Advanced Wireless ICT Healthcare Research

Matti Hämäläinen, Pekka Pirinen, and Zach Shelby

Abstract — **Recently, the methods to improve general hospital logistics and processes have been under heavy investigation all over the world. Especially in the public healthcare and welfare sectors, the improved process practices can save a lot of time from supporting tasks which could be redirected to personal, patient care duties. Changes in processes directly affect overall healthcare costs. How to shift work load from supporting activities to patient-centric care, and make the patient passage through hospital processes more convenient using wireless technology are discussed in this paper. Some examples on hardware implementation related to the topic are also discussed.**

Index Terms — **communications, hospital, positioning, tracking, welfare**

I. Introduction

The recognized problem at the hospital level globally is inefficiency in the management of healthcare processes. The bottlenecks, such as long waiting and searching times, double writing, lost instruments and a lack of all information needed in situ can easily be pointed at. All these listed issues are too common problems, and unfortunately they are not limited only to the healthcare sector. So, these new solutions and improved procedures can be exploited more generally.

The key point in the research area to be discussed next is to define processes in hospital, healthcare and welfare sectors, which can be rationalized by adopting new wireless technologies and new practices. More benefit can be achieved if the novel actions could be focused on daily working processes. It is also desirable that the promoted techniques are invisible to the user, which makes it much easier to adopt these techniques and processes.

In a public hospital in Oulu, Finland, it has been estimated that ordering and handling of deliveries in a surgical department may take up to 167 hours and 147 hours per week, respectively. In a regular ward having 26 beds, 13 hours are spent for ordering and 21.5 hours for handling of deliveries per week [1]. Another study shows that by using an electronic patient record and wireless communication, medical doctors can save about 15 % of their time. For nurses, the saving could be more than 10 % [2].

If all this workload saved can be redirected to patient care activities by decreasing the double writing etc. subsidiary activities, the financial savings in the whole healthcare sector could be extremely large. In addition to the financial savings, this improves the overall quality of care. It is a well-known problem that there is a lack of labour in the healthcare sector, and it is in everybody's interest to use the labour available as efficiently as possible in nursing.

THIS paper reviews the wireless healthcare sector research activities which are currently ongoing at the University of Oulu, Finland.The following discussion is based on the ideas and work carried out by the WILHO Consortium in the Oulu region in Finland. Besides the Centre for Wireless Communications (CWC), the other main contributors for the WILHO research are the Intelligent Sensor Group at the Computer Engineering Laboratory (ISG) and Optoelectronics and Measurement Techniques Laboratory (OEM) at the University of Oulu, Oulu University Hospital (OUH). In addition to the academic players, the consortium has three active SME's: ODL Health Ltd. (ODL), Whealth Ltd. and Sensinode Ltd. All these parties have formed the WILHO Consortium to improve the utilization of wireless technologies in hospitals, and promote the concept globally. The WILHO Consortium and its general goals are introduced in [1],[3].

II. Wireless Playground

There are several areas in the healthcare segment where wireless technologies can effectively be utilized. Some of these are summarized in Fig. 1. The WILHO Consortium has defined the Wireless Hospital concept which has been widely promoted all over the world. Because the consortium includes two hospitals (both private and public), the use-case scenarios are adopted from real needs. There are also possibilities to demonstrate the new ideas in real environments due to the hospital construction projects both hospitals have.

The following sections discuss the possibilities and scenarios to utilize wireless technologies in the hospital environment.

A. Wireless Hospital Concept

In this section, the wireless hospital concept is shortly illustrated. The main ideas are to integrate wireless support to the hospital top level management. In addition, using the wireless technology makes it possible to keep track of personnel and goods in real-time inside the hospital.

Wireless integration makes it possible to easily combine all medical, diagnostic and clinical data together whenever

This work was supported in part by the Finnish Funding Agency for Technology and Innovation (Tekes), ODL Health Ltd., WHealth Ltd., Nokia Oyj and Sensinode Ltd.

Dr. Hämäläinen, Dr. Pirinen and Mr. Shelby are all with the Centre for Wireless Communications (CWC), PO Box 4500, FI-90014 University of Oulu, Finland (e-mail: {matti.hamalainen, pekka.pirinen}(at)ee.oulu.fi). Mr. Shelby is also with Sensinode Ltd, Oulu, Finland (e-mail: zach.shelby(at)sensinode.com).

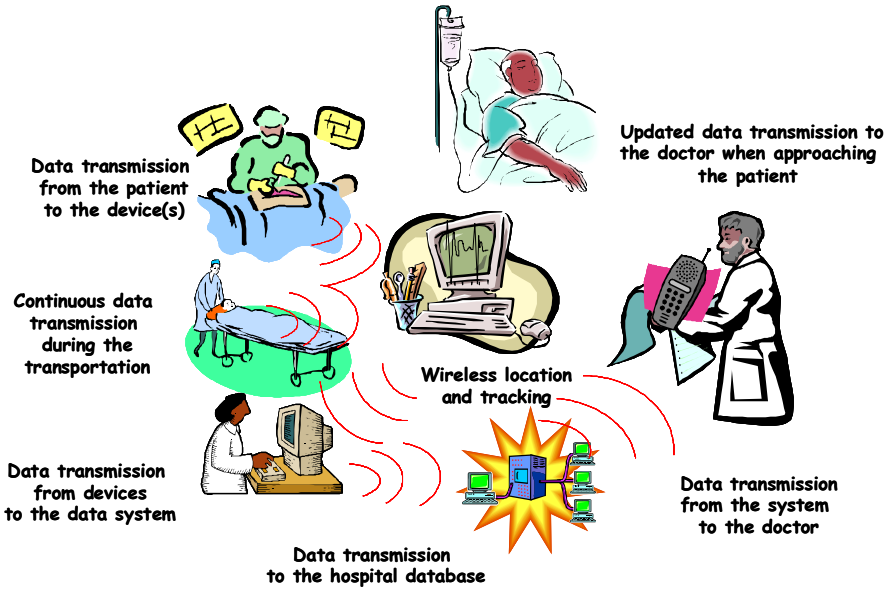

Fig. 1. Example of the wireless playground at the hospital.

needed. Merging data from several sources is not location related either. From the patients' point of view, the benefits are coming from simpler entrance processes, minimized queuing and more efficient care.

Electrical patient records (EPR) need to support new wireless access methods. The EPRs are storing all the care history related to the patient, and all the new medical information collected during the care period inside a hospital. After-care and self-care data can also be collected and stored in an EPR. The latter processes can be done using tele-health approaches.

Ubiquitous, distributed and centralized services related to the patient's problems are the most efficient tools to improve the transit speed of a patient. However, it goes without saying that the process improvement needs to be done without reflection to the patients' safety.

The work carried out within the WILHO Consortium was realised also in a WILHO Roadmap. The roadmap introduces the way that hospitals should proceed towards the final goal, a wireless hospital concept. Typically the transition plan is made for 5-7 years. As background material for the roadmap, a comprehensive inquiry within the global healthcare operators was accomplished.

1) Network topologies

The core of the Wilho-concept is a Wireless Hospital Area Network (WHAN®) which has an open interface with the Hospital Information System (HIS®), and also with various applications related to different hospital processes [3].

The use of a flexible radio interface can support several radio standards. By replacing the cables with wireless connections, the maintainance of the network infrastructure becomes much easier and cheaper. During the installation of new services or communication standards, there is no need for constructional maneuvers due to wireless technology from an infrastructure viewpoint.

a) Wireless Hospital Area Network

The most important property of the WHAN is heterogeneity. Several standardized radio protocols can be used to access the core network, which can be either wireless or based on a wired solution. A flexible radio interface improves the future enlargement ability of the system. Therefore, the system is not limited only to the radio technologies that are available during the initial system installation.

Because all patient real time information is stored in electronic databases which can be accessed everywhere inside the coverage area of the wireless network, the care taking processes will improve. New diagnostic information coming from the laboratory or monitoring device can be directly taken into account in the decision making process by any doctor involved in the patient's nursing. This eliminates the delay coming from the manual data booking processes.

Using the wireless network, patient information can also be automatically transferred into the personal digital assistant (PDA) device of the staff when they are approaching the patient. Due to the automated mechanism, all the latest information related to the patient is always available.

b) Wireless body area network

On the patient side, the monitoring of vital parameters in real-time is possible using wireless sensors and non-invasive measuring instruments. Removing the cables between the monitoring device and the patient significantly improves the movement ability. This also has an improving effect from the healing point of view in some cases.

The data from the non-invasive sensor or monitoring node can be directly transferred to the access point, which is passing the message to the core network. The other option is to collect data in a centralized manner from all the nodes controlled by a portable base station (PBS). The latter option utilizes point to point links between the sensor nodes and the PBS, and the connection between the individual sensor and the fixed infrastructure is therefore created through the PBS. Heterogeneous thinking could also be valid inside the

wireless body area network (WBAN). This allows the utilization of different radio protocols in the system. The general idea of a WBAN is depicted in Fig. 2.

The same procedure can also be exploited in in-human monitoring. WBANs can be used, for example, to route signals coming from swallowed sensors to the core network.

Not only restricted to controlled medical treatment, these approaches can be used in long term, real-time patient monitoring. Afterwards all the latest patient data is available for diagnostic use by any doctor or nursing staff anywhere in the hospital. In addition, using advanced networking techniques, the data can be delivered to specialists located even in other country. By establishing a real-time tele-health link, the patient care process can be maximized.

2) Equipment

The key element when establishing a wireless healthcare network is the equipment going to be used. The devices should be small and easy to use. A typical aspect of human behaviour is resistance against changes. That is why the tools used in the wireless healthcare sector should be familiar. Any new devices that have to be carried with in addition to the existing gadget will typically face resistance. This requires that the new features should be implemented in the terminal device that is currently used. If this is not possible, the new device should support all the existing healthcare features that are in use. Such a device can be a PDA or a cellular phone.

The patient is also requiring more advanced services in the patient room. Connection needs to Internet or personal emails even from the ward are not so unusual nowadays. Personal amusement services can be supported by computer access which has been implemented in the patient bed. This peripheral can also be used by the nursing staff during control visits. This type of dual use reduces implementation costs.

Patient monitoring includes various vital functions, such as electrocardiogram (ECG), oxygen saturation, blood pressure, body temperature, and respiratory rate. Non-invasive and wireless technology is widely applicable in this context. For example, as a part of the WILHO research, a sensor belt was developed and tested for respiratory rate measurement [4]. High resolution accelerometers and pressure sensors were utilised successfully in the experiments.

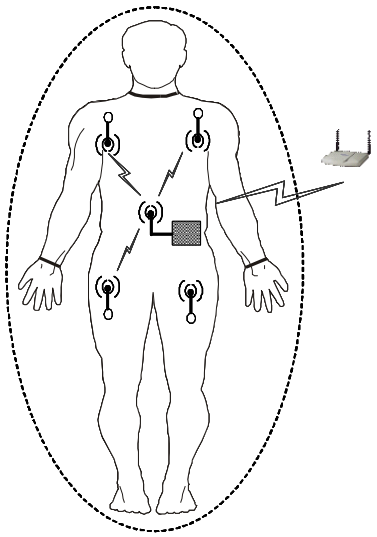

Fig. 2. Wireless body area network for health monitoring.

The source signals from various sensors have different power level, data rate and update frequency requirements. These issues should be carefully addressed at the access point where the signals are combined and packetized for wireless transfer. Examples of the biomedical measurement data parameters are shown, e.g., in [5]. Furthermore, multi-access protocols are analysed and compared, especially with respect to the power requirements.

3) Technology

The radio technology used in the peripheral is not the main issue because several features to be utilized can be implemented using the most common radio standards. On the other hand, different radio standards can give additional value to the application due to their own characteristics. For example, ultra wideband (UWB) technology is superior in the localization accuracy point of view [6]. A UWB based radio interface can also be used when the amount of transferred data is high, and very fast links need to be established. UWB signals can also be used in transmission power limited environments. On the other hand, radio techniques such as Zigbee, Wibree and Bluetooth can also be used when the data rate requirements are not so high.

Near field communication (NFC) or radio frequency identification (RFID) tags support also services that can be utilized under the wireless hospital concept.

Different IEEE 802.11 based radios support both data communication and localization purposes. The technology is also very mature, and there are lots of applications and devices already commercially available. Nowadays, the IEEE 802.11 standard is also a universally utilized wireless technology in hospital wireless communication networks.

Patients should be capable of taking care of themselves despite different methods, technologies and tools, perhaps under the supervision of the healthcare system or care providers. Seamless operation is then the key issue. On the other hand, different technologies and processes in healthcare should support the care providers' tasks, not the other way around. This may mean, for example, context sensitive, location sensitive or problem-sensitive wireless applications. The connection to the service providers' data base does not necessary finish when the patient is sent out of the hospital. Patients might need a connection to the healthcare system even after they have left the hospital. Using wireless technology, this link could be maintained.

B. Application areas

1) Registration to the hospital

When the patient first time arrives to the hospital, or what ever institute adopting the concept, check-in there is only one desk where the registration needs to be done. During the check-in process, all the information related to the patient and his or her visit is asked. Next, the patient is provided by a wireless tag, which contains all the necessary information concerning the visit to the institution in question. Later on, the intelligent hospital infrastructure can guide the patient's

progress inside the building. In addition to help the patient's movement, the system keeps the personnel aware about the patient progress within the process.

When the patient is approaching, e.g., a certain hall or investigation room, a notification can automatically be sent to the corresponding nurse. To improve the service, each patient can be dedicated to the corresponding nurse in advance.

2) *Real time phase information*

Real-time tracking could be exploited in several hospital logistic actions. For example, an immediate alarm when the cleaning has been completed in an operating-room is possible to direct to the nurses and doctors, such as the surgeon or anaesthesia doctor. In a ward, the patient can be prepared in time because the status of the other ongoing processes related to the action are known. This information is called phase information. The automated process can save time, and make the utilization of the operating-room more beneficial by shortening the transfer times between the consecutive operations.

3) *Positioning*

The location and tracking (LT) applications inside a hospital can be based on largely adopted wireless local area network (WLAN) standards, such as IEEE 802.11. The adoption of GPS indoors is not feasible solution due to the very low received signal power at the ground level. Obstacles such as roofs will easily block the signal and make GPS useless.

On the other hand, IEEE 802.11 based LT is already utilized in several environments and the technology is mature. Typically, the hospitals and other public premises have also WLAN already installed. This technology could offer area LT services if very high accuracy is not needed. For example, a coarse positioning could be enough to locate people inside a hall. If the accuracy demands are higher, there are also more advanced techniques available, such as ultra wideband (UWB), which could offer centimetre level accuracy due to the extremely large inherent signal bandwidth.

It is also possible to merge a positioning service to a security application. Under physical threat, a staff member could send an alarm signal, which carries also the location information. The need for such services is nowadays becoming more popular in public departments, including the healthcare sector.

4) *Real time material tracking*

Real time material tracking relates to stock monitoring but can be extended to the invoicing process. If all the material flow inside the hospital can be followed piece by piece, real care costs can be easily directed to the corresponding patient. For example, implants and other more expensive materials can be charged based on real consumption.

5) *Storehouse monitoring*

One of the interesting applications where wireless technologies can be utilized is monitoring storehouses' contents. This part is easily exploitable from the healthcare sector to every storehouse.

At the hospitals, the tracking of medicine, implants and other tools and instruments is typically done manually. In the worst case, the process requires double writing; once in the warehouse and the other time in the office, where the information is added to the electronic data base or ordering software.

6) *After-care*

After the patient has been treated in a hospital and disbanded, e.g., after the surgery, the after-care monitoring can be carried out using new tele-health techniques. The patient could be equipped with wireless sensors, which are collecting the vital parameter information. The data could then be transferred to the personal computer and routed to the hospital electronic patient record. The established link can also be two directional, so the patient can easily get feedback and guidance from the hospital.

Using the advanced body area sensor network it is also possible to monitor the patient's feelings. This information can be helpful when designing the medication and training exercises for the patient. If the feelings can be recognized remotely, it also improves the patient's safety sensation.

C. *Other wireless utilization in healthcare*

1) *Pain meter*

As a part of the WILHO project in Oulu, a wireless pain meter has been developed. This device can be used to collect patient's subjective pain feelings, and to transfer the momentary information immediately to the nursing staff, or a data base for after-care monitoring. The meter scales ranges from zero (no pain) to ten (unbearable pain), and the patient can select the most appropriate indication of his/her pain level. If the level exceeds the pre-specified threshold, an immediate alarm to the nurse's terminal will be sent.

2) *Environment aware sensors*

Embedding wireless sensor networks into the environment increases the utilization of WBANs in the healthcare or welfare sector. The sensors are ideal for sensing, e.g., toxic chemicals in close vicinity of the patient, or in the neighbourhood. Sensor nodes are possible to implement in other measuring devices, such as heart rate monitors, cars, weather stations, watches etc. The remote monitoring could be carried out through the cellular network, for example. A mobile terminal (a phone or PDA) could also be the final device to be used with the application.

3) *Training*

The healthcare sector is not the only one which can utilize wireless technologies in the human well-being improvement. As an example, the wireless positioning service, which can be used to delivered human vital parameters in real-time, is implemented in a skiing tunnel in Vuokatti, Finland. Using the in-tunnel wireless sensor infrastructure, the performance of the skier can be remotely monitored in real-time. It is also possible to evaluate the

efficiency of the training session afterward with the trainer. [7]

4) *Enterprise resource planning system*

To support the adaptation of wireless technologies in the hospital environment, an enterprise resource planning system (ERP) was created within the WILHO project. Using the ERP it is possible to quantitatively measure the cost benefit which is coming due to the new process models.

To make the decision of purchasing and adopting new technologies in the hospital easier, all the processes within nursing actions, including the equipment expenses, are modelled as consecutive process phases. The calculation outputs the total expenditure advantage from new technology installation taking also into account labour costs. The final evaluation criteria are improved efficiency and quality of nursing, reduced costs and better staff well-being. To get all the information out from the ERP, similar calculations should be done before and after the new technology investments. It should be noted that the final cost improvement can be seen only in a long run.

III. Look to the Future

In the future, tele-health will play a big role in the global healthcare business. There are not enough specialists for every hospital, so the utilization of the common knowledge base will increase. Tele-health might be an answer for this increasing problem. Advanced data communication systems are allowing real time video conferences but also remote operations are possible. These technologies are already used in developing countries. However, the technology could be made available for all people.

The findings and ideas from the WILHO work have been, and will be, piloted in the two hospitals involved in the project.

IV. Conclusions

This paper reviews the recent research activities from the WILHO Consortium from Oulu, Finland, toward the wireless hospital concept. New hospital concept will utilize advanced wireless technologies to improve the cost efficiency and quality of care, as well as hospital processes and logistics. The project findings will shift nurse's work load from supporting tasks to nursing and patient care activities.

Due to the CWC's recent activities in the wireless healthcare research area, the CWC has an opportunity to organize the Second International Symposium on Medical ICT (ISMICT 2007) in Oulu, Finland on December 11 – 13, 2007.

V. Acknowledgment

The authors would like to thank all the WILHO Institutes for fruitful co-operation. The Finnish Funding Agency for Technology and Innovation (Tekes) is also acknowledged for the funding through their FinnWell technology program.

VI. References

[1] H. Rissanen, K. Isokanniainen, P. Pirinen, and E. Alasaarela, "*Wilho - a New Concept of Wireless Management of Healthcare Processes*", 6th Nordic Conference on eHealth and Telemedicine (NCeHT), Helsinki, Finland, Aug. 2006, pp. 229-230.

[2] C-Quest Partners Oy, "*Comparative study of a Finnish and a UK district hospital's doctors' time spending patterns*", Unpublished research report, 2006.

[3] http://www.wilho.net/

[4] T. Reinvuo, M. Hannula, H. Sorvoja, E. Alasaarela, and R. Myllylä, "*Measurement of respiratory rate with high-resolution accelerometer and EMFit pressure sensor*", in *Proc. IEEE Sensors Applications Symposium (SAS 2006)*, Feb. 2006, pp. 192-195.

[5] S. Arnon, D. Bhastekar, D. Kedar, and A. Tauber, "*A comparative study of wireless communication network configurations for medical applications*", *IEEE Wireless Communications*, vol. 10, pp. 56-51, Feb. 2003.

[6] J.-P. Montillet, G.T.F de Abreu, H. Saarnisaari, I. Oppermann, "*Comparison of UWB and WCDMA positioning accuracies*", 2005 IEEE 61st Vehicular Technology Conference, VTC 2005-Spring.

[7] I. Oppermann, L. Stoica, A. Rabbachin, Z. Shelby, and J. Haapola, "*UWB wireless sensor networks: UWEN - a practical example*", IEEE Communications Magazine, Vol. 42, Issue 12, Dec. 2004, pp. S27 - S32