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Sensor Network for Extended Health Monitoring of Hospital Patients

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***Abstract*—Modern hospitals are equipped with a variety of medical devices for the care of the patients. A particular group of devices are the ones that monitor the patients' vitals such as heart rate, oxygenation or blood pressure. Monitoring these vitals allows the doctors and nurses to respond quickly in case a patient's condition is degrading and even to save his life. The disadvantages of such a system is that it is usually bulky, and patients who are wired cannot move away from the room. This paper proposes an efficient monitoring infrastructure for hospitals using compact and wireless devices that can be worn by every patient at all time, transmitting real-time data to a central place, which can be accessed by the doctors for expert diagnosis.**

I. Introduction

Apart from curing the diseases, the hospital must take care of the well-being of the patients. Although it is hard to attach a health monitoring system to every patient in a hospital, it provides further follow-ups on the patients even when they leave their rooms. This allows doctors and medical staff to observe the evolution of the vitals of the patients without having to actually be in the room. Even though such systems already exist, they are mostly wired and not meant to be carried outside patients' rooms.

Constant monitoring also allows prevention of random incidents, such as people having cardiac arrests while in the bathrooms and not being monitored. The use of a low range wireless technology such as IEEE 802.15.4 allows not only to transmit data with low power requirements, but also a finer localization of the devices if required.

Another advantage of such carried devices is the possibility for the patient to be monitored directly from home by adding only a small device to the patient's Internet router. Such advantage would allow the release of patients sooner while still being monitored. Therefore, the doctors can save time checking the follow-up patients. This tremendously reduces the healthcare cost for both the patients and the hospitals. The infrastructure presented in this paper is based on a network of wearable devices recording patient vitals such as heart rate, oxygenation, and blood pressure and transmitting data in real time using 6LoWPAN, an IPv6 protocol based on the IEEE 802.15.4 standard [1]. More intensive care can include devices with ECG (Electrocardiography), EEG (Electroencephalography) or EMG (Electromyography) broadcasted to a server for analysis and recording. The infrastructure is also complemented by a wearable node that interfaces with smartphones or a home network to carry the information when the patients are not located within range of the hospital.

In section II, we describe the sensor nodes worn by the patients. Section III presents the infrastructure as a whole and section IV describes the main issues and challenges for such implementation.

II. Sensor Nodes

The sensor device has two fundamental requirements. It needs to be compact and light weight so the patient can comfortably carry it, and it needs to transmit different types of sensor data over the radio to the hospital. In order to meet the first requirement, the device needs to be equipped with a small battery, and therefore the device must consume very low power.

The radio chosen in this proposal comply the IEEE 802.15.4 standard because of its low power characteristics, which limits the bandwidth to 250kbit/s. Even though the bandwidth is limited, this MAC layer allows the implementation of IPv6 using the compressed headers of 6LoWPAN. Therefore, there is virtually no limitation for the number of devices that can be connected to the network. Another advantage is that the packets can be carried over a more conventional network with minimum requirements.

The portability of the device makes them suitable for using outside the hospital infrastructure as well. By the mean of a device collecting sensor data, it can be transmitted to another Internet-capable devices through the mean of Bluetooth or Wi-Fi. Such device acts as a super-node that regroups the important sensor data into one single data flow. This super-node is desired to be a portable, lightweight and power-efficient device that will be a gateway to the Internet, where the device can be mounted onto the patient, or placed at patient's home. Using this connection, the user sensor data can be transmitted to the hospital in real-time for extensive patient diagnosis.

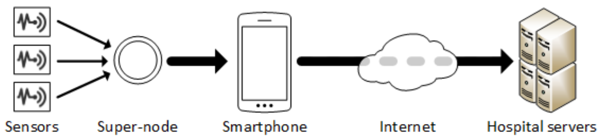

Figure 1. Mobile monitoring using a super-node connected to a smartphone

However, current basic patient information needs to be provided to the patient through this device after preliminary sensor data processing. This entails that the super-node must be in charge of performing basic signal processing on the body sensor data. Candidates for this super-node can be a smartphone, other embedded system with Internet connection capability or both smartphone and the embedded system.

A smartphone embeds multiple wireless adapters that can be used in our design. The Bluetooth or Wi-Fi can be managed to handle multiple body sensor data to the smartphone. Particularly using Bluetooth Low Energy (LE) technology over the classic Bluetooth technology can drastically reduce the power consumption in the smartphone [2], as well as on the each sensor node. Furthermore, the maximum bandwidth supported by the Bluetooth LE suites the bandwidth limitation of the 6LoWPAN. This proves interoperability from one wireless protocol to the other wireless protocol.

As presented in Figure 1, the smartphone can be used as a simple gateway from a super-node that integrates all sensor data. In this case, another embedded system must be declared as a super-node. A customized embedded system can be introduced in our design. As an example, a Xilinx Zynq-7000 All Programmable SoC [3] can be the heart of the system where it governs wireless transmission and signal processing in real-time. By running an embedded Linux on this dual-core Cortex-A9 ARM processor, the flexibility of software development and usability of the system for preliminary sensor data processing can be easily achieved on the super-node level. In addition, any type of wireless adapter can be attached to this processor including Internet, Bluetooth and 6LoWPAN services. This device can be connected to the Internet as shown in Figure 2.

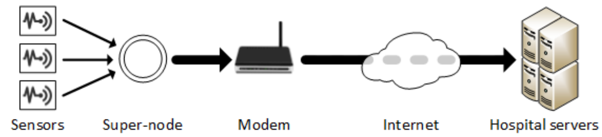

Figure 2. Home remote monitoring using a super-node connected to a home network

III. Network Infrastructure

For efficiently using the sensor devices in hospitals, the sensor data needs to be acquired, centralized and then processed. In order to acquire the data, several transceivers have to be placed around the hospital. Due to the limited range of IEEE 802.15.4 standard, several transceivers will need to be installed on each floor. However, one of the specialties of this standard is the possibility to perform multiple hops to reach a router. Therefore, the range of the network expands with the patients moving around. If for some reason the signal can't reach a certain router, it can be carried away through another router. Another advantage is the reduced power consumption, as the device can select to relay the data instead of transmitting it directly if it consumes more energy. This makes it very easy and cost effective to create relays for the data.

The limited range of radio standard used in this paper enables the approximate localization of the patient. Location of the router relaying the data can be used to estimate the location of the patient within its range. Combined with the actual signal strength measured on other devices, the precision can be accurate enough to locate a patient within a limited set of rooms [4]. Figure 3 shows the sample configuration of a hospital infrastructure for sensor network.

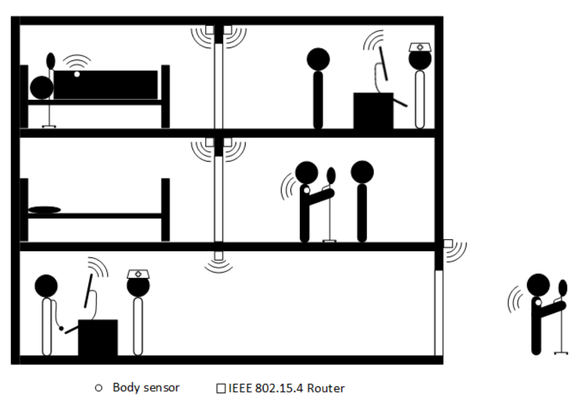

Figure 3. Hospital infrastructure for sensor network

The centralization of the signal is important to provide hospital-wide availability of the data. A doctor monitoring a patient on a specific condition can receive an alert directly on a pager or phone, regardless of his physical location. This also enables a quick response from the medical personnel as all the required information is accessible immediately.

More than just displaying and logging the information, a dedicated server can be configured to react in specific conditions, such as low blood oxygenation, or high blood pressure. This can lead to an anticipation of the worsening of a condition, and therefore a better treatment can be provided to the patient.

IV. Issues and Challenges

One issue that arise from the use of small devices is the autonomy. Even if the power requirement is lowered to a minimum, the autonomy might not be enough through the duration of the patient hospitalization. This adds the need for mean of recharging the device when needed. Although the use of wireless charging could be considered for wireless devices, it risks affecting the signals recorded by the sensor, and so must be avoided. The simplest solution is to plug the sensors when patient is back in his hospital room. Additionally, the electromagnetic perturbations produced by the devices might affect some other instrumentation devices. Therefore, these sensors may not be used everywhere in the hospital. However, the frequency and modulation of the IEEE 802.15.4 being the same as most of the Wi-Fi networks, they will be usable where Wi-Fi is already present and harmless.

Another issue is the limited bandwidth. If the sensor is limited to sending vital constants every few seconds, the bandwidth of 250 kbit/s is enough to accommodate several patients and their sensors without saturating the network. However, broadcasting the vitals in real-time through the network requires more throughput, and having too many sensors broadcasting on the same area might generate a bottleneck for the data. The requirement for streaming can be reduced if the sensor provides some signal analysis, for example detecting some anomalies. In that case, the sensor provides a summary of the vitals unless something weird is detected, in which case the sensor would decide to directly stream the vitals. Thus the bandwidth can be preserved at the battery's expense. In case the user is not in the proximity of the hospital, the super-node can be used to do this processing instead of the sensors. It can also implement compression algorithms in order to reduce the amount of data going through the internet.

Use of higher computing power can also be achieved online, using server that can be located directly inside the hospital. If the data is too complex to be analyzed by the sensors, or the super-node when not in the hospital, the server can take over and provide a higher efficiency. Centralized processing not only allows merging data from several sensors, but also between patients, and detect for example epidemics.

Last issue is the configuration of the devices. In order to operate properly, each device should be associated with one patient. However, the size of the device makes it difficult to register to the network. A serial number on the device to enter on the system would suffice, but the use of NFC can improve the procedure by allowing a wireless registration of the device. In terms of patient confidentiality, the NFC would also allow the transmission of the network encryption key that prevents unauthorized data collection [5, 6].

V. Conclusions

This paper presented a concept of wireless network for extended health monitoring for hospital patients. It allows not only the monitoring of patients inside the hospitals, but also remote monitoring with minimum additional hardware. It centralizes the acquired data for quick access by the medical personnel and enables improved follow-up of the patients. Finally, standardized component allows a greater interoperability of the devices inside the network.

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