

A Distributed Network Management Approach to WSN in Personal Healthcare Applications

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Abstract—This paper describes the development of a Wireless Sensor Network personal health monitoring system called Medical MoteCare which uses a combination of medical and environmental sensors. SNMP and CodeBlue agents are incorporated in the system as is the network management software JaguarSX. Network management models and tools provide an alternative, scalable and affordable solution to WSN health monitoring applications that allow for data storage correlation and dissemination as well as timely alerts when parameters are breached. This work forms part of a large grant aimed at providing assistive healthcare for the elderly.

Keywords: *Wireless Sensor Networks; Network Management; Data Correlation.*

I. INTRODUCTION

This paper describes the development of a Wireless Sensor Network (WSN) Personal Healthcare application capable of monitoring a patient's vital signs such as temperature, heart rate and blood oxygen level. The WSN based medical application uses network management tools and models to store and correlate the collected data and issue warnings if thresholds are breached. The Medical MoteCare prototype aims to assist all stakeholders in the personal healthcare arena to improve the monitoring and, therefore, the health outcomes for the aged, the chronically ill and the infirm. It is the latest in a series of 4 prototypes that have been developed so far [1], [2], [3], [4].

An ageing population trend is particularly noticeable in developing countries and, overall it is forecast that, between the years 1990 and 2020, the proportion of people aged between 65–74 will increase by 74% [5]. The impact of these population changes means that governments and relatives/caregivers will need to spend increasing amounts of money and time to care for this cohort. Wireless sensor networks offer some hope for decreasing the cost of monitoring the elderly and sick in their own, or in nursing, homes. Wireless Sensor network nodes (Motes) equipped with sensors can be used to monitor such items as temperatures in the environment or on the person, cameras may be linked to motes to enable remote monitoring and

thresholds can be set to ensure that action is taken if a particular limit is reached.

The justification for this research is spread across economic and social imperatives, such as helping governments to limit the rising costs for caring for the sick and the elderly whilst not jeopardizing the standard of care. One overarching area of interest of the healthcare industry is in heterogeneous and autonomous data acquisition systems. It is important to develop cost effective treatments which optimize patient safety, while minimizing treatment cost and the possibility of malpractice litigation.

This paper describes Medical MoteCare as a proof of concept of a network management based healthcare monitoring system and reports on the outcomes. The next section provides background information while section 3 outlines health sensing and monitoring. Section 4 describes the architecture of the Medical MoteCare based on an adaptation of the Three-Tier and SNMP Proxy Network Management Organizational Models, using the network management tool JaguarSX. Section 5 describes the system and a scenario setting is outlined in Section 6 and results are displayed and discussed in Section 7. The conclusions are drawn in Section 8.

II. BACKGROUND

Given the increase in the numbers of the elderly and the current and projected nursing shortages, health care organizations must find ways to meet demands with fewer resources [6]. The ability to integrate sensors for fall detection, video surveillance, sleep disorder monitoring, heart attack identification and problems with obesity, will improve the usefulness of the Medical MoteCare prototype. People will be able to move about in their own home secure in the knowledge that they are being monitored. Just as airplanes are monitored by air traffic controllers, our patients may be monitored remotely by healthcare providers or carers who will have access to the patient's information via a web server and, in the case of an emergency or at a predetermined time, via audio and video links [7].

The following statistics illustrate the potential savings that can be gained by using home monitoring systems that allow patients to leave hospital early. Table I provides the following figures from 2004 for the United Kingdom:

TABLE I. ECONOMICS OF UK PATIENT CARE [8]

Explanation	Amount
Average cost of care per week/per person in a hospital	GB Pounds 805
Average cost of care per week/per person in a nursing home	GB Pounds 337
Average cost of care per week/per person in own home	GB Pounds 120

Other statistics from [8] further illustrate the savings that can be made if mobile health devices are used by early discharged patients in Germany (Table II). The figures exclude administrative costs that are also applicable if using a mobile monitoring system.

TABLE II. ECONOMICS OF GERMAN PATIENT CARE AND MOBILE HEALTH DEVICES [8]

Explanation	Amount
Early discharged hospital patients (mobile services (20% of total))	3.3 million Euros
Average costs for one hospital day	150 Euros
Average number of hospital days saved through early discharge	3 days
Total yearly cost savings through early discharge	1.5 billion Euros

Thus health economics reveal that potential savings can be made by using mobile and wireless home monitoring devices. Hopefully patients will not be admitted to hospital unnecessarily; they may be discharged earlier; the burden on emergency services could be reduced; medical personnel could remotely assess patients, the patient and relations could reduce their travel times and home visits by experts could be reduced.

III. HEALTHCARE SENSING AND MONITORING

A sensor is a device that detects the presence and/or the variation of some physical phenomena and converts the sensed quantity into a useful signal that can be directly measured and processed, such as voltage or current. A smart sensor is a sensor that provides extra functions beyond those necessary for generating a correct representation of the sensed quantity. Often they possess processing, storage, and decision making capabilities. Table III below outlines sensing properties and examples.

TABLE III. SENSING PROPERTIES AND EXAMPLES [9]

Sensing properties	Examples
Physical properties	pressure, temperature, humidity, and flow
Motion properties	position, velocity, angular velocity, and acceleration
Identification	by personal features
Biochemical	by biochemical agents
Contact properties	strain, force, torque, slip and vibration

For health monitoring, wearable medical sensors are of particular interest as these devices are used to monitor a set of key ambulatory parameters in domains such as oncology, paediatrics, and geriatrics. Some of these parameters include: heart rate for cardiac function; acceleration during walking and running for activity; body temperature for illness; virtual capacity for severity of airway obstruction in chronic obstructive pulmonary disease; blood glucose for vascular or neurological complications; EEG for seizure disorders, confusion, head injuries, brain tumours, infections, degenerative diseases, and metabolic disturbances that affect the brain; ECG waveform for cardiac arrhythmias; blood pressure; arterial oxygen saturation for sleep disorder; and body weight [10].

The Medical MoteCare system sensing can be achieved with on-body and off-body sensors. With on-body sensors, the elderly can be mobile and the on-body sensors can form a body area network (BAN) which reacts when the conditions recorded imply that the elderly needs immediate assistance (Fig.1). In Medical MoteCare, the network management software suite Jaguar SX is utilized for correlating the data and alerting the caregivers if problems arise.

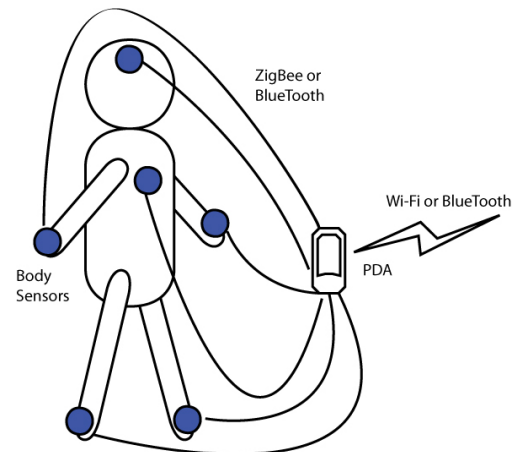


Figure 1. Body Sensors and Communications.

IV. MEDICAL MOTE CARE DESCRIPTION USING JAGUAR SX

The strength of the Medical MoteCare system is its innovative deployment of a network management model in a scalable, flexible way to manage multiple sensors and networks of sensors reliably and securely. The building of the Medical MoteCare system brings the integration and testing of specialized sensors for healthcare monitoring (pulse oximeters, light and temperature sensors with Zigbee motes [10]) through the use of an enhanced version of the Harvard CodeBlue software suite [11], a Simple Network Management Protocol (SNMP) Agent, and the Network Management (NM) tool JAGUAR SX for scalability, performance improvement and data correlation.

The Medical MoteCare system was based on the adaptation of the Three-Tier and SNMP Proxy Network Management Organizational Models [12]. The SNMP Proxy enhancements enabled this system to improve the scalability, modularity and flexibility of the system by potentially bringing to the developer communities the freedom of selecting from a vast range of existing SNMP based NM tools to fit their specific WSN application requirements. The adapted Three-Tier NM Organizational model can be seen in Fig.2.

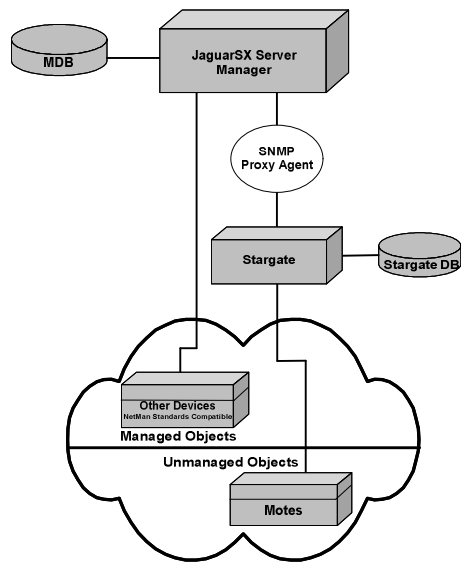


Figure 2. Adapted Three-Tier NM Organization Model to the Medical MoteCare System [12].

The enhancements in the adapted Three-Tier NM Organization model with a tailored SNMP proxy agent shown in Fig.2 allow for the natural implementation of any SNMP-capable NM tool in the Medical MoteCare system. This makes the system not only capable of having more than one manager entity without the risk of over polling the managed devices, but also makes it platform independent by allowing SNMP standard communication with any number of NM systems acting as Manager, Middle Manager or Agent Entities.

The integration of an SNMP agent in conjunction with the CodeBlue Communication module enabled the system to be accessed via any network management tool that understands SNMP. This ensured that the system was able to scale up easily and provide a robust and well tested, standardized environment.

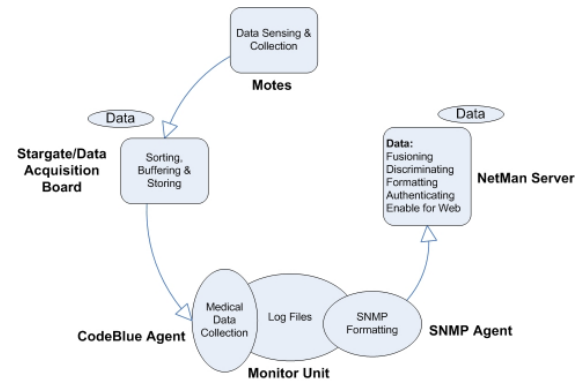


Figure 3. System Process Overview for the Medical MoteCare System [13].

The system process overview of the Medical MoteCare System in Fig.3 depicts the high level system processes for each of the system components (labeled in bold). A more detailed explanation of these components and their processes is further explained in this section.

The WSN architecture of this prototype was based on MicaZ motes [2] which added robustness to the system communication (as a result of the use of the Zigbee protocol). The sensors include the Pulse Oximeter, a medical sensor from BCI, Inc. consisting of a standard finger or ear sensor, a pulse oximetry module (BCI Micro Power Oximeter board) and a mote [6].



Figure 4. MicaZ Mote [10].

Blood oxygen saturation (SpO₂), pulse and plethysmogram waveform data are relayed via a serial interface to the MicaZ node. The pulse oximeter mote device periodically transmits packets containing the measured samples.

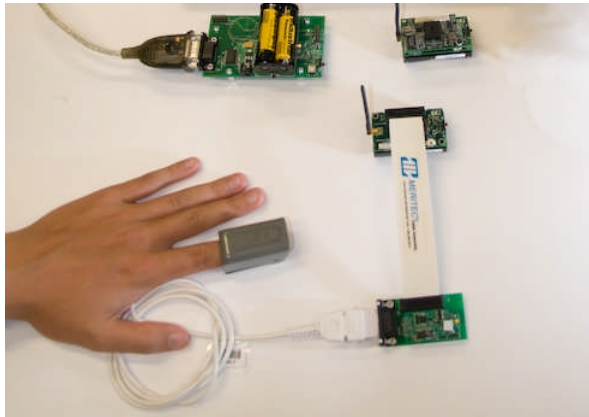


Figure 5. The Pulse Oximeter [14].

The MTS310CA flexible sensor board has a number of sensors such as light and temperature which are incorporated into the Medical MoteCare system, to illustrate the potential importance of environmental impacts on the physical condition of a monitored patient. For example, an elderly depressed person might need adequate lighting to alleviate mental health problems. The light sensor could prove that the light is appropriate. Alternatively, if a person, who has suffered a heart attack recently, suddenly starts sweating, the symptoms could signal another attack or it may be that the room is too hot.

The Data Acquisition Board is the Stargate Personal Server processing board sourced from Crossbow. The Personal Server, Stargate has the ability to connect wirelessly to other devices using Wi-Fi, GSM and GPRS. This hardware allows a system to move from a centralized network management system to a distributed one.

The Monitor Unit comprises the enhanced CodeBlue software that incorporates log files of data recordings captured by the sensors on the MicaZ motes and an SNMP agent to enable it to deal with standardized network communication using the SNMP protocol. The Monitor Unit connects to the Gateway Mote either via a USB connection, a serial connection or Internet Protocol (IP) [2].

On the Monitor Unit side CodeBlue captures the data and stores it locally on log files. It is then sent through an SNMP agent after a request is made by the Network Management Server. The CodeBlue system with the incorporated SNMP agent provides access to the widely accepted TCP/IP protocol suite. As motes have extremely limited processing power, battery life and transmission budgets, SNMP was not implemented on the motes themselves as the additional overhead would have dramatically reduced battery life [2]. In the Monitor Unit of the Medical MoteCare system, using the CodeBlue component, an SNMP agent was set up to act as an IP-based Data Delivery Unit (DDU). The DDU is able to act as an agent and deliver information collected on the WSN into a TCP/IP based network [2]. In keeping with the philosophy of the team to utilize as much existing and freely available code and protocols as possible, several Object Identifiers (OIDs) from RFC 1213 were used for the Medical MoteCare system (see Table IV). An object identifier is a

label used to name an entity. Structurally, an OID consists of a node in a hierarchically-assigned namespace, formally defined using the ITU's Telecommunication Standardization Sector (ITU-T) Abstract Syntax Notation 1 (ASN.1) standard. Successive numbers of the nodes, starting at the root of the tree, identify each node in the tree. Designers set up new nodes by registering them under the node's registration authority [15]. Standard and customized Management Information Bases (MIBs) for the Medical MoteCare system are set out in Table IV. The customized MIB was developed by the mHealth team at UTS creating specific OIDs for the polling of health and environmental data from the WSN nodes [3].

TABLE IV. OBJECT IDENTIFIERS USED FOR THE MEDICAL MOTE CARE

OID	Variable Name	Utilized for
1.3.6.1.2.1.2.2.1.1	ifIndex	mote ID as number
1.3.6.1.2.1.2.2.1.2	ifDesc	mote ID as string (mote-xx)
1.3.6.1.2.1.2.2.1.6	ifPhysAddress	mote ID as hex value
1.3.6.1.2.1.2.2.1.10	ifInOctets	pulse sensor value
1.3.6.1.2.1.2.2.1.11	ifInUcastPkts	light sensor value
1.3.6.1.2.1.2.2.1.16	ifOutOctets	oxygen sensor values
1.3.6.1.2.1.2.2.1.17	ifOutUcastPkts	temperature sensor values

The Medical MoteCare system incorporated an SNMP agent. The development of more sophisticated SNMP versions such as SNMPv3 allows for more security which is important when dealing with medical data. The benefits of SNMPv3 for the Medical MoteCare system are that data can be collected securely from SNMP devices without the fear of the data being tampered with or corrupted. This is vital in any healthcare system. As well, confidential information, for example, the SNMP Set command packets that change a router's configuration, can be encrypted to prevent its contents from being exposed on the network. The incorporation of the SNMP agent to the MoteCare Monitor Unit was facilitated by the use of SNMP4J, an enterprise class, free open source and up-to-date SNMP implementation for Java [3]. The system therefore utilized an agent derived from the SNMP4J standard example which provided a static SNMP table to hold the sensor data and allow for SNMP requests [2].

The log file is used to communicate between the CodeBlue component and SNMP agent in the Monitor Unit. The structure of the files consists of time and data stamps, Mote/patient ID and sensors available. The standard format is as below:

```
<date stamp> <time stamp>:<Mote/patientID number
type of sensor = data from the sensor>
```

An example is set out below:

```
<14 Jan 2008 10:25:16.939 EST : <patientID= 102
PULSE= 92>
```

Upon detection, the motes will continuously send data from the sensors with IDs on a first come, first served basis.

After the motes are detected, data with an ID code are sent and logged into the Monitor Unit [2].

This Medical MoteCare system utilized commercial software in the form iReasoning MIB Browser for MIB browsing and MIB customisation and SysUpTime Network Monitor and Jaguar SX for alert configuration and event correlation. iReasoning MIB browser allowed the team to load standard and proprietary MIBs for the Medical MoteCare system and issue SNMP requests to retrieve agents' data, or make changes to the SNMP agent. JaguarSX allowed for correlation of data so that alarms could be issued on more than one parameter.

See Fig. 6 for a screen shot of the iReasoning MIB Browser, which will be explained in the section describing the implementation of the Medical MoteCare system.

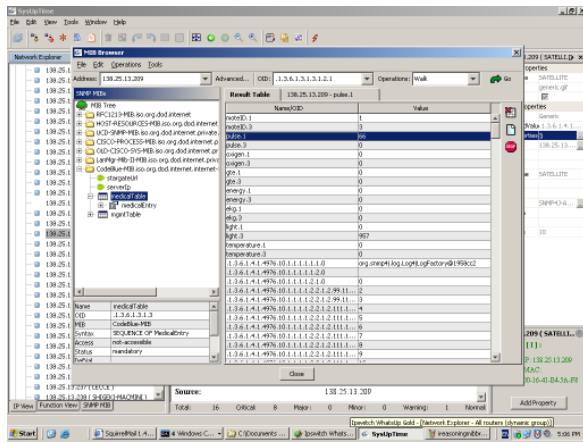


Figure 6. iReasoning MIB Browser.

With the iReasoning MIB Browser and SysUpTime Network Monitor, all network information is stored in a relational database such as FirebirdSQL, PostgreSQL or SQL Server to enable easy and efficient device management and reporting. In a similar manner, the data monitored from the wireless sensor based healthcare application will be stored in such a database to facilitate its manipulation and provide secure storage, discrimination and fusion of data as specified as a requirement of such a healthcare monitoring system.

The SysUpTime Network Monitor can alert network administrators or, in the Medical MoteCare implementation, the health carer, by email, sound, the running of a script, or triggering, as well as taking corrective actions such as executing remote Windows or Linux commands. The data is stored in a relational database that can be accessed via the Internet. Refer to Fig. 7 for a graphical overview of SysUpTime Network Monitor.

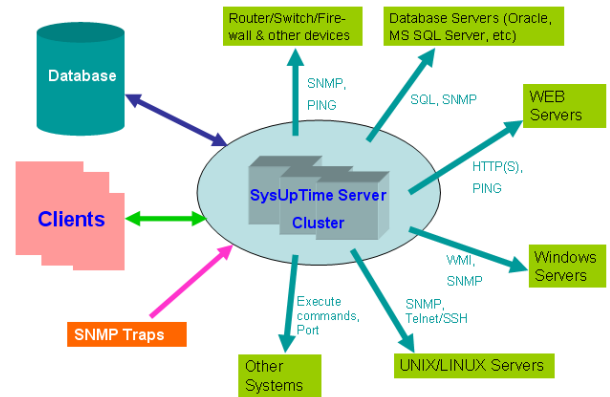


Figure 7. Overview of SysUpTime Network Monitor. Source: <http://www.ireasoning.com/sysuptimeoverview.shtml>

Using SysUpTime Network Monitor as a NM tool further illustrates the flexibility of using a variety of NM software packages in the Medical MoteCare system. Fig. 8 illustrates the user interface of SysUpTime Network Monitor. In the Performance Graph section of the screen shot, the heart rate of the tester is shown increasing and decreasing in value – the horizontal line indicates the pre-set threshold that will ensure that a warning is given once the threshold is reached. The remote SNMP agent properties are displayed on the right hand side of the screen and show the OID 1.3.6.4.1.4976 that corresponds to the pulse oximeter sensor on the mote as well as the name and IP address of the host (Satellite and 138.25.13.209 respectively) where the agent is residing. It also shows the SNMP version number.

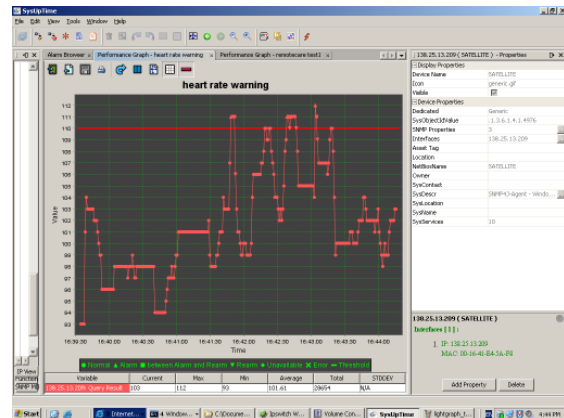


Figure 8. SysUpTime Network Monitor.

As can be seen in Fig. 8 the Medical MoteCare system using the NM tools iReasoning MIB Browser and SysUpTime Network Monitor was able to display medical data in graphical form in real time as well as provide alarm triggering. However the author wanted to illustrate some of the data fusion aspects of NM tools by implementing correlation of medical data and alarm triggering and for that the author used the NM tool Jaguar SX. This will be further discussed in the following section.

Event correlation techniques embedded in various network management tools are expected to allow for the development of personalized applications specific to certain health conditions. Current techniques such as rule-based reasoning (RBR), code-based reasoning (CBR) and case-based reasoning [12] are utilized to add intelligence to system and network management tools by correlating variables and prioritizing them based on thresholds for labeling, various algorithms and hierarchical structures associated to them. For instance if a sufficient number of ‘events’ in the system are triggered at the same time, e.g. temperature of the person and temperature in the environment, the system will check correlation and prioritize in order to trigger an alarm, message or action [16].

The NM tool Jaguar SX was implemented in the Medical MoteCare prototype with the purpose of adding intelligence to the system by making use of network management correlation techniques to interpret multi-variable collected data and automatically react or prevent harmful health conditions. The system was tested for alarm triggering functionality. Fig. 9 shows a partial view of the Jaguar SX Monitor Exceptions window in which the multi-variable alarm triggering conditions are configured. The compared values and conditions from variables identified by Object ID on column five can be correlated by grouping them into the same Object Group in column four. In order for Jaguar SX to trigger an alarm or notification, all the compared value conditions with the same Object Group have to be “True” (refer to Compare Value and Compare Type on columns six and seven).

ID	Monitor Type	Enabled	Object Group	Object ID	Compare Value	Compare Type	Compare Object	Severity	Action	Trip Count	Reset Count	Frequency
34	codeblue-mote	Yes	1	light	120	LESS_THAN	VALUE_CURRENT	INFORMAT	NOTIFY	2	10	1
32	codeblue-mote	Yes	1	oxygen	80	LESS_THAN	VALUE_CURRENT	WARNING	NOTIFY	5	10	5000
33	codeblue-mote	Yes	1	pulse	50	LESS_THAN	VALUE_CURRENT	CRITICAL	NOTIFY	2	10	1
35	codeblue-mote	Yes	1	temperature	37	GREATER_THAN	VALUE_CURRENT	MAJOR	NOTIFY	2	10	1

Figure 9. Partial View of Jaguar SX Monitor Exceptions Window.

V. MEDICAL MOTE CARE SYSTEM DESCRIPTION

In Fig. 10 below the implementation of the Medical MoteCare System is illustrated. For the implementation of Medical MoteCare the researcher set up the system as follows. A tester was fitted with pulse oximeter device, which was connected to the sensor board on the mote via a serial cable. As the data are being collected it is sent wirelessly to the Stargate Personal Server. The Stargate then sends the data through an Ethernet port to the monitor unit where it is stored in the form of log files created by the CodeBlue component. This step enables the agent to access the collected data and transform it into a SNMP format which makes it accessible to any network management tool that is SNMP-compatible, such as the iReasoning MIB

Browser, SysUpTime Network Monitor, Jaguar SX or any other commercialized or open source network management tool.

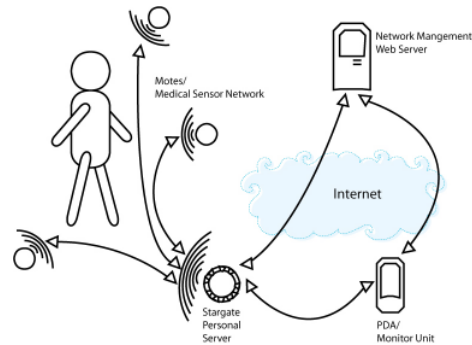


Figure 10. System Overview for the Medical MoteCare System [13].

This step enables the agent to access the collected data and transform it into a SNMP format which makes it accessible to any network management tool that is SNMP compatible, in this instance with iReasoning MIB Browser, SysUpTime Network Monitor and JaguarSX. See Fig. 11 for advantages of this system.

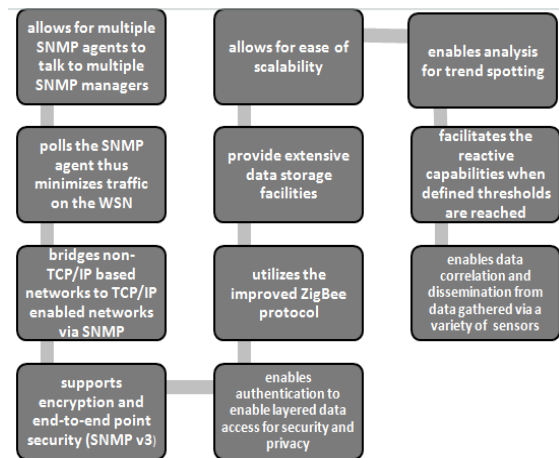


Figure 11. Advantages of Medical MoteCare System [2].

VI. SCENARIO SETTING

In this section, a typical clinical scenario that serves for the testing and simulation of the system is described. A middle aged woman has recently recovered from the after-effects of a severe car accident. She had to spend two months in hospital and has now returned to her home. She immediately began to experience flashback and panic attacks as she relived her accident. The doctor suspected tachycardia and suggested she wore a pulse oximeter while resting during the afternoon and at night so that he can monitor her condition and ascertain whether the medication he has

prescribed is succeeding in regulating her heart rate. The doctor has asked her to use the pulse oximeter for one week so that he can establish enough evidence to decide whether he needs to change her medication or test for other conditions such as Wolff Parkinson White syndrome. Wolff-Parkinson-White syndrome (WPW) represents an abnormality of the heart's electrical system. In patients with WPW, there is an extra electrical connection between the atria (the upper chambers) and the ventricles (the lower chambers). This abnormal electrical connection can cause episodes of rapid heart rhythms called paroxysmal atrial tachycardia, pre-existed tachycardia, or pre-existed atrial fibrillation [17]. The aim of the monitoring is to ascertain if the heart rhythm reverts to normality during this week of monitoring and medication.

VII. TESTING

In order to test the above scenario in a laboratory setting the author set up the following implementation using five (5) participants to test the Medical MoteCare system (refer to Fig. 10). The participants ranged in age from 20 to over 60 years old.

With the testing, the author was attempting to establish that the system would detect the variations in the heart rate and blood oxygen levels as if the monitored person was starting to experience a panic attack. The system would send a critical alarm via a red flashing screen and an email to the carer notifying them that a particular threshold was reached. The author tested the system on five participants performing a variety of activities that could change the heart rate while connected to the system in a testing setting as described below.

The system captured the readings of the heart rate and blood oxygen levels as the participants carried out the different activities. Furthermore the system was expected to react to predefined thresholds and alert the carers to potential problems. The system was able react to a series of correlated thresholds – for example if the heart rate is over a particular threshold but the blood oxygen level is normal a warning notification is generated whereas if the heart rate is high and the blood oxygen is low a critical alarm is produced.

A. Experiments to Simulate Increased Heart Rate

In this scenario, two testers were each attached to a pulse oximeter and given the following instructions. For the first minute they had to sit calmly while the resting heart rate figure was established. They then were asked to stand and walk on the spot slowly while still attached to the system. Pulse oximeters are supposed to be used on a patient at rest but to increase the heart rate artificially, the researcher had the testers walk quickly on the spot. At the end of these two minutes they were instructed to walk quickly for two minutes. The graph in Fig. 12 below shows the changes in the heart rate with the threshold marked to show when the

system was to react – in this case, for the purposes of testing, the figure of 110 bpm was selected.

Fig. 12 illustrates the results of one experiment where the heart rate went over the 110 bpm and the alarm trigger screenshot is shown in Fig. 13.

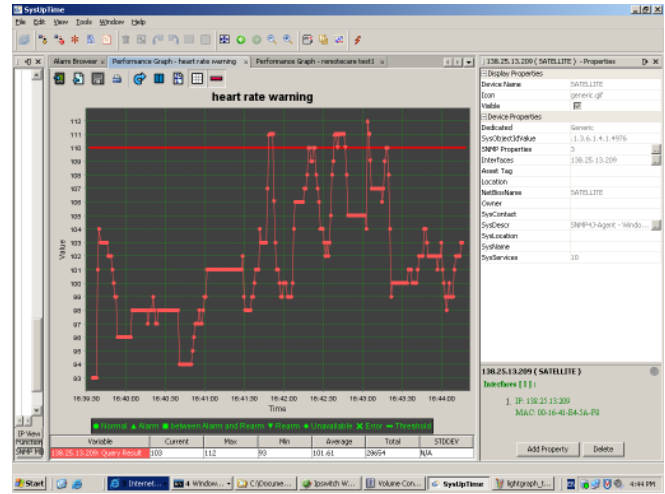


Figure 12. Graph from iReasoning MIB Browser.

In Fig. 13 a list of triggered alarms, illustrating different levels of severity, is shown. In the top row alarm, a critical event, highlighted in red, is shown. Column Severity can indicate ‘Critical’, ‘Normal’ or ‘Warning’. The next column indicates the IP address of the source where the event was polled. Time and date stamps are indicated in the next columns and in the last column, the current value of the heart rate plus a description of the alarm is located.

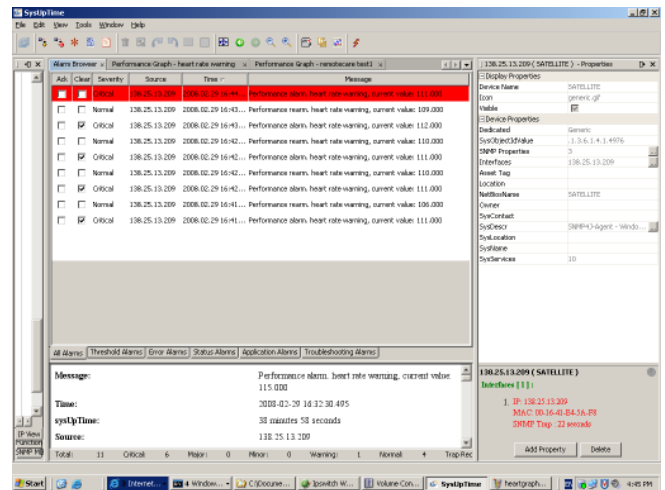


Figure 13. SysUpTime Network Monitor Alarm Triggering.

The screen shot of Fig. 14 shows the Simple Mail Transfer Protocol (SMTP) configuration window used by

SysUpTime Network Monitor to send email alerts once a preset threshold has been reached.

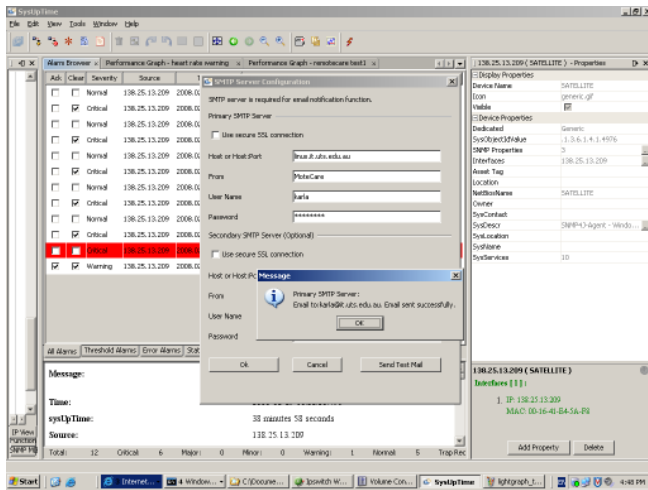


Figure 14. SysUpTime Network Monitor Email System Alert.

Fig. 15 shows the email sent to the carer indicating that a heart rate warning has been triggered and shows the current heart rate value (in this case 118 – well over the threshold of 110 bpm)

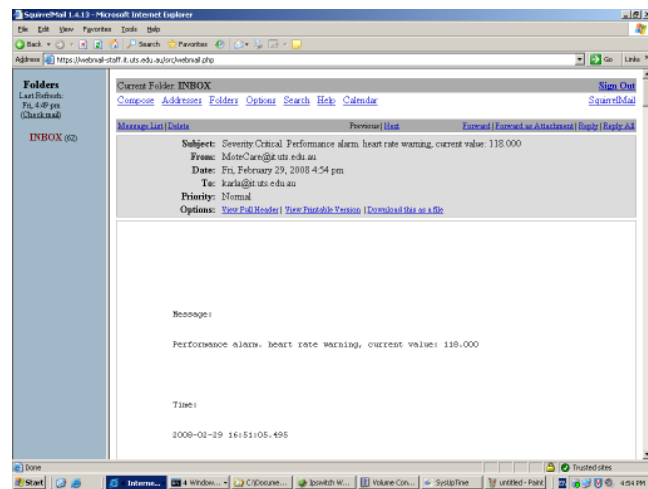


Figure 15. SysUpTime Network Monitor Email System Alert Scenario to Simulate Increased Heart Rate.

The author was able to demonstrate that the Medical MoteCare was capable achieving the requirements of monitoring healthcare variables via network management tools. However to make the system more robust and useful the author utilized Jaguar SX to demonstrate event correlation for more than one healthcare variable.

B. Data Fusion with NM Event Correlation

The Medical MoteCare system implemented Jaguar SX by incorporating a customized MIB in the system engine of Jaguar SX and by performing the appropriate discovery and

polling of the medical and environmental notes via the SNMP proxy. See Fig. 16 for a view of the discovered system devices via JaguarSX and refer to Fig. 17 for a graphical view of the collected medical data in real time.

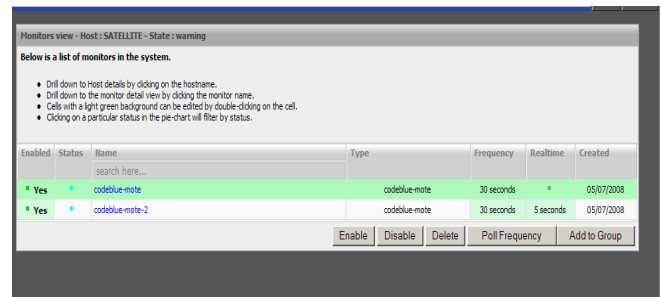


Figure 16. JaguarSX WebUI Discovery of the Motes.

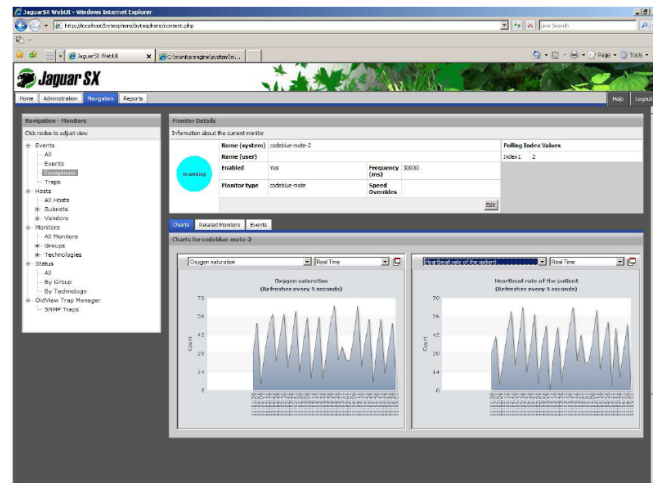


Figure 17. JaguarSX WebUI Data Collection of Heart Rate and Oxygen Level in Real Time.

As can be seen in Fig. 17 both blood oxygen level and heart rate measurements are being measured in real time with the resulting graphs being refreshed every five seconds. A false sensor was used to generate extreme variations of data to test the responsiveness of the system to sudden fluctuations in the monitored data. There may be limitations regarding security here. As in real world scenarios, there could be falsification of measurement values. If falsified data is delivered to the sensor (like higher temperatures, etc.) a consistency check may need to be done. This will be explored further in our next iteration. The Monitor Exceptions module of Jaguar SX was used to setup the conditions for multiple variable event correlation. In Fig.8 the monitor exceptions from the variables oxygen, pulse, light and temperature have been configured to trigger an alarm in the event of their preset conditions, corresponding to the "Compare Values" in column six and "Compare Types" in column seven.

ID	Monitor Type	Enabled	Object Group	Object ID	Compare Value	Compare Type	Compare Object	Severity	Action
34	codeblue-mote	Yes	1	light	120	LESS_THAN	VALUE_CURRENT	INFORMAT	NOTIFY
32	codeblue-mote	Yes	1	oxygen	80	LESS_THAN	VALUE_CURRENT	WARNING	NOTIFY
33	codeblue-mote	Yes	1	pulse	50	LESS_THAN	VALUE_CURRENT	CRITICAL	NOTIFY
35	codeblue-mote	Yes	1	temperature	37	GREATER_THAN	VALUE_CURRENT	MAJOR	NOTIFY

Figure 18. Jaguar SX WebUI Monitor Exceptions Configuration Page.

Alarm triggering is colour coded depending of its level of criticality, for example a critical alarm is bright red whereas a minor or warning alarm is colored yellow or blue respectively (Fig. 19).

As can be seen in Fig. 20, the Medical MoteCare system triggering alarm module from the Jaguar SX window shows a diverse set of alarm notifications generated from preset multi-variable conditions. For example, long term reports show a patient's history of oxygen saturation levels for a predefined period of time, such as, in this case for the last hour. Different types of graphs can be selected by the medical personnel as can a number of different reporting styles. We are now able to customize the triggers and alarms of the Jaguar SX system to individualize alarm triggering, based on a patient's medical history and their current medical condition.

With a ubiquitous Medical Monitoring System, we can use data mining techniques to create models and templates to assist in the prediction, prevention and treatment of a wide variety of possible medical conditions. This will form the focus of our ongoing work.

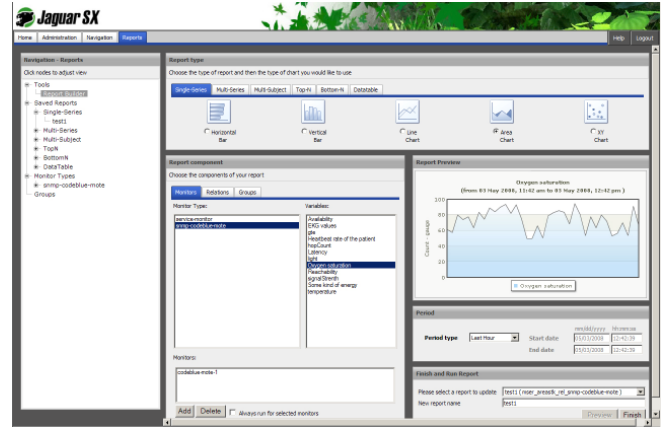


Figure 20. Jaguar SX Reports Module for Oxygen Saturation.

To further illustrate the versatility of the system, the users can access the Medical MoteCare system through the use of a PDA or a smart phone (Fig. 21). This would enable carers to move around while still being able to monitor patients remotely.

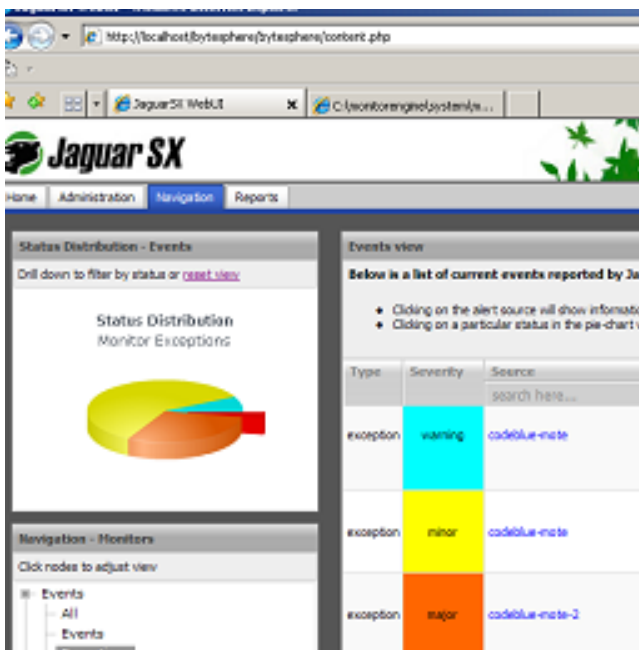


Figure 19. Jaguar SX Alarm Triggering for Heart Rate & Oxygen Level.



Figure 21. Mobile Medical MoteCare.

Fig. 21 shows that JaguarSX has discovered the Medical MoteCare system via SNMP and is able to push this information to a smart phone or PDA.

VIII. CONCLUSION

The Medical MoteCare system demonstrates the feasibility of using traditional network management systems for monitoring personal health parameters in an inherent NM distributed environment. The incorporation of medical sensors to the prototype allowed for the feasibility testing of the system for the handling of medical data. The use of an SNMP agent and a tailored MIB enhanced the scalability, modularity and flexibility of the system by potentially bringing to the researcher or developer communities the freedom of selecting from a vast range of existing SNMP based NM tools to fit their specific WSN application requirements. This was exhibited by the implementation and testing of NM tools of varied complexity and purpose, namely iReasoning MIB Browser, SysUpTime Network Monitor and JaguarSX. The Medical MoteCare System developed is a proof of concept that the use of standard network management tools and models. iReasoning MIB Browser, SysUpTime Network Monitor and Jaguar SX can assist in the development and implementation of robust distributed, wireless sensor networking applications for monitoring healthcare parameters for patients. This NM tool and, consequently any other NM tool that utilizes the SNMP NM standard protocol, can be successfully integrated into WSN applications, and, in this case, of a personal health care monitoring nature. The implementation of JaguarSX added intelligence to the system by utilizing NM correlation techniques to interpret the collected events automatically and react, or sometimes even anticipate from the collected statistical data, harmful health conditions.

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