Wireless medical sensor network with ZigBeeTM

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Abstract: - While Bluetooth is wide spread in wireless applications today a new radio technology called ZigBee comes up to the market. Though ZigBee tends not the same market segment like Bluetooth it competes with Bluetooth in several applications. The initial market for ZigBee, defined by the promoting organization, the ZigBee Alliance, is the wireless automation of home, building and industrial applications. But so called personal area networks with low data rates (LR-WPAN) would be as well a field of application for this upcoming radio technology.

The fast growing market for wireless technologies such as wireless LAN or Bluetooth - even in medical environments - show the need for smart solutions as a cable replacement for patient sensors as well as for the infrastructure of clinical information systems that offer great advantages for both, patient and clinical personal in everyday life.

Furthermore the network capabilities of ZigBee provide more functionalities especially for the field of medical body area networks. Due to lower power consumption this new radio technology offers longer run time for battery powered mobile and autonomous sensor devices.

This research evaluates radio technologies for low power sensor networks and compares the use of Bluetooth and ZigBee in medical body area networks. For these composition proceedings a multi sensor network based on ZigBee technology was developed to examine the advantages and disadvantages of each technology.

Key-Words: Body Area Network (BAN), ZigBee, Bluetooth, Medical Sensor Network, Patient Monitoring, Telemedicine

1 Introduction

Permanent logging of vital signs is a proven method for supervising the health status of patients suffering from chronic diseases, such as Diabetes and Asthma. The most prominent area of application for long-term logging of patient data is cardiology, where 24-hour-ECGs are required for therapy control and as early indicators for impending heart attacks. In general there is an increasing demand for permanent patient monitoring beyond clinical usage, for example clinical aftercare and monitoring of risk patients.

Medical monitoring procedures usually require more than one sensor to be attached to the human body. Stroke risk patients should not only observe their blood pressure values, but supervise additional parameters related to blood oxygen saturation, temperature and weight on a long-term basis. Patients with high blood pressure are facing an increased risk of serious cardiac diseases without any symptoms of pain. Continuous monitoring of related parameters enables efficient early warning mechanisms and prevention measures. Current monitoring technology requires "cabling" of patients. They have to wear a set of wired sensor elements, linked to several devices for processing and visualization of the sensor signals. For external connectivity, typical remotely used stand-alone systems provide a serial port at best.

Using wireless multi-parameter monitoring technology, a wide range of diseases could be prevented, treated and managed more effectively today – for the benefit of both patients and health system. Additional future applications are subject to research and development. Existing and upcoming new wireless technologies are also tending to medical applications and wireless body area networks, but are they really applicable? This Paper describes the evaluation of a ZigBee based Body Area Network [1], [2] with different medical Sensor for

2 State of the Art

Healthcare monitoring.

Today two standardized wireless communication technologies – Bluetooth [4] and ZigBee [3] – and a number of specific solutions to build up a wireless sensor network are competitors in the field of medical applications. But as they are mainly deployed in consumer electronics, it has to be checked if they also fit into a medical device for real-time and of course long-term monitoring of vital signs.

The requirements for medical healthcare monitoring are:

- Different data throughput and update rates, depending on the sensors to be used
- Low latency
- Low power consumption

• High reliability

Current low power sensor network concepts transmit their data in a very short time span. They focus on applications with small data packets and intermittent or low periodic and low latency data. Sensor nodes are most of the time in a power saving sleep mode. This low duty cycle limits the average drain current, because the energy consuming transmission window is reduced to a minimum. The crucial parts from the hardware perspective are the time keeping circuit and the activating and deactivating time of the device, which has to be done within a few milliseconds. If more data has to be transmitted or higher packet sizes are needed, the data rate has to be increased to keep a low duty cycle. But increasing the data rate results in higher bandwidth, which is not always available and reduces receiver sensitivity.

Often data packets are blown up due to necessary protocol overhead for network synchronization, device addressing and quality of service (QoS).

For low latency and guaranteed data rate you have to keep your network synchronized. All nodes are allowed only to send data at a predefined point of time. To inform sensor nodes about changes in this TDMA scheme, nodes periodically have to listen to the channel. This listening period, where the receiver is active often consumes almost the same energy as the transmission.

This kind of synchronized network is used by Bluetooth. Low latency and data rate are guaranteed, but the protocol overhead is high and wake up from sleep mode takes a lot of time.

Zigbee is offering capabilities keeping the protocol overhead and duty cycle low, without to much loss in latency. ZigBee uses a CSMA mechanism, where the node is transmitting its data as soon as the channel is free. You can choose between an unslotted and a slotted network. In a slotted network a PAN coordinator sends a beacon to synchronize the attached nodes. Within a transmission window a node can send its data as soon as the channel becomes free. This reduces synchronization effort, but is a problem for latency. Therefore ZigBee offers another mechanism called guaranteed time slot (GTS), which allows each device to send data within a specific duration of time. Unfortunately this functionality is not implemented today.

Most of today's wireless systems – Bluetooth, ZigBee and also WLAN - use the 2.4 GHz ISM Band due to worldwide usability. Each Wireless technology deals with the interference problem in another way. Bluetooth uses a Frequency hopping spread spectrum scheme (FHSS) with a small bandwidth and a data rate of 1 Mbit/s. ZigBee on the other hand uses direct sequence spread spectrum peak data rate of 250 kBit/s to cope with the interference problem.

First of all, Bluetooth was designed as a wireless technology for cable replacement. Therefore it is mainly

used for audio application (headsets, mobile phones, etc.). The most used and implemented profile for Bluetooth modules is the so called serial port profile (SPP) which just replaces a serial cable link.



Fig. 1: Signal range and data rate of different wireless transmission standards

For these applications (shown in figure 1; [7]) high data rates and continuous data transfer in real-time is needed. All of these results in a stack size of more than 250 kByte.

Comparing ZigBee against Bluetooth the stack size is much smaller (see table 1). This results from focusing on lower data rates, smaller data packages and the need to develop applications directly on the ZigBee protocol stack.

Table 1: comparing Bluetooth and ZigBee protocol

	Bluetooth	ZigBee
Stack Size	250 kByte	432 kByte
Data Rate	1 Mbit/s	250 kbit/s
Information Rate	~720 kbit/s	~128 kbit/s
Packet Size	2870 Byte	127 Byte

For a highly reliable Body Sensor Network used for healthcare monitoring, Bluetooth with its highly synchronized network architecture seems to be the appropriate solution. But can a less power consuming ZigBee based wireless network be an alternative solution?

2 Problem Formulation

The ZigBee Alliance [3], as the promoting consortium, claims the development of a LLL communication standard: low cost, low power, low data rate.

In the aspired markets home, building and industrial automation short control commands are sent to a larger number of machines or sensor signals from different network nodes - spread over a wide area - are carried together. In this case all the features of a LLL system totally fit into the situation. But what about ZigBee in a medical environment? In this field of application an inexpensive and economical solution is also desirable, of course. But how do medical signals match with the demand of low data rate. Let's take a closer look on data rates that derive from medical sensors, especially those used for continuous patient monitoring.

In medical diagnostics the most important signals that are measured on a patient are called vital signs. Some of the vital signs are numerical values that slowly change over the time and only once in a while need to be refreshed on a monitoring display. The patients' temperature would be one of those numerical signals. Another type of vitals signs are continuous wave forms. The characteristic run of these curves gives a lot of information to physicians. Next to the pulse wave (plethysmogram) or the respiration wave, the ECG (electrocardiogram) is the most well known signal used in patient monitoring and medical diagnostics.



Fig. 2: ECG-signal (left) and Pulse wave (right)

Due to the frequency components contained in these signals, a certain sampling rate is necessary when converting the analog signal from the primary sensor into digital values for further signal processing in a microcontroller or PC. While the highest frequency component in a pulse wave is lower than 20 Hertz, the distinctive form of the QRS-complex in an ECG signal leads to 100 Hertz as the highest frequency component.

For further signal processing these signals must be sampled with at least the double value of the highest frequency component contained in the original signal. Typical sampling rates in medical applications are 100 Hertz for a pulse wave signal and 400 Hertz respectively for an ECG. Table 2 shows the needed data rates when digitizing with an 8 up to 16 bit ADC.

Table 2: Data rates from medical devi	ces
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Signal	Sampling	Bits	Data volume
	rate		in bits / s
Temperature	1	10	10
Movement	20	10	200
Breathing	20	10	200
Pulse wave	30100	10	3003000
One lead ECG	100	10	1000
Three lead ECG	100400	816	800 6400

The ZigBee communication protocol allows a general packet size of 127 byte to send data from one node to another. In such a package a payload of 86 byte is provided for user specific data. Due to limited frame size of each data package the user data has to be fragmented into several packages. With the data volumes of different sensors from table 2 the value of required packets ranges from one packet per second up to 10 packets per second. The resulting data rate from user specific payload and package overhead therefore reaches a maximum of 9.9 kbit / s.

Combining several medical devices to a body area network all devices have to share the same medium and therefore the data rate has to be split up among each of them. But counting the data rates of a sensor set a patient might wear as a body area network the useable data rate of ZigBee should be sufficient.

3 Problem Solution

To observe stroke risk patients, patients with sleep disorder or high blood pressure a body area network consisting of several wearable medical sensors was composed. This comprises five different autonomous sensors, a three-lead ECG, a sensor for breathing, a pulse oximeter, a sensor for movement and a temperature sensor. Figure 2 shows all these sensors and their placement on the human body. Furthermore this figure shows our sensor combination VitaSENS[®] consisting of an ECG and a pulse oximeter. The little black box on the left breast of the silver man measures the three-lead ECG and the oxygen saturation via a little clip at the ear.

The breathing of a patient can be observed with nasal cannula which is worn under the nose. A pressure sensor at the end of a flexible tube, which is located at the patient's neck, gives a continuous curve of the patients breathing.

The sensor for movement measurement is realized as plaster and is fixed at the chest. This sensor gives information about the movement of the patient. For example while the patient is sleeping, such a sensor counts how often the patient turned around a night or slept in dorsal or prone position. The three axis of movement are analyzed and only the results have to be transferred several times per minute.



Fig. 3: ZigBee sensor network

The temperature sensor is also realized as plaster and can be fixed anywhere on the body. It sends quite rarely the actual temperature to the receiver. It transmits the actual temperature to the receiver in very large intervals.

A wrist band holds the electronics for the pulse oximeter. The sensor itself is realized as a standard finger clip with a short cable to the wrist band. It measures the pulse, oxygen saturation and transfers a continuous curve called pulse wave curve or plethysmogram.

Connecting all these sensors we use a ZigBee compliant platform and the protocol stack from figure8wireless [5]. After filtering and some signal processing done by microcontrollers all data (ECG, position, temperature, pulse and oxygen saturation) is transferred ZigBee compliant.

4 Conclusion

ZigBee is suitable for a body area network, though the data rate and packets of ZigBee are very small and especially the continuous waveforms of ECG and pulse oximeter require a high data rate.

The data rates of each of our five sensors are small enough to gain profit of a small duty cycle while sending data and switching the whole sensor in sleep mode. This means power consumption can be reduced in comparison to Bluetooth. As all sensors have to share one channel the over all data rate is currently limited to 128 kBit/s. Even the accumulated data rate of all sensors is still low enough to have room for further sensors, without overloading or even blocking the transmission channel.

Compared to Bluetooth power consumption in the case of sending data is nearly equivalent, but ZigBee benefits from its ultra low power sleep mode and very short wakeup times. Though Bluetooth provides a sleep mode, it is not practicable to overcome the long wakeup times, by storing data and sending it in short bursts, taking advantage of Bluetooth's higher data rates. This is due to the fact that medical continuous wave forms have to be analyzed by a physician in real time, which means that any lag in the transmission would be unacceptable.

It is possible to realize a body area network with the new ZigBee communication technology that consumes less energy than an implementation with Bluetooth radio modules. The operating time of the medical devices can be significantly increased which may enable patient monitoring twenty-four-seven.

Practical tests have shown that ZigBee is even robust enough to use it in an environment with a WLAN installation or next to other Bluetooth devices [8].

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