quality, data resolution and increase in the number of measurement parameters will in general help to prevent complications. Biomedical sensors for organ specific variables will be able to replace the coarse global variables. Digital wireless solutions will be able to collect "point of care" information, based on new wireless technological platforms. Seamless communications render possible automated and enhanced documentation quality. From a macro economically point of view, it is important to develop technology that can reduce use of resources, improve infrastructure and increase efficiency. From an individual point of view, freedom of movement combined with the confidence of 24/7 medical supervision, will be an important gain.

2. Overall project objectives

The overall objective was to develop, implement and test a biomedical wireless sensor network (BWSN) comprising body sensors that communicate wirelessly with the patients control device for monitoring and external communication. The project focused especially on wireless communication and multi-sensor signal integration. Further, the purpose was to create a basis for collaboration on product and services opportunities, included spin off projects.



3. Sensors made wireless and integrated

The BWSN shows monitoring of all wireless sensors at the same time. Four different sensors were integrated:

- Memscap Wireless Pressure Transducer
- Millicore DigiVent Pulmonary Air Leakage
- Novosense CardioPatch ECG sensor
- VTT Heart Monitoring Accelerator

Below is a short description of the different sensors.

3.1. *Memscap Wireless Pressure Transducer*

Memscap AS

MEMSCAP
The Power of a Small World™

Memscap is a leading provider of innovative micro-electromechanical systems (MEMS)-based solutions. MEMSCAP's Sensor Solutions Business Unit is located at Skoppum in Norway and offers a wide range of multi-applications sensors for critical aerospace/defense, medical/biomedical and energy or industry related equipment.

Memscap Wireless Pressure Transducer

The Memscap Wireless Pressure Transducer (WPT) developed during the BWSN project is based on the Memscap SP840 series of physiological pressure sensors with disposable dome.

Memscap WPT is providing digitized and pre-scaled pressure readings over a wireless interface.

The wireless link is utilizing the TinyOS based BWSN Sensor Message Format over an IEEE 802.15.4 compliant radio.

Pressure Range:	-20 to 300 mmHg
Overload Protection:	> 10 000 mmHg
Pressure Medium:	Disposable plastic dome

3.2. Millicore DigiVent Pulmonary Air Leakage

DigiVent® Pulmonary Air Leakage

Management System of today

DigiVent® is a Pulmonary Air Leakage Management System used for evacuating air and fluid from the pleural cavity after a pulmonary surgery. Optimal management of the patient is made possible by a MEMS (Micro Electro-Mechanical Systems) flow sensor that measures actual air leakage in ml / min. DigiVent® displays either the real-time air leakage rate, or, with the push of a button displays the average air leakage rate for the past 1, 3, or 6 hours. This enables the clinician to assess patient changes over time. DigiVent® also measures the patient's intrapleural pressure through a pressure sensor.

Millicore AB

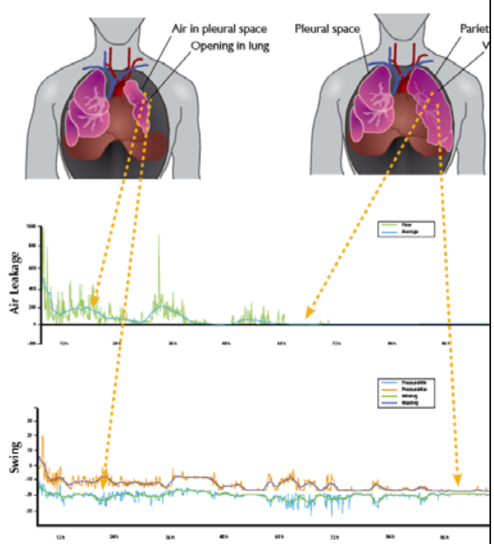
Millicore is a Swedish medical technology company focusing on smart, MEMS-based, disposable products. Millicore was founded in 2003 and is owned by the founders and by 4 of the largest venture capitalists within life science in Sweden. Head quarters are based in Stockholm with market presence in the US and in Germany.

Millicore

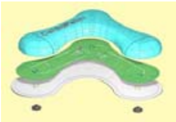
DigiVent® Wireless

The BWSN cooperation makes it possible for Millicore to supply the physician with a more complete data. The actual and historical trend of the patient's intrapleural pressure and flow can be transmitted live and directly from the DigiVent into a monitoring system of his/her choice. This will tremendously increase the amount of information for the physician on which he/she can base decisions on.

As an example the picture illustrates a typical DigiVent® patient. The left picture shows a patient with an air leakage from the lung into the pleural space and thus a collapsed lung. Note the difference in pressure between inspiration and expiration. The right picture shows the re-expanded lung of the patient; no air leakage and note that the pressure curves for inspiration and expiration have converged.



3.3. Novosense CardioPatch ECG sensor



Completely Wireless ECG

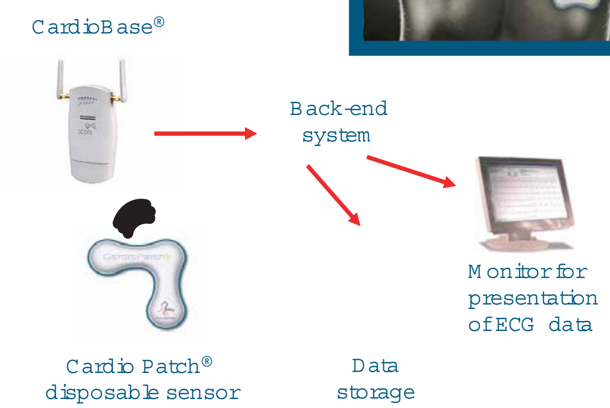
CardioSense® Key Competitive Advantages

The system offers considerable financial savings, as well as increased safety, convenience and quality, compared with conventional ECG systems:

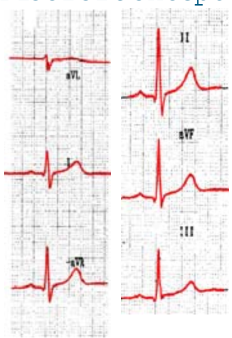
- Reduction in handling time
- Avoids false alarms
- Improved patient mobility and convenience
- Continuous monitoring chain maintained, both within the hospital and between hospitals
- Better work environment for surgeons and nurses
- Minimized risk of infection due to avoiding the use of wires
- Improved signal quality due to reduction of artefacts (erroneous ECG signals)

Market potential

10 BUSD market worldwide
10 000 USD per hospital bed/year
1 million relevant hospital beds



Proof of Concept



Intellectual Property Rights

A patent has been granted in Sweden for "A system and method for wireless generation of standard ECG leads and an ECG sensing unit therefore, no. SE0600328-9, PCT/SE2007/050059". The field of technology has been extensively investigated and patents analysed in detail by leading patent specialists. Novosense is proceeding to PCT aiming for EU, the US, Japan and selected RoW markets.

The Company

Novosense AB is a biomedical engineering company located at the Ideon Science Park in Lund in the southern part of Sweden.

Together with leading researchers at Lund University, the company has developed a unique, completely wireless ECG system – CardioSenseSystem®, which will replace today's stationary and portable cable-based ECG monitoring equipment. The system is based on disposable wireless sensors (CardioPatch®) that communicate via radio directly with a base station (CardioBase®).

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3.4. VTT Heart Monitoring Accelerator

Heart acceleration monitoring

Heart acceleration monitoring can be used to gather additional information of hearth operation both during surgery and post operation treatment. There is a risk of graft occlusion in coronary artery bypass grafting, and acceleration monitoring provides real time data of myocardial function: the method facilitates beat to beat detection of regional myocardical iscemia when heart surface acceleration is monitored during cardiac surgery. During post operational phase, it provides uninterrupted monitoring in of iscemia and arrytmia.

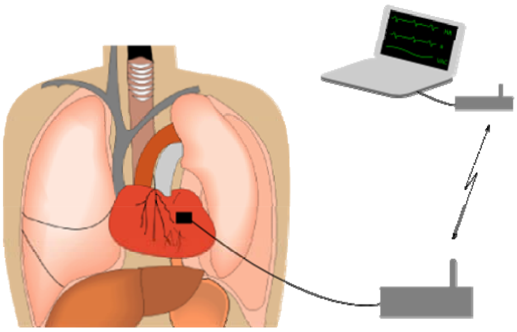
Acceleration monitoring has some benefits over traditional methods: It's more sensitive than EKG or invasive hemodynamic monitoring and otherwise than echocardiography or angiocardiography, it can be used for constant monitoring. Facilitation of local detection of parenchymal inscemia is an added value.

VTT – Technical Research Center of Finland

VTT is an independent Finnish research institute which has had a well established position in Finnish industry for several decades, providing our customers new innovations and technologies, and also impartial testing. Our expertise consist of a comprehensive portfolio of scientific know-hows, such as: electronics, ICT, chemistry, energy and material technology.

This project has been carried out in VTT Sensors center, in which world leading research on smart sensors, micro mechanical systems, nanophysics and radio frequency systems is being carried out. In addition to single sensor and electronic devices, we also develop system integrated circuits, sensor arrays, related readout and communication electronics and packaging. VTT Sensors is part of the Center of Excellence on Low Temperature Quantum Phenomena and devices, funded by the Academy of Finland.

VTT WHAM – VTT Wireless Heart Acceleration Monitoring



As the modern medical patient care requires many different parameters of patients condition to be monitored, wiring and equipment congestion can became an impediment in everyday work of health care professionals.

The work done in BWSN project will enable easier application of the devices in question: The wireless patient monitoring enables uninterrupted measurement of heart acceleration along the other vital signs. When no physical wiring between the sensor and the monitoring station is needed, monitoring is continuous and uninterrupted monitoring in the clinical pathway to prevent complications in reached. The solution is also cost effective, since only one common monitoring station for all the wireless sensors is needed. The data can also be collected and analyzed in greater detail later, either for medical diagnosis or scientific work.

4. Wireless communication solutions

Today a number of wireless communication solutions are available. Typical short ranges solutions are Bluetooth, ZigBee and several other more or less proprietary solutions. Several of these solutions are intended for short range, in-room (10m) range and are reasonably power efficient. Moving wireless solutions in to body-area networks (BAN) or personal area networks (PAN) for carrying important health information is adding another level of quality of service mostly unavailable in current wireless solutions. In critical applications loss of communication cannot be tolerated.

Based on input from the sensor vendors, the communication solution requirements have been specified. The requirements have been organized as common requirements for all sensors and two cases, where Case 1 is related to the Novosense ECG sensor and Case 2 is valid for the rest of the sensor providers.

Common requirements

- Global synchronization
- Retransmission of lost data
- Two-way communication
- Encryption
- Identification
- Authentication
- Power consumption: <0.4 mW/Kbit
- Error detection/correction
- On-board or On-chip 12-bit A/D converter
- On-board or On-chip microcontroller

Case 1:

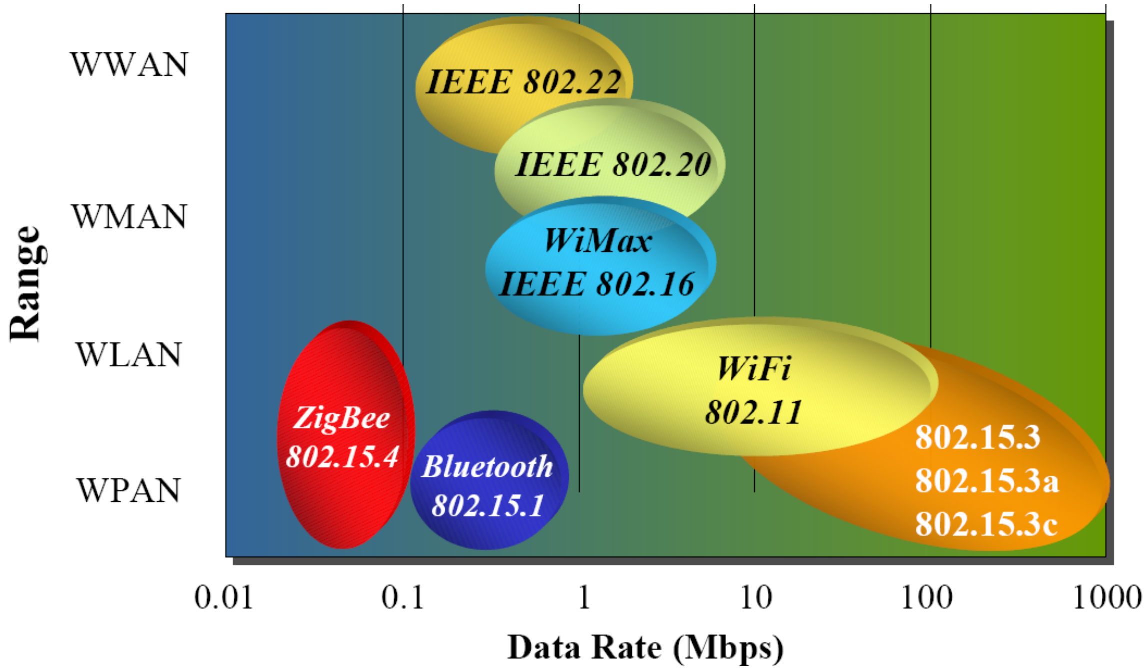
- Data rate < 100 Kbit
- Global synchronization 250 us resolution
- Range: 70m
- Number of units per piconet: > 120
- Number of A/D channels: >10
- Handover across base stations

Case 2

- Data rate < 50 Kbit
- Global synchronization relaxed resolution
- Range: 10-15m
- Number of units per piconet: 20-40
- Number of A/D channels: 3-5

4.1. Available products

As shown in the figure below, the trade-off between different network functionality may vary significantly. Both history and available technology is setting the scene of today.



Although most of these network solutions are aiming at mobile functionality, they all consume significant power. In the context of BWSN several applications are only requiring low bandwidth (<10kb/s) and it is important to trade the reduced speed requirements in for increased battery life and improved security/robustness. In the current project phase it is important to sort our state-of-the-art technology and consciously select available technology when adequate. More important is to pinpoint the deficiencies of available technology and develop improved solutions within the BWSN project.

4.2. Bluetooth solutions

Bluetooth is a low cost, low power, short range technology, originally developed as a cable replacement solution to connect various devices such as mobile phone handsets, headsets and portable computers. Bluetooth is often described as a Personal Area Network (PAN) technology, and has also been used to connect to various sensor devices. The Bluetooth specifications are managed by the Bluetooth SIG (Special Interest Group). In addition to the core specifications, The Bluetooth SIG has specified a number of profiles. Each profile describes how a particular application can be implemented including which parts of the Bluetooth protocol should be use to support the profile.

Most of the basic BWSN requirements seem to be supported by the Bluetooth technology with some important exceptions.

The exceptions are related to the network topology with a high number of units, global synchronization and for Case 1: Handover across base stations.

Bluetooth and the BWSN requirements:

- **Global synchronization** – Basic Bluetooth topology supports clock synchronization within a piconet consisting of one master device and up to 7 slave devices. A basic timeslot is 625 microseconds, and all devices within a piconet share the same clock. If more than 8 active network members are required, it is needed to link piconet into scatternets, where some device members are members of more than one piconet (timeshared).

- **Retransmission of lost data** – this is supported using an appropriate communication link
- **Two-way communication** - Supported
- **Encryption** - Supported
- **Identification** – Supported through SDP (Service Discovery Profile)
- **Authentication** - Supported
- **Power consumption: <0.4 mW/Kbit** - Supported with careful selection of Sensor communication scenario, appropriate Bluetooth profile and Bluetooth low power options. Might be a problem for Class 1 version.
- **Error detection/correction** – Supported
- **Data rates of 50 or 100 Kbit/s** – Supported
- **Range** 10-15 or 70m – Supported by selecting appropriate radio transceiver. (Class 1 or Class 2)
- **Number of units per piconet –** Basic Bluetooth piconet topology consists of one master and up to 7 slave devices. More devices can be supported by utilizing scatternets, where some devices are members of more than one piconet or by parking and unparking inactive members. An alternative solution could be to add more parallel piconets.

Case 1

The main limiting factors in using Bluetooth for Case 1 are:

- Global synchronization 250 us resolution
- High number of simultaneously active units
- Handover between base stations.

Case 2

The main limiting factor in using Bluetooth for Case 2 is the high number of simultaneous active units in the system. There is a possibility to utilize the low power parking mode to park and unpark devices in a piconet and thus increase the number of slaves to 255, but this would result in a rather high latency.

4.3. IEEE 802.15.4

One of the hottest emerging candidates for WSN communication is the ZigBee Technology. Building on the IEE 802.15.4 standard the proposed aims of ZigBee is certainly approaching demands of the BWSN project. Some key features are:

Operation range	10m (30m)
Channels	16 (2.4GHz ISM band)
Data rate	20kb and 250kb
Nodes:	255

Standards are nice, but in real life we have to use some available silicon system implementing ZigBee. Apparently most available motes for WSN systems seem to use the ChipCon developed CC2420 (or derivative of this chip) for wireless communication.

In order to be as realistic as possible we find it appropriate to use specifications for the CC2420 chip in our assessment.

Chipcon CC2420
The CC2420 is a fully integrated transceiver (just a few external components) designed for the 2.4 GHz band. In the BWSN project we should probably evaluate the fitness of the 2.4GHz band due to crowding of several other quite common functions like WI-FI and microwave ovens. For sure significant interference exists, degrading performance.

However, for now we will use the maximum specifications and keep in mind we need significant headroom to alleviate for disturbance in real life environments.

The available band is split in 16 channels each with 5MHz bandwidth. The maximum speed is 250kb/s for each channel. Although 255 nodes (motes) are addressable, we believe the limited number of channels is most important in BWSN networks.

- **Global synchronization** – The ZigBee protocol supports synchronization through "beacon" signals transmitted over the network. Some sort of reference clock is assumed. One report indicates feasible synchronization in the order of 100µs, but results are inconclusive.
- **Bit Error Loss** is low compared to other protocols due to robust modulation scheme (DSSS) and initial measurements indicate high tolerance to noise interference.
- **Two-way communication** - Supported
- **Encryption** - The CC2420 is using AES-128 encryption and dedicated hardware is provided for efficient encoding/decoding with two embedded keys.
- **Authentication** - Supported
- **Power consumption: <0.1 mW/Kbit** – Power is less with shorter distance and can be set in hardware.
- **Error detection/correction** – Supported
- **Data rates up to 250 Kbit/s** – Supported
- **Range** 10m nominally with high sensitivity CC2420 30m feasible.
- **Number of units** is nominally 255, but channel limitations are limiting number of nodes to 16 simultaneous nodes. CSMA-CA may be explored to increase node count.

4.4. IEEE 802.15.4a (UWB-IR)

The UWB-IR based radio (Novelda radio) is a conceptual different solution compared to the carrier based communication hardware that are most commonly used in Bluetooth and ZigBee solutions. The lack of carrier also implies that the allowed frequency band is not divided into a number of channels. Instead a number of pseudo-random (PR) sequences in the time-domain replace what is normally referred to as a channel. The length of the PR-sequence determines how many nodes that can be supported for each piconet. In the receiver, the PR-sequence is compared to a template and statistical methods are used to determine which symbol/channel that was received. The topology of the Novelda radio thus opens for trading important parameters like power consumption, number of channels, BER and degree of hardware encryption. The Novelda radio is mainly targeted for applications where low power consumption is important. A consequence of this is that the data rate is set relatively low. The defined limitations with respect to emitted power (power density) also limit the range of this radio. The BWSN common requirements seems reasonable compared to the physically specifications of the Novelda radio.

Novelda and the BWSN requirements:

- **Global synchronization** – Technically possible. Implementation depends on protocol used
- **Retransmission of lost data** – Supported by microcontroller
- **Two-way communication** - Supported
- **Encryption** - Supported either by PR-sequence or by using microcontroller
- **Identification** – Supported
- **Authentication** – Supported
- **Power consumption: <0.4 mW/Kbit** - Supported
- **Error detection/correction** – Supported
- **Data rates of <50kbit/s** – Supported
- **Range** 10m – Supported
- **Number of units per piconet –** By using a sufficiently long PR-sequence a large number of units are supported

Case 1
The Novelda radio needs to be tested further for this case.

Case 2

- **Data rate** < **50 Kbit** - Supported
- **Global synchronization relaxed resolution -** Can be supported.
- **Range: 10-15m –** Up to approximately 10m
- **Number of units per piconet: 20-40 -** Supported
- **Number of A/D channels: 3-5 –** Can be supported on card

4.5. BWSN common sensor message format

The BWSN project has developed and implemented a common sensor message format or communication protocol. All sensors use this message format for communication. ***In appendix 1 is a description of the message format.***

5. Software platform for multi sensor visualization and data storage

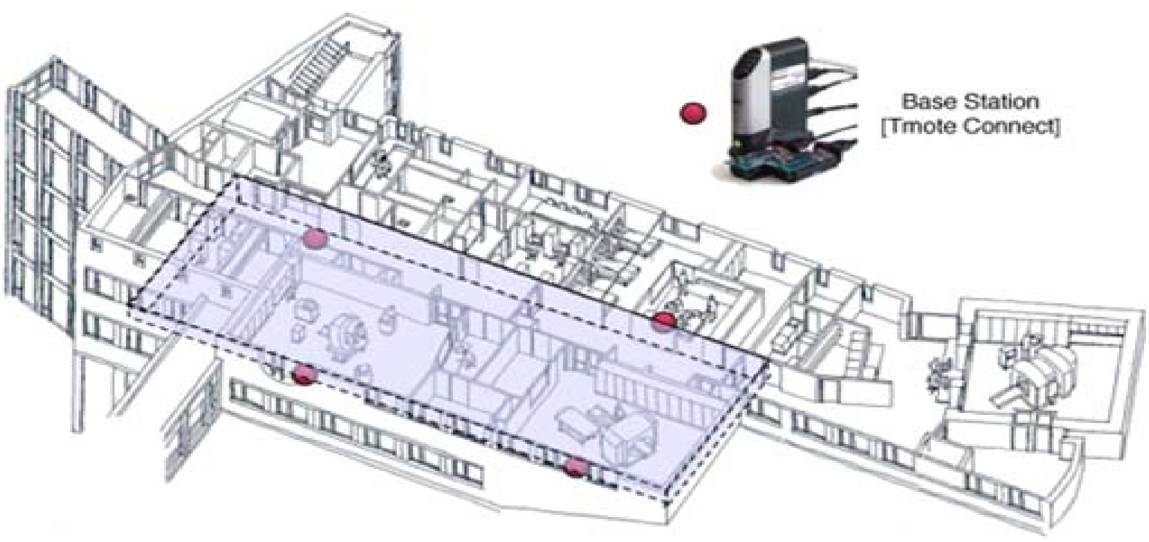
The TinyOS operating system is designed for wireless embedded sensor networks requiring minimal code size due to constraints in available memory inherent in the sensor network. NesC (Network Embedded System C) is used as programming language in TinyOS application building. TinyOS offers software libraries both for embedded devices (nesC) and for computer visualization and storage (Java). Based on the TinyOS libraries, custom modifications were done to tailor the software to the BWSN project specifications.

The message format of BWSN closely follows the TinyOS message format, which enables easy radio to serial communication and message conversion between sensor platform and computer software. The common communication protocol, described in Sec. 4.3, is initially defined for the embedded software. Thereafter the TinyOS message interface generator (MIG) is used to generate Java message objects for the gateway application. Hence, a common BWSN message object library is shared between the visualization, storage and serial communication. Since all the sensor platforms utilize the same message format, all messages can easily be decoded by all applications implementing the BWSN message library. The serial communication acts as a BWSN message source allowing other applications, like the visualization application, to request a copy of a specific messages type. A monitor application request messages containing sample data and plots the signals on screen according to sensor specification contained in the message. Storage will be a separate application utilizing the same interface to the source as the monitor.

6. Testbed for wireless multisensor testing

A pragmatic choice of hardware platform involved a network consisting of motes, Tmote™ Sky commercially available from MoteIV in USA. Tmote™ Sky motes were chosen due to their properties as IEEE 802.15.4 compliant devices for mesh based networking. Tmote™ Sky features embedded humidity, photo and temperature sensors, 250kbps Chipcon Single-Chip 2.4 GHz IEEE 802.15.4 transceiver, a 8MHz TI MSP430 microcontroller with 10kB RAM from Texas Intruments, antenna, connectors for external sensors, and facilitates programming, powering and data collection via USB. The motes can also operate on two 1.5V batteries.

The TmoteTM Sky platform has a seamless integration between the mote hardware and the TinyOS open source component based operating system. The motes were defined as mobile stations communicating with base stations. For base stations, we used Tmotes connected to a Tmote Connect, that serves as gateway appliance connecting to a TCP/IP based LAN infrastructure. Four Tmote Connect base stations were deployed in the operating room area of the Interventional Centre, as indicated on the figure below, covering two operating rooms, a corridor and an anesthesia preparation room.



All communication between the mobile motes and the server are done through the base station. The software running on the base station, an application distributed with TinyOS called TOSBase, acts as a simple bridge between the serial and radio links. When a server need to send out a message, TOSBase will forward this message to the radio link and send it to motes with the same predefined group ID. Equivalently, it listens to the radio link and filters out messages that do not contain the same group ID as its own. TOSBase includes queues in both directions, with guarantee that once a message enters a queue it will eventually exit on the other interface. Only when the queue is full, new messages will be blocked until space is freed. By using a base station that interfaces with both the wireless network and the wired local area network, the system becomes modular, scaleable and very flexible. One can imagine that the Life Science Testbed can be extended to include home monitoring by deploying a base station in a home, and link it to the central server at the hospital. The server-system can then serve as a clinical decision support system and enable the medical personnel to visualize the desired sensor data regardless of patient location or serve as an early warning system.

Gateway Server

The central server can serve a large number of base stations which in turn serves a number of sensor platforms. The server responsibility is to maintain a table containing all the sensors and third party applications (clients) connected through the system. This allows individual and remote configuration of motes. As new clients, like a monitor, request data from a specific sensor, the server will provide the client with the sensor properties necessary to configure itself for this sensor.

Radio interface

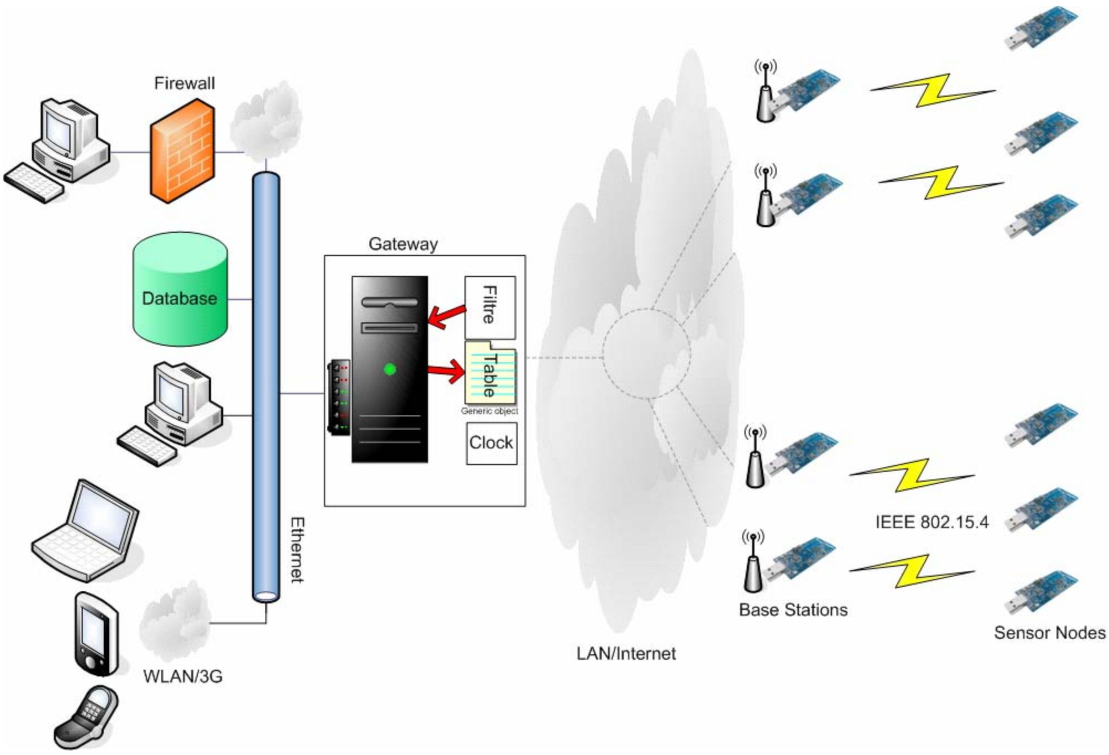
All communication over the radio interface follows the predefined BWSN protocol designed to uniquely identify sensor platforms, enable remote configuration and time synchronization. When a sensor platform is powered up within the wireless network, it transmits a boot indication message to the base station which forwards this to the gateway. The gateway validates the requested service, indicated by the boot indication message, and returns a message containing configuration settings according to available resources. After receiving a configuration the mote can try to renegotiate for a different configuration. Configuration of the sensor platform is done over at least three steps where the sensor platform either negotiates a more suitable configuration for the service it offers or returns the initial configuration to receive a “ready to send” message. Expected connection time after a three step configuration is approximately 140 ms.

Time synchronization

Within the wireless radio interface consisting of sensor platform and base station, the base station transmit its time estimate at regular intervals and the receiving sensor platforms can estimate a global time within its local network. In the same manner, the server application transmits a time stamp to all its base stations, seeing to a global time for every individual network served. Prior to storage, the server estimate the actual time the sample was taken and tags it with a date and time.

Roaming protocol

The addressing scheme and routing in the current wireless network is a ”selective broadcast” i.e., the base station consider every packet received a broadcast message, while the same messages are rendered invalid at the neighboring sensor platforms. Every packet sent by mobile motes is decoded by hardware and rejected from everyone but the base stations. For medical sensors, vital data is acquired and sent to the base station, and the communication protocol can not afford to loose connection during base station switching. By utilizing a soft handover scheme, all motes are communicating with one or several base stations simultaneously, thus the chances of a broken connection link are minimized. By maintaining several links to the base stations, the chances for successful data delivery is increased. As several base stations receive identical messages, the redundant data is filtered at the central server.



7. Dissemination and spin-off projects

A BWSN website is established www.bwsn.net for internal communication, document archiving, and also external communication. The project results have been presented at several occasions, e.g. meeting hosted by the Wireless Life Science initiative. The project results will also be presented at an open meeting February 8th, 2008 at the Norwegian National Hospital.

The project has created in-depth knowledge among the partners about their expertise and efforts within the nanotechnology, sensor and communication field. This has resulted in several joint efforts for establishing new projects, e.g. EU applications, SME-ERA application, and ERA-NET application.

8. Conclusions and recommendations

8.1. Conclusions

The biomedical wireless sensor network (BWSN) was developed, implemented and tested at the Interventional Centre at the Norwegian National Hospital. The BWSN shows monitoring of all wireless sensors at the same time. Four different sensors were integrated:

- Memscap Wireless Pressure Transducer
- Millicore DigiVent
- Novosense CardioPatch ECG sensor
- VTT Heart Monitoring Accelerator

A BWSN website is established www.bwsn.net for internal communication, document archiving, and also external communication. The project results will be presented at an open meeting February 8th, 2008 at the Norwegian National Hospital.

The main conclusion is that the BWSN shows the future opportunities for supporting mobility while monitoring vital body functions in hospital and home care. The BWSN is a first version solution where important technical barriers have been solved. The BWSN needs to be further developed in order to cover security handling, improved signal integration and visualization, achieve extended mobility outside the surgery room, monitoring of several patients/persons at the same time, and further adaptations to medical experts needs for information included integration with other patient systems. Even though we developed a comprehensive test bed and test procedures, “Gold Standards”, we were only able to perform limited testing within the scope of the project.

8.2. Recommendations

The BWSN project comprises a unique collaboration covering both sensors, communication solutions, sensor network development and testing in user environments. The BWSN and the collaboration form an important platform for further technical development and business development in order to penetrate a market expected to increase a lot in the future. Based on the results from the BWSN project, the project partners extended with SINTEF Norway, have suggested a BWSN project phase 2 (BWSN-II), to be performed in 2008-2009. In the project phase 2 we propose to extend the BWSN focusing on the following topics:

- Reliability in the monitoring of patient vital signals from sensors, specifically investigating:
  - Electromagnetic interference
  - Stability
  - Security
  - Artifacts during movements
  - Network robustness
- Alarm functions
- Reliability with multiple wireless network link technologies
  - Patient or body PAN communication
  - Global communication with UMTS/GPRS or similar

  - Seamless integration with reliable network/sensor protocols
  - Network architecture development to support mobility (ie handover), high and low data rate sensors, changing data rates, sensor failure, sensor changing.
  - Integration with a central hospital database and decision support systems.
- System Integration
  - Modular solutions (improve the plug in functionality): components with standard interfaces at the sensor and network protocol levels
  - Possibility for the ”hot” changing/implementation of sensors from multiple suppliers
  - Implementation of standard open operating system (Tiny OS) and sensor application software

The strategic value and impact of the project will be multi-faceted. Firstly, the individual sensor companies will achieve wireless sensor solutions at product quality that will make these SMEs competitive on the open market. They will be able to further test their sensor solutions within real hospital and home care environment. In addition these results will have strategic marketing importance to the sensor companies.

Secondly, a component supplier will improve a new radio technology based on UWB impulse radio. This will have strategic impact for Europe in the ability to test this technology and highlight its potential within a biomedical environment. UWB technology is currently being led by U.S. companies assisted by the FCC which has passed a ruling allowing UWB transmission within specific frequency bands. It is of importance that European companies have access to this technology.

Thirdly, the IVS, National Hospital of Norway will gain an advanced test bed using “Gold Standard” procedures for testing biomedical wireless sensor networks. This will be make it possible for the sensor and communication suppliers to achieve documented verification and approval supporting market penetration of their products. Further, the BWSN test bed will be a showcase of the wireless hospital and home care of the future. Financing and organizing implementation and use of biomedical sensor networks are critical, and it is important to build up knowledge about the opportunities among key interest groups, e.g. politicians, health care administration, patient groups.

And fourthly, the public R&D enterprises (VTT, Acreo, Imego, SINTEF) will build practical competence in ICT, sensors and networks for biomedical applications, strategically important areas for future Nordic R&D. This will contribute to a strong network of R&D enterprises to allow for cooperation and participation in the European Framework programs in the specific area of ICT for the elderly, a specific challenge for the European 7th Framework program. The maintenance and development of strong public R&D entities within the Nordic countries is necessary to keep the region competitive with other geographical areas such as the rest of Europe, U.S. and the Far East which have strong public research institute funding in the area of ICT.

Appendix 1: BWSN Sensor Message Format

Version 1.2

Edited by Åsmund Sandvand, Memscap AS
17 December, 2007

1. BWSN Network definitions

A network of BWSN sensors is defined by a number of sensors communicating with a network coordinator at a predefined set of radio channels using the same Group ID. More than 1 simultaneous network can be built by defining different radio channels and/or Group ID.

At startup, each sensor will transmit a startup message at the default radio channel communicating its presence and capabilities. After an optional configuration sequence, the network coordinator will request the sensor to start transmission of sensor data.

BWSN Default Channel = 26 (valid channels are 11 to 26, and the TinyOS default is channel 11)

BWSN Default Group ID = 0xd7 (TinyOS default is 0x7d)

2. BWSN message format

The general BWSN message is shown in Figure 1. As shown, the application message is included as TOSH DATA of the TinyOS message

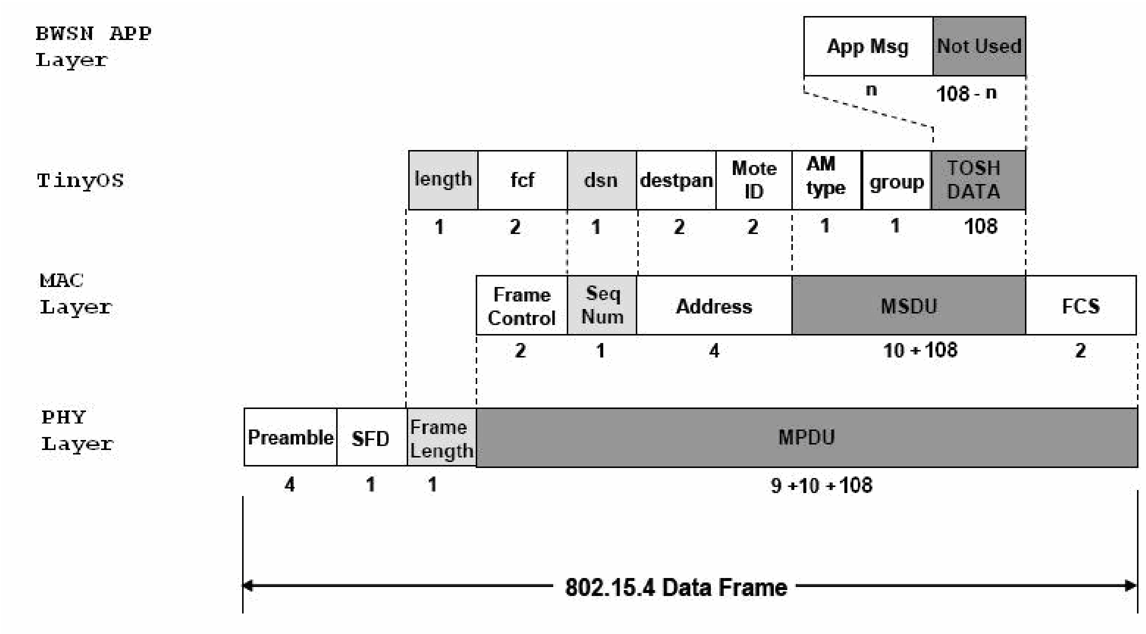


Figure 1 BWSN protocol stack

TOSH_DATA_LENGTH is fixed at 108 octets (28 is default for TinyOS), resulting in a frame length of 127 which is maximum in 802.15.4, and octets not used for an application message is simply not used. Application Message Type is included as AM type in the TinyOS layer.

16 bit CRC calculation and verification is performed at MAC layer by hardware.

In order to maximize data transfer, this version of the BWSN Sensor Message Format does not include any MAC security operations.

Encryption and authentication should be considered for future versions. Please observe that enabling encryption and authentication will decrease the available space for TOSH_DATA with up to 16 octets.

3. BWSN Application Messages

As shown in Figure 1, the BWSN Application Message is included in the TinyOS Message with the following header:

```
uint8_t length;
uint8_t fcfhi;
uint8_t fcflo;
uint8_t dsn;
uint16_t destpan;
uint16_t addr;
uint8_t type;
uint8_t group;
```

The size of the header is 10 octets.

For BWSN, we have defined the messages as listed in Table 1.

AM Type	**Value**	**Description**
AM_OSCOPEMSG	10 (0x0A)	Raw Data / Oscilloscope message
AM_OSCOPERESETMSG	32 (0x20)	Reset sample number
AM_CONFIGUREMSG	51 (0x33)	Configuration message
AM_STARTOPERATIONMSG	52 (0x34)	Start operation
AM_STOPOPERATIONMSG	53 (0x35)	Stop operation
AM_PINGREQUESTMSG	54 (0x36)	Ping Request
AM_STATUSREQUESTMSG	55 (0x37)	Status Request
AM_BEACONMSG	56 (0x38)	Beacon Message
AM_CONFIGURERESPONSEMSG	71(0x47)	Configure response
AM_BOOTINDICATIONMSG	72(0x48)	Boot indication
AM_PINGRESPONSEMSG	73(0x49)	Ping Response
AM_STATUSRESPONSEMSG	74 (0x4A)	Status Response
AM_DATAMSG	75 (0x4B)	Raw Data

Table 1 BWSN Active Message Types

3.1. Messages from network coordinator

3.1.1. Reset sample number (AM_ OSCOPERESETMSG = 0x20)

```
typedef struct OscopeResetMsg
{
  /* Empty payload! */
} OscopeResetMsg_t;
```

Reset sample number is used to reset the sequence number on any ongoing raw data message stream

3.1.2. Configure (AM_ CONFIGUREMSG = 0x33)

```
typedef struct ConfigureMsg
{
  uint32_t timestamp;
  uint32_t msBetweenSamples;
  uint8_t SamplesPerMessage;
  uint8_t RadioChannel;
  uint16_t newMoteID
} ConfigureMsg_t;
```

Configure is used to set the sensor node sampling rate and Radio Channel. It can also be used to request a change of the sensor Mote ID.

3.1.3. Start Operation (AM_STARTOPERATIONMSG = 0x34)

```
typedef struct StartMsg
{
  uint32_t timestamp;
} StartMsg_t;
```

Start Operation is used to start transmission of sensor data

3.1.4. Stop Operation (AM_STOPOPERATION_MSG = 0x35)

```
typedef struct StopMsg
{
  uint32_t timestamp;
} StopMsg_t;
```

Stop Operation is used to stop transmission of sensor data

3.1.5. Ping Request (AM_PINGREQUESTMSG = 0x36)

```
typedef struct PingRequestMsg
{
  uint32_t timestamp;
} PingRequestMsg_t;
```

Ping Request is used to check response time of sensor

3.1.6. Status Request (AM_ STATUSREQUSETMSG = 0x37)

```
typedef struct StatusRequestMsg
{
  uint32_t timestamp;
} StatusRequestMsg_t;
```

Status Request is used to ask for status of sensor

3.1.7. Beacon Message (AM_BEACONMSG = 0x38)

```
typedef struct BeaconMsg
{
  uint32_t timestamp;
} BeaconMsg_t;
```

Beacon Message can be used to transmit global timestamp

3.2. Messages from BWSN sensor

3.2.1. Raw Data / Oscilloscope message (AM_OSCOPEMSG = 0A)

```
typedef struct OscopeMsg
{
  uint16_t sourceMoteID;
  uint16_t lastSampleNumber;
  uint16_t BWSNchannel;
  uint16_t data[48];
  uint8_t status;
  uint8_t numberOfSamples ;
  uint32_t timestamp;
} OscopeMsg_t;
```

Raw Data / Oscilloscope message is used by sensor nodes to transfer raw data in blocks of 48 16-bit samples at a time.

This message is based on the original TinyOS Oscilloscope message with the addition of a status, numberOfSamples and timestamp field.

Octets	Field	Description
2	`sourceMoteID`	Address of sending node
2	`lastSampleNumber`	Number of last sample
2	`BWSNchannel`	Sensor channel ID (see table Table 3)
96	`data[48]`	48 16-bit data samples
1	`status`	bit field: `status[0]` is low_batt indication, `status[7..1]` unused
1	`numberOfSamples`	The number of samples contained in the message
4	`timestamp`	32-bit timestamp

Table 2 Raw Data /Oscilloscope message fields

The BWSNchannel field is used to identify the BWSN signal source.
Each company will manage a separate range of channels.

BWSNchannel	Company	Description	Typical sample rate
100 – 199	Memscap	Pressure Sensor	100 samples per second
200 – 299	Millicore	Air Leakage Sensor	2 samples per minute
300 – 399	Novosense	ECG	1000 samples per second
400 - 499	VTT	Accelerometer	250-1000 samples per second

Table 3 BWSN channels

A sensor can send a *Raw Data / Oscilloscope message* that is only partly filled with data. The numberOfSamples field will contain the number of samples contained in the message.

3.2.2. Configure response (AM_ CONFIGURERESPONSEMSG = 0x47)

```
typedef struct ConfigureResponseMsg
{
  uint16_t sourceMoteID;
  uint16_t BWSNchannel;
  uint8_t response;     // success = 1
  uint8_t status;
  uint32_t timestamp;
  uint32_t msBetweenSamples;
  uint8_t SamplesPerMessage;
  uint8_RadioChannel;
} ConfigureResponseMsg_t;
```

Configure Response is used to report outcome and current settings after receiving a *Configure Request*.

In case of a change of Radio channel, the *Configure Response* message shall be sent on the existing channel, followed by a change of sensor radio channel.

Octets	Field	Description
2	`sourceMoteID`	Address of sending node

2	`BWSNchannel`	Sensor channel ID (see table Table 3)
1	`response`	
1	`status`	bit field: `status[0]` is low_batt indication, `status[3..1]` unused `status[7..4]` number of BWSN channels if more than 1.
4	`timestamp`	32-bit timestamp
4	`msBetweenSamples`	Time in milliseconds between samples
1	`SamplesPerMessage`	Number of samples per message
1	`RadioChannel`	Radio channel number

Table 4 Configure response message fields

3.2.3. Boot Indication (AM_ BOOTINDICATIONMSG = 0x48)

```
typedef struct BootIndicationMsg
{
  uint16_t sourceMoteID;
  uint16_t BWSNchannel;
  uint16_t status;
  uint32_t timestamp;
  uint32_t msBetweenSamples;
  uint8_t SamplesPerMessage;
  uint8_t majorVersion;
  uint8_t minorVersion;
} BootIndicationMsg_t;
```

Boot Indication is used at startup to communicate sensor presence and capabilities.

Octets	Field	Description
2	`sourceMoteID`	Address of sending node
2	`BWSNchannel`	Sensor channel ID (see table Table 3)
1	`status`	bit field: `status[0]` is low_batt indication, `status[3..1]` unused `status[7..4]` number of BWSN channels if more than 1.
4	`timestamp`	32-bit timestamp
4	`msBetweenSamples`	Time in milliseconds between samples
1	`SamplesPerMessage`	Number of samples per message
1	`majorVersion`	Major version number
1	`minorVersion`	Minor version number

Table 5 Boot Indication message fields

3.2.4. Ping Responce (AM_ PINGRESPONSEMSG = 0x49)

```
typedef struct PingResponseMsg
{
  uint32_t timestamp;
} PingResponseMsg_t;
```

Ping Response is used to respond as quick as possible after receiving a *Ping Request.*

3.2.5. Status Response (AM_ STATUSRESPONSEMSG = 0x4A)

```
typedef struct StatusResponseMsg
{
  uint16_t sourceMoteID;
  uint16_t BWSNchannel;
  uint8_t status;
  uint32_t timestamp;
  uint32_t msBetweenSamples;
  uint8_t SamplesPerMessage;
  uint8_t majorVersion;
  uint8_t minorVersion;
  uint8_t strength;
} StatusResponseMsg_t;
```

Status Response is used to respond to a *Status Request*.

3.2.6. Raw Data (AM_DATAMSG = 0x4B)

```
typedef struct DataMsg
{
  uint16_t BWSNchannel;
  uint16_t data[53];
} DataMsg_t;
```

Raw Data is used by sensor nodes to transfer raw data in blocks of 53 16-bit samples at a time. The use of *Raw Data* is optional and provided as an alternative to using the *Raw Data /Oscilloscope* message.

Nordic Innovation Centre

Nordic Innovation Centre

The Nordic Innovation Centre initiates and finances activities that enhance innovation collaboration and develop and maintain a smoothly functioning market in the Nordic region.

The Centre works primarily with small and medium-sized companies (SMEs) in the Nordic countries. Other important partners are those most closely involved with innovation and market surveillance, such as industrial organisations and interest groups, research institutions and public authorities.

The Nordic Innovation Centre is an institution under the Nordic Council of Ministers. Its secretariat is in Oslo.

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