TOWARDS ASSISTIVE HEALTHCARE: PROTOTYPING ADVANCES IN WIRELESS SENSOR NETWORK (WSN) SYSTEMS INTEGRATION AND APPLICATIONS

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ABSTRACT

The large increase in Australia's aging population promises to be major economic and social issue for local, state and federal Government bodies. The healthcare budget is expected to increase dramatically and the burden on healthcare services will require not only a massive injection of capital funds but an increase in qualified care givers. The authors believe that assistive healthcare monitoring is one viable and cost-effective solution to alleviate the burden of the healthcare system today and in the future. The authors in this paper describe their third Wireless Sensor Network (WSN) prototype called MoteCare and anticipate the implementation of the next, more advanced prototype. Details of the improvements are covered followed by an objective system evaluation and conclusion.

KEYWORDS

Wireless Sensors Network, Health Monitoring, Motes

1. INTRODUCTION

Much like the rest of the western world, there has been a significant shift in the age make-up of Australia's population in the past 20 years, as a result of sustained low fertility and increased life expectancy. In fact, Australia's aged population is increasing dramatically and it is expected that, within a decade, the ratio of workers to retirees will drop significantly. The ageing of the population is one of the major transformations being experienced by Australia's population (Rowland D., 2003), and is a current focus for both economic and social policy. Much of the discussion around population ageing focuses on issues associated with an increasing proportion of old (over 65 years) people; for example, expenditure associated with income support, the provision of health and disability services, and family and community care. Inevitably, in a civilized society, community healthcare has to be extended to those in their own homes. The cost of caring for the increasing numbers of aged persons in private dwellings, nursing homes or hospitals will be a huge challenge for the government. For those seniors who prefer to live independently in their own homes, constant monitoring is essential to provide adequate care as there is an increased risk of falls, strokes and other health problems which could prove life threatening (Australian Bureau of Statistics, 2005).

Our research investigates the use of Wireless Sensor Networks (WSN) for healthcare monitoring application (Lawrence E. et al., 2004) (Riudavets J. et al., 2004) (Lubrin E. et al., 2006a) (Lubrin E. et al., 2005b) (Lubrin E. et al., 2006d) as a possible solution to managing the care of the next generation of older people, namely the baby boomers. However, those in the healthcare field may need some convincing as medical practitioners are typically conservative and rightly require evidence that a new approach to health care will work. In addition, those who pay for health care, insurers and governments, want to know if it will really save money.

To thoroughly probe the potential feasibility and acceptance of this technology we applied a multi–method research approach comprising of a combination of research methodologies (Gialis G.) which includes a literature review coupled with the development of three working prototypes to test the viability of Wireless

Sensor Networks (WSNs) as healthcare monitors of chronically ill or aged persons. As well, we have conducted two anonymous web surveys on the potential acceptance of these devices as health monitors by users (Lubrin E. et al., 2005a) (Lubrin E. et al., 2006b) (Lubrin E. et al., 2006c).

These networks promise to revolutionize health care by allowing inexpensive, non-invasive, continuous, ambulatory health monitoring with almost real-time updates of medical records via the Internet. Many patients can benefit from continuous monitoring as a part of a diagnostic procedure, optimal maintenance of a chronic condition or during supervised recovery from an acute event or surgical procedure (Jovanov J. et al., March 1, 2005). To address the issues outlined above and target the aged population cohort whose health conditions are more vulnerable, we envisage an end-to-end solution where a non-intrusive front end is required to capture critical health information and an infrastructure is needed that is capable of disseminating the information, making appropriate decisions, and providing timely response to emergency situations.

Section 2 of this paper provides an overview of the emerging statistics showing the increases in the elderly segment of the population and the health consequences of this trend. Section three provides a technical overview of WSNs, and finally outlines the prototype and architecture development of our third WSN health monitoring solution with a brief description of the evolution from the first version to the third more advanced prototype (MoteCare). In section four we describe in detail the recent technical improvements to be implemented in the 4th prototype to address healthcare issues and we evaluate the overall system, identifying advantages and disadvantages in applying the proposed system advances to the monitoring system under examination. Finally the paper concludes and points the way to further research and development.

2. BACKGROUND

According to the Australian Bureau of Statistics in the last 20 years, there has been an 18% increase in over 65s, a 26% increase in 45-64s, the 25-44 year-old age group is static at 30% of the population, and there has been a 70% decline in under-25s in the past 20 years (see chart).

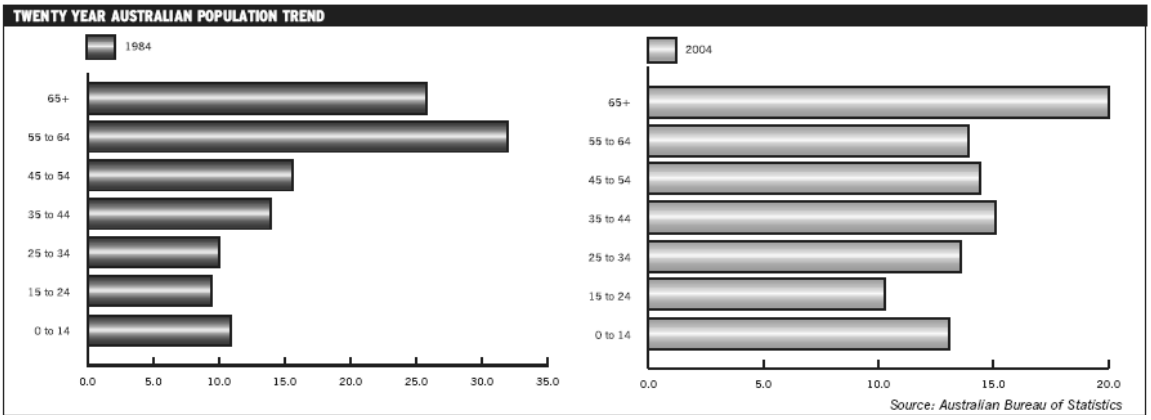

Figure 1. Australian Population Trends (Australian Bureau of Statistics, 2004)

The population aged 65 years and over is projected to increase from 2.5 million in 2002, to between 6.1 and 11.7 million in 2101. As a proportion of the population, this is an increase from 13% to between 29% and 32%. Over the same period, the proportion of children aged 0-14 years is projected to decline from 20% of the population, to between 12% and 15%. In 2002, nearly 13,000 people aged 65 and older died because of fall-related injuries (Hendriks M. at al., 2005). More than 60% of people who die from falls are 75 and older (CDC, 2005) (Gillespie L.D. et al., 2003) (Hendriks M. at al., 2005). The New England Journal of Medicine (NEJM, 2004) states that the chances of surviving a fall, heart attack or stroke are six times greater if the senior gets help within an hour. Gururajan et al (Gururajan R. et al, 2005) stated most healthcare information is both time and life critical, so it must be captured and/or delivered whenever and wherever needed. The following section provides a technical overview of WSNs.

3. WSN TECHNOLOGY AND HEALTH MONITORING

Recent technology advances in integration and miniaturization of physical sensors, embedded microcontrollers and radio interfaces on a single chip (WIMS, 2006) wireless networking (Otis B.P. and Rabaey J. M., 2003), and micro-fabrication (Ghovanloo M., 2002), have enabled a new generation of WSN suitable for many applications (Raskovic D. et al., 2004). Miniature sensors may sense and collect huge amounts of information coming from nature, either from the environment or from our own bodies. WSN applications interact and share the obtained data with similar or even other types of applications from all across the world in a secure manner. Over the last few years, many WSN applications have been developed (Yoneki E. et al., 2005). Examples include environments monitoring (Martinez K. et al., 2004), rescue operations (Michahelles F. et al., 2003), habitat monitoring (Szewczyk R. et al., Jun. 2004), plant monitoring in agriculture (Burrell J. et al., January-March 2004). However, the most exciting application domain still in its early stage development is patient monitoring which covers different scenarios such as mass-casualty disasters, health emergencies, home and hospital care (Jovanov J. et al., March 1, 2005) (Welch J. et al., September 2004) (Gao Tia et al., 2006).

One key WSN technology in the remote healthcare monitoring domain is tiny battery-powered sensors called Motes. These sensors, developed at the University of California, Berkeley, and resold by Crossbow Technology Inc, organize themselves into a wireless network, sharing data with one another and with computer.

Already, a number of commercial and research groups are involved in developing tools or systems for patient monitoring based on particular WSNs. Intel, for example, developed its own brand wireless sensor network devices called iMote (Intel-Mote) and a platform from which data processing can occur, the Stargate (Stargate, 2005). Harvard University is developing CodeBlue, a platform based on mote sensors network technology useful for a range of medical applications, including pre-hospital and in-hospital emergency care, disaster response, and stroke patient rehabilitation (Welsh M. et al., 2005). The Johns Hopkins University Applied Physics Laboratory is developing the Advanced Health and Disaster Aid Network (AID-N) for improving the way to provide emergency care in pre-hospital situations. Electronic triage tags with sensors continuously monitor the vital signs and locations of patients until they are admitted to a hospital (VitalMote Technology) (Gao Tia et al., 2006). The department of Computer Science, University of Virginia are developing AlarmNet, an architecture for smart healthcare, continuous monitoring of assisted-living and independent-living residents based on mote technology (Wood A. et al., 2006).

3.1 Mote Features

Made with off-the-shelf parts, Motes are low cost, low-power consumption and allow for Commodity-Based Wireless Networking. They range in size from a few centimetres to a matter of millimetres, so they can be placed in an extremely space-constrained area. Various sensor measurements capabilities are provided by each mote, ranging from measuring the surrounding magnetic field and sound levels, to measuring temperature, light and 2-axis acceleration, therefore a variety of application fields are covered, such as military applications (enemy detection) or medical applications (monitoring of vital statistics).

All these and many other applications take advantage of a specific feature inherent in every Mote, that is the ability to self-form an ad-hoc mesh wireless network with other Motes using *multi-hop protocol.* An ad-hoc multi-hop routing application forwards packets from other Motes to one that is close by, but cannot be reached by the original sending Mote. Ad-hoc networks are characteristically not reliable over the long term. Nodes may suddenly stop working or may physically move out of range. Multi-hop allows for these dynamic changes in network topology. Ad-hoc networks are designed to minimize the use of energy so it can work off batteries from at least many months to a few years. One of the challenges to ad-hoc networks is that broadcasting is energy and time inefficient. Therefore, a multi-hop protocol must be able to dynamically determine which nodes (motes) would be the better or the best parent to a transmitting mote (network adaptability) depending on the route-decision schemes selected (e.g. shortest-path-first algorithm with a single destination node, i.e. the root, and active two-way link estimation) (Xbow, 2006).

There are several multi-hop protocols designed specially for TinyOS, the operating system loaded upon the Motes. Surge is one of the oldest and is a useful demonstration of multi-hopping but does not include power management. We used this protocol for our first 3 prototypes. Another protocol is Destination-Sequenced Distance Vector (DSDV), developed at Intel-Berkeley Labs and it has power management features. One of the latest and perhaps most promising to date is Blast by Alec Woo of UC, Berkeley. Blast is reported to benefit from the extensive use of estimators and uses advanced power management (Xbow, 2006).

3.2 WSN Health Monitoring Prototypes

The authors developed three prototypes to ensure that we understood the intricacies of working with these tiny devices over a period of 30 months. Many technical issues had to be resolved as these devices are still in a preliminary development stage and they are quite expensive s currently they cost around US$50 a piece. As demand for them increases and processors become cheaper, this price may decrease dramatically. Our experience has been gained by working with a set of 10 motes (both Mica2 and MicroDot Motes) and sensors such as light, temperature, sound, and accelerometers. Our first research test bed demonstrated the use of the network management tool, Multi Router Traffic Grapher (MRTG). MRTG enables data from the motes to be displayed graphically on the web and thus would allow medical/caring staff the ability to access patient data from anywhere in the world by the use of a simple web browser (Riudavets J. et al., 2004). Our second research test bed demonstrated a similar system using PDAs. We were able to show that MRTG's compression is such that, even with months of data, the amount of space required would only be a matter of hundreds of kilobytes. A remote feature of our system is also available, where authorized users are able to view the information graphically on a website. This data can be displayed on a laptop or PDA which has Internet connectivity. Our system is more easily set up than proprietary implementations (Lubrin E. et al., 2005b). Our third prototype, MoteCare, improves on the performance and reliability of the system by separating the 'business logic' from the interface. The addition of Crossbow's Stargate, as local server, allows for the ability to access the Mote sensor network by various mobile devices (PDA, cellular, etc), enabling a true mobile monitoring experience and removing the processing burden from the Mobile Monitor (refer to the high level view on Figure 2) (Lubrin E. et al., 2006a).

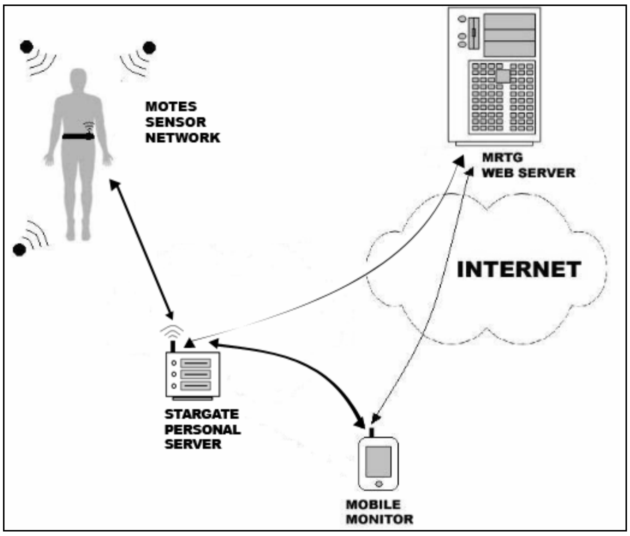

Figure 2. High level architecture of MoteCare (Lubrin et al, 2006d)

The main advantage of our system lies in its use of commodity-based hardware – PDAs and Motes – as well as the use of open-source technology, namely the free network management tool, MRTG rather than the development of specific devices. Open-source products eliminate the requirement to pay royalties, while commodity-based equipment reduces dependence on one specific vendor for maintenance; thus, resulting in cost savings (Lubrin E. et al., 2006d).

3.3 MoteCare: the Architecture

Figure 3 shows the layered view of MoteCare with the latest updates (in white) to be implemented in the 4th prototype. It is divided into four key layers: Application, Services, Middleware and Hardware. The lowest level of the architecture consists of the sensor nodes which provide physical access to vital signs and environmental parameters. The motes could be used to monitor body temperature, heart rate and pulse rate, as well as many other parameters once particular sensors such as pulse oximeter sensors (implemented in the 4th prototype) or electromyogram sensors are attached.

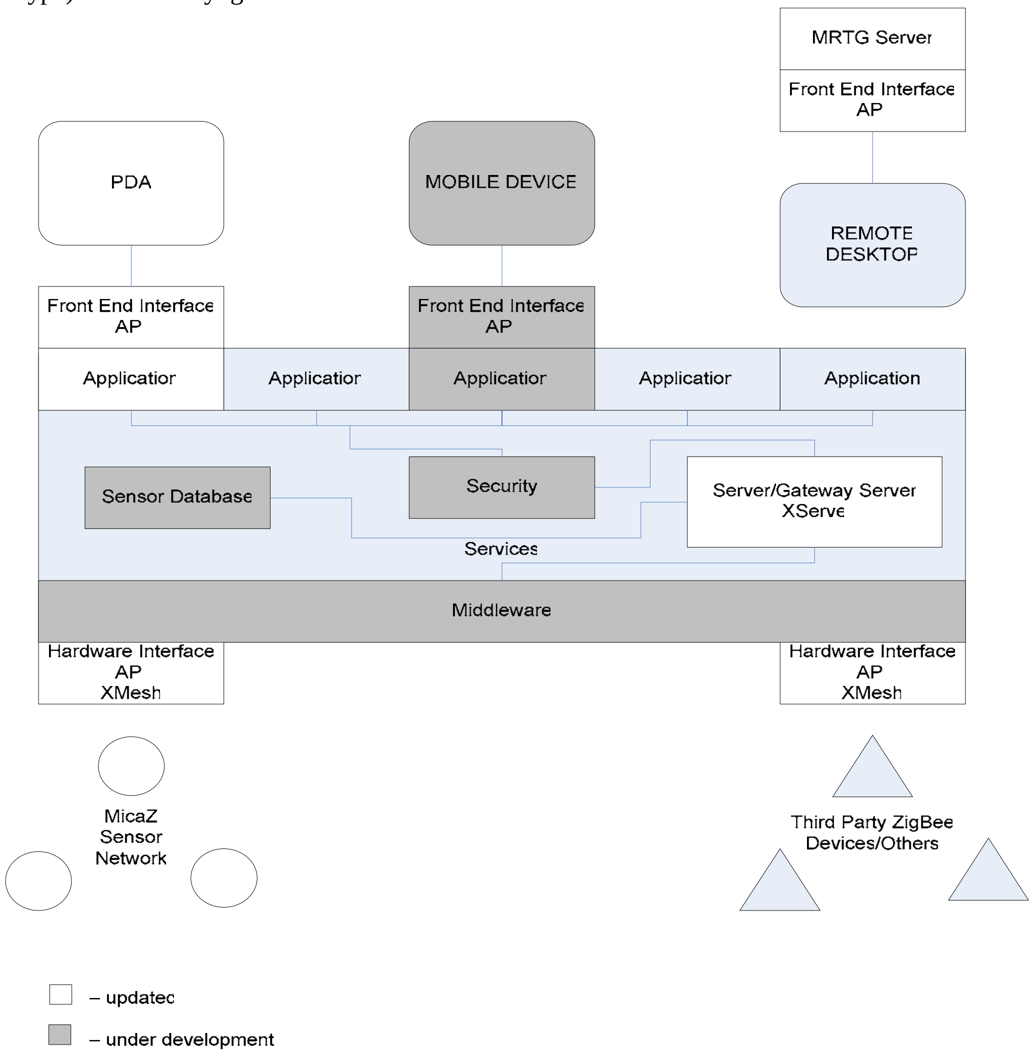

Figure 3. Architecture of the 4th Prototype

The middleware platform, under development, will provide appropriate abstraction and functionality for interfacing with the application layer above and the sensor loop below. The novel purpose here is to build a platform which unifies various underlying sensor networks while supporting all kinds of applications. In fact with the inclusion of the middleware layer transparency is provided to the applications/services that utilize the sensor networks between heterogeneous sensor networks; roughly speaking the requirement of sticking to just one brand of sensor devices will be removed. This concept of providing a middleware layer is not unique to sensor networks. Research and development work has been done with other heterogeneous networks on middleware development. However, the standardization of resource-constrained wireless devices, of which Zigbee (ZigBee, 2006) is a major contender, will most likely reduce the responsibilities of the Middleware layer. In this case, the layer will act only to provide transparency to heterogeneous networks only in terms of purpose and not hardware (Lubrin E. et al., 2006a).

The introduction of MicaZ in our prototype in place of Mica2 allows an easier middleware implementation since these new sensor nodes are a 2.4 GHz, IEEE802.15.4/ZigBee compliant. MicaZ features several new capabilities that enhance the overall functionality of wireless sensor networking; some of them are discussed in detail later in the next section.

The next layer is the Services layer where the bulk of the system is located. It provides services to a client. Four major components make up the Services layer: Security, Server, Communication and Database. The Security component ensures that any transmission is permitted and secure. In addition, security policies are implemented in this component to determine who gets access to what and for how long, etc. Clients that wish to connect to the system must authenticate themselves, after which a connection that encrypts transmission is set up (Lubrin E. et al., 2006a).

The next major component within the Services layer is the Server, namely the Stargate personal server, which in our prototype includes the Middleware layer as well. Depending on the nature of network – centralized, distributed – the Services layer would reside within the Hardware layer or would be located on different machines/locales. Basically the Stargate is located locally nearby the patient, acting as the gateway to the motes sensor network (MSN). Portable devices such as the PDA, the mobile monitor, can connect with the Stargate and use its capabilities. As the gateway to the MSN, the Stargate is programmed to accept commands from clients, such as requesting to transmit data, requesting sensor information, focusing on a Mote, changing the sampling rate, turning on/off a Mote or groups of motes, configuring the sensors network, store small amount of information, send warning message, and etc. (Lubrin E. et al., 2006a).

The last layer in this architecture is called the Application layer. Depending on the device used (workstation, mobile or portable device) to access the system the application will be tailored to function within certan specifications. A graphical front-end is presented to the user which is simplistic in nature and intuitive to the beginner, able to display the readings from the sensors in real-time (fig. 4). Elements added to the graphical user interface to accommodate the capabilities of the system include, for example, the user – either the patient or a doctor present – opening a new window in the application to configure at least 1 Mote in the sensor network.

The application server consists of the MRTG server and the socket server. The MRTG server employs a Perl script to read the received text file and extract the required data. Every time MRTG captures another measurement, all files are updated so several patients can use the service at the same time. MRTG allows for publishing all the health and environment parameters sensed by the wireless network sensor in a website in form of graphics (fig. 5). The advantage of this prototype is the fact that such graphics are also easily displayed on a small mobile device (Lubrin E. et al., 2006d).

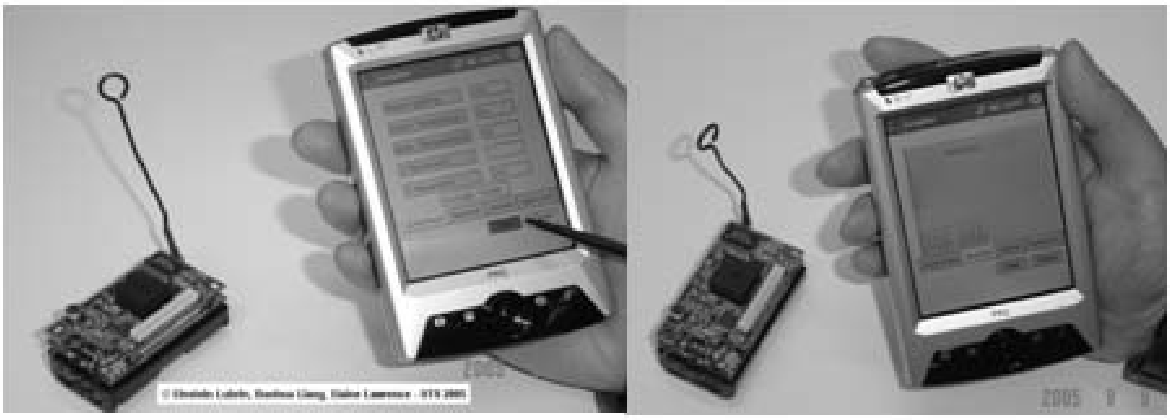

Figure 4. Third Prototype – Mobile Monitor GUI (Lubrin E. et al., 2006d)

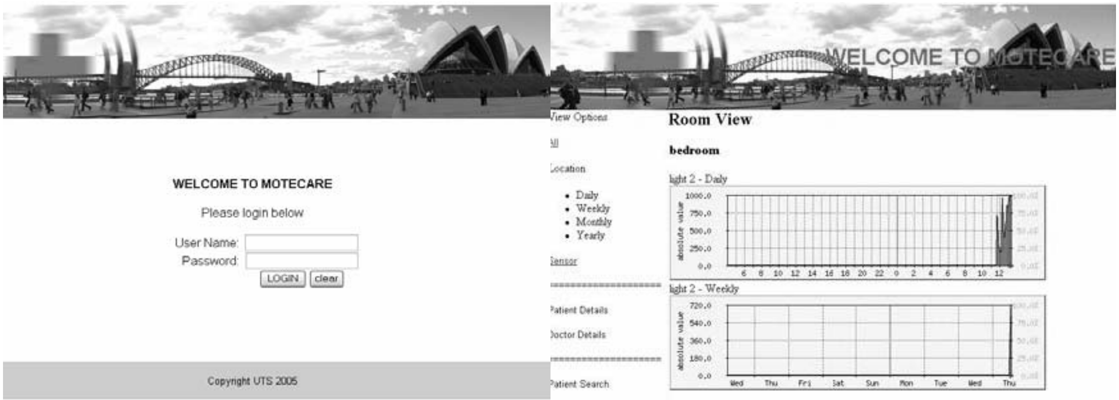

Figure 5. Third Prototype – Web Service MRTG

4. ARCHITECTURE ADVANCES FOR 4TH PROTOTYPE

The advances we aim to introduce into the health monitoring system architecture for the 4th prototype are both hardware and software. Concerning hardware improvements we have focused on updating the Motes Sensor Network, in regards to both the wireless controller module (MicaZ) with ZigBee standard support (completed) and the sensor boards (pulse oximeter and GPS – being implemented), and the Mobile Monitor by GPRS cell phone module allowing immediate phone calls warnings (being implemented) . At the software side we needed to update the MSN operating system, namely TinyOS in order to support the new wireless module at 2.4 GHz (completed), and to introduce Xmesh networking stack for advanced mesh networking (being implemented). We intend to introduce the Xserve platform as gateway server middleware in order to connect the MSN to the Internet. Xmesh and Xserve are both Crossbow Technology.

4.1 MicaZ and ZigBee Wireless Module

The main improvement introduced with MicaZ is the RF transceiver chip which allows a radio communication over 2.4 GHz and data rate up to 250 Kbps. All the other specifications are similar to the precedent version Mica2. The MicaZ is the latest generation of Motes. The MPR2400 (2400 MHz to 2483.5 MHz band) uses the Chipcon CC2420, IEEE 802.15.4 compliant, ZigBee ready radio frequency transceiver integrated with an Atmega128L micro-controller. The same Mica2, 51 pin I/O connector, and serial flash memory is used; the maximal data rate reached by MicaZ is 250 Kbps versus the 38.4 Kbps of Mica2, with a current draw showed in table 1. It is powered by 2 AA batteries and consumes roughly 20 mA when active, resulting in a battery lifetime of 5–6 days of continuous operation with practical indoor range of approximately 20–30 m.

Table 1. Current draw of MicaZ and Mica2

Operating Current (mA)	MICAz	MICA2
ATMega128L, full operation	12 (7.37 MHz)	12 (7.37 MHz)
ATMega128L, sleep	0.010	0.010
Radio, receive	19.7	7
Radio, transmit (1 mW power)	17	10
Radio, sleep	0.001	0.001

4.2 Sensor Boards

4.2.1 MTS420 Sensor board with GPS Location Tracking

The MTS420 offers five basic environmental sensors: humidity, temperature, barometric pressure, light, 2-axis accelerometer sensor with an additional GPS module. The GPS module (Leadtek GPS-9546) is powered via a DC-DC booster, which maintains a constant 3.3 volt input regardless of battery voltage. The booster output is programmably enabled. The output from the GPS module is connected to a serial UART, USART1, interface of the Mote. An active, external, antenna is supplied with the module (figure 6). GPS sensors track patients, providers, and ambulances who are outdoors, e.g. at the scene of the emergency, with accuracy of 3 meters (CEP) (Xbow, 2006).

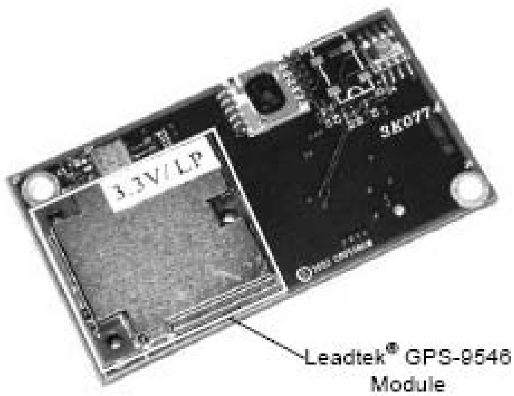

Figure 6. MTS420 Sensor board with GPS (Xbow, 2006)

In the 4th prototype we intend to add in one mote node with this very powerful Crossbow sensor board with GPS module (figure 6) allowing geo-location of patients with the pulse oximeter sensor (fig. 7) developed by Harvard University under the CodeBlue project.

4.2.2 Pulse Oximetry Sensor

We have commenced work with 5 wireless, pulse oximeter sensors based on a commercial pulse oximeter module from BCI, Inc. (Figure 7), designed by Harvard University for our 4th prototype. The device consists of a standard finger or ear sensor, a pulse oximetry module (BCI Micro Power Oximeter board) and a mote. The pulse oximeter module has a serial interface that relays SpO2, pulse, and plethysmogram waveform data to the MicaZ node using a secure protocol. The device consumes approximately 18mA while processing and transmitting data. The pulse oximeter board consumes only 6.6 mA, in addition to the 20 mA consumed by the MicaZ mote in full operation, and is small enough to integrate into a compact package. The device transmits periodic packets containing heart rate, SpO2 (blood oxygen saturation), and plethysmogram waveform data.

Figure 7. Pulse oximeter sensor (AlarmNet, 2007)

4.3 Mobile Monitor

We have updated the mobile monitoring side with a an I-mate JasJam running Windows Mobile 5.0 Pocket PC with data cell phone capabilities (GPRS/WCDMA), Bluetooth, Wi-fi 802.11b/g, 128 MB of ROM and 64 MB of RAM. These features allow a complete connectivity of the mobile monitor both to the WSN (via the Stargate) and to the server side (namely MRTG) (see fig. 2). Moreover the GPRS module will permit phone call warnings directly to the emergency personnel if a serious health event occurs. This last system feature will be implemented and tested in our 4th prototype.

4.4 Software Platform

At the mote network tier we have updated the operating system, namely TinyOS, and the hardware interface API with a more advanced mesh networking stack. If the RF link become unavailable, due to change in RF environment (presence of new obstacles, e.g. wall, etc.) or when the device become unavailable (i.e. moved out of network or physical failure), automatic re-routing can be activated in these systems which feature self-healing capabilities. Finally at the server tier we will apply the XServe for bridging the MSN to the web in one step. Xserve translates the sensor readings into XML files, therefore is very usable for web service applications.

4.4.1TinyOS

TinyOS is an object-oriented, event-driven operating system designed from the ground up for low-power devices with small memory footprint requirements. It provides a well-defined set of APIs for application programming. These APIs provide access to the computing capabilities of the sensor node, allowing for intelligence within the network. Using these capabilities, sensor data can be pre-processed on the node, optimizing both network throughput and battery life by avoiding unnecessary send and receive messages (Xbow, 2006). We needed to update TinyOS in order to completely exploit the potential of MicaZ radio communication. We installed the TinyOS version 2.0 in our sensor network for the 4th prototype.

4.4.2 XMesh

The Xmesh protocol stack is an open-architecture, flexible, and powerful embedded wireless networking and control platform built on top of the TinyOS operating system. To optimize mass application requirements, different network topologies including star, hybrid and mesh are supported. Xmesh provides dual support for the ZigBee standard and advanced mesh networking. The ZigBee standard defines star and hybrid star topologies for battery-powered end-nodes and a line-powered wireless backbone. Xmesh also provides support for entirely battery-powered, multi-hop networks with extended year operation. In this topology, every node acts as a router, providing easy network extensibility without requiring any line power. Xmesh fully supports bi-directional message communication throughout the network with fast alert/alarm propagation to support safety and security applications with stringent, response time requirements (Xbow, 2006).

4.4.3 XServe

XServe is the software component that provides a simple, yet powerful API from the Intra/Internet to the wireless sensor network. Due to the low power and memory footprint requirements in wireless sensor networks, communication is streamlined through message formats and network protocols. This differs from the IP protocols used for Intra/Internet applications. XServe stands as the gateway between the wireless sensor network and IP-based applications. This platform is capable of encapsulating sensor services for assistive healthcare web-based applications (Xbow, 2006).

XServe's architecture provides reliable translation of sensor network data into XML messages for rapid integration into applications. The XML interface is integrated with gateway server, providing a standard web service interface. In our 4th prototype the manually entered patient information will be captured in a SQL database and converted into an XML data format. The geo-location and pulse oximeter data (heart rate and blood oxygen saturation) generated by the motes will be transmitted in XML by XServe and automatically integrated into each patient's electronic care record. These combined XML datasets may then be shared via web-service XML RPC calls. The resultant XML data is compatible and shareable with similarly structured web services. This means that the contextual healthcare data that is captured by our application could be combined with hospital medical record, laboratory, radiological and nursing data (Wood A. et al., 2006).

4.5 Discussion of System Advances for 4th Prototype

This section identifies advantages and disadvantages in applying the proposed system advances to the monitoring system under development for our 4th prototype. Following we list the pros and cons of the designed system advances.

Pros:

- Cell phone capabilities
- High data rate
- ZigBee interoperability
- Dynamic routing

Cons:

- Power consumption
- Bulky sensors
- RF interference
- XMesh and XServe proprietary software

The phone capabilities introduced with our new PDAs allow for establishing fast connections with the emergency personnel for warning calls. This is advantageous for developing personal health monitoring applications in which a phone call is made when health problems develop. In our previous prototypes only warning alarms (such as sounds) were made on the motes so the implementation of emergency phone calls will represent a major step forward in our 4th prototype.

The high data rate reached by the MicaZ allows for more than doubling the amount of data collected from the MSN even if the power consumption results are very high in respect with the Mica2. However we will implement a more reliable network power management, XMesh technology which uses network-wide time synchronization to enable very low power operation.

The ZigBee interoperability of MicaZ is fully exploited by XMesh which enables reliable routing links to third party ZigBee devices. XMesh includes support for self-forming, self-healing networks and is optimized for dynamic routing. Based on the RF link characteristics, XMesh automatically determines the optimal route through the network to the gateway, minimizing the power requirements throughout the network. When an RF link degrades in quality or becomes unavailable, XMesh automatically re-routes messages through other nodes in the network. Combined with the ability to select the optimal radio channel, this dynamic routing capability provides for self-healing, reliable communication even in environments with heavy interference, including WiFi communication in the 2.4GHz band (Xbow, 2006).

The MicaZ with pulse oximeter and GPS, to be implemented in the 4th prototype, will be quite bulky, but we believe just at the early-stage since advances in integration and miniaturization will progressively reduce the entire sensor size.

The overlapping of ZigBee standard and WiFi with consequent loss of data is avoided by proper software configuration (Crossbow, 2006). Finally XMesh and XServe are proprietary technology so licence fees must be paid in order to implement it in our next prototype. Our original intention was to develop a completely open source system such as we developed in our first three prototypes but this will not prove possible for the 4th prototype that we have designed. We are also examining ways to ensure that the communication costs involved in using the mobile phone capabilities of the PDA are kept to the minimum.

5. CONCLUSION

The authors of this paper have been motivated to develop a remote health monitoring system as a way to bring down costs and improve the standard of healthcare for the increasing number of elderly, ill and frail persons in Australia. This paper has outlined the improvements we have designed for the 4th prototype of

MoteCare. We have completed the design phase and have started to implement the features now that we have bought the pulse oximeters. This paper illustrates our methodology of gradually improving the prototypes as advances are made in both the hardware and software available for Wireless Sensor networks. Our next paper will outline the implementation of the 4th prototype.

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