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# Policy based Agents in Wireless Body Sensor Mesh Networks for Patient Health Monitoring

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***Abstract***

*There is presently considerable research interest in using wireless and mobile technologies in patient health monitoring particularly in hospitals and nursing homes. For health monitoring,, an intelligent agent based hierarchical architecture has already been published by one of the authors of this paper. Also, the technique of monitoring and notifying the health of patients using an intelligent agent, to the concerned hospital personnel, has also been proposed. We now present the details of the functioning of four main intelligent agents, viz., the nurse agent, the sensor agent, the database agent and the ward boy agent, for intimating the health information to the concerned doctor in the hospital, based on certain policies relevant to the hospital. The policies, in our case have been worked out based on the temperature parameter monitored by the "nurse agent". We have considered just as an example, the physiological parameter viz., the body temperature monitoring, for our policy based agent implementation. The implementation has been carried out using JADE-LEAP agent development kit. The details are presented in the paper.*

***Keywords:*** *Patient Monitoring, Wireless Sensors Mesh Networks, Agents, JADE-LEAP*

## 1. Introduction

The cost of healthcare services has been increasing and this has been posing severe challenges for policy makers, healthcare providers, hospitals, insurance companies and the patients. Under the circumstances, a major problem to be tackled is on taking care of the healthcare services of a large number of patients within easy reach. This challenge can be met by deploying an appropriate patient monitoring systems in hospitals. In the context, it is observed that there has been some progress related to patient monitoring using wearable devices using short-range communications. As increasing number of patients start wearing such communicating devices, a comprehensive patient monitoring solution can be developed using wireless sensor networks (WSNs) and the quality and reliability of patient monitoring can be improved by using wireless sensor based mesh networks (WSMN). In this case, the information on vital signs of a patient can then be transmitted to base stations by means of Intelligent Agent – which would replicate the human nurse, and will be picked up by the appropriate healthcare professional on his/her mobile device [1][2].

A hierarchical architecture for health monitoring using such Intelligent Agents has already been published by one of the authors of this paper [3][4]. We present in this paper the details of the functioning of an "intelligent ward boy agent" for intimating the health information to the concerned doctor in the hospital, based on certain policies relevant to the hospital. The

policies, in our case have been worked out based on the temperature parameter monitored by the "nurse agent". We have considered just as an example, the physiological parameter viz., the body temperature monitoring, for our policy based agent implementation. The implementation has been carried out using JADE-LEAP [5][6] agent development kit. The remainder of paper is organized as follows. Section II talks about Intelligent Agent based Routing in Wireless Sensor based Mesh Network. Section III provides the details on the algorithm developed to make agents function based on certain policies relevant to the hospital, for patient monitoring and notification and also the implementation. Section IV gives the results of the research study carried out and the conclusion.

## 2. Intelligent Agent based routing in Wireless Body Sensor Mesh Network (WBSMN)

In a typical existing hospital system, the hospital administration or the concerned department maintains the records of all patients, doctors and other details. The hospital administration would manage the business of patients admitted in wards of the departments. Then we have nurses to take care of the patients admitted in the wards of the department. Any emergency pertaining to a patient admitted is intimated to the duty doctor by the ward nurse. In the agent based system that we have conceived we discuss on how the patient information would flow from the patient through the nurse to the concerned doctor. Also to derive certain policies to be followed, we discuss how such vital health data may be compared with some set target/threshold values – upper and lower, to detect changes in the conditions or patterns of the parameter being monitored to facilitate the concerned doctor to come to some diagnostic conclusions.

In the conventional scheme, if the patient's condition is normal (0) the nurse just records the data. But if there is some abnormality (1) – above a certain upper threshold or below a certain lower threshold, then the nurse informs the duty doctor immediately who is expected to take appropriate action as needed towards treatment. In such a case, a chart using the parameters frequently measured by the nurse, say for example the body temperature is obtained and this would reveal the trend for that physiological parameter for the patient concerned. The concerned doctor could then come to some diagnostic conclusions based on this data chart. The corresponding binary codes for this scheme of manual operation are shown in parenthesis in Figure.1.

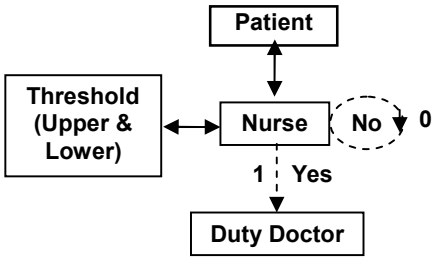


Figure.1 Threshold based patient information flow

In the system discussed above, we always need a nurse to keep monitoring the health of the patient and also keep informing the duty doctor. But we can't always rely on human beings for this monotonous job, when the periodicity of monitoring is concerned. In this

context, we can profitably employ wireless body sensors which can keep continuously monitoring the health of the patient and inform the doctor through wireless means. So we have come up with an architecture [1-3] which uses Wireless Sensors employing agents (replicating the nurse) to perform the health monitoring based on the set target/threshold condition.

In our architecture, a wireless body sensors based Mesh network (WBSMN) consisting of spatially distributed autonomous devices using body sensors to cooperatively monitor the physiological conditions of patients at different locations (wards), transmit the data to the nearest Access point i.e. mesh nodes at wards. These mesh nodes use multihop routing to inform the mobile devices like the PDA or backbone network. The Intelligent agents [7-12] are mainly used as a middleware in acquiring and transmitting the sensed signal information. The ultimate aim of the architecture is finally to inform the doctor anywhere, anytime, through his hand held device, about the condition of the patient. Taking all these into consideration we have proposed a hierarchical WBSMN [3][4] employing intelligent agents for health care monitoring application and the details are explained below.

### 2.1 Intelligent agent based hierarchical routing

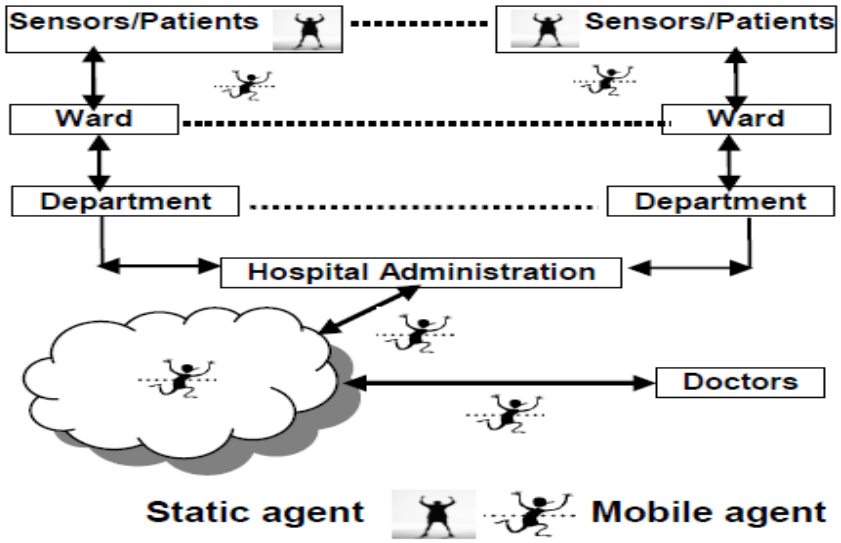


Figure. 2 Intelligent agent based hierarchical scheme

In this section we will consider the global scenario of the overall architectural features of a WBSMN shown in Figure.2. In the architecture we conceive the mesh nodes to be placed in each of the wards, departments and the hospital administration buildings. In order to replicate the functions of the ward nurse and the roaming human agent who normally carries the patient information from wards to departments/hospital administration/doctors, we make two intelligent agents to perform these functions. Taking these into consideration we have come up with decentralization of the architecture employing mobile agents from the ward level and upward and static agents (to replicate the nurse) at the patients.

In this scenario let us consider five types of sensors fixed on a single patient. Each sensor provides real time physiological readings that need to be monitored. The devices transmit

only after receiving a message from their cluster head or when an event occurs to the patient. For the moment let us not take into consideration the time synchronisation aspect, since we are now discussing the architectural features of the proposed system only. To reduce the cost and power consumption a cluster based topology be used for a single patient. The sensors in the Body Sensor Network (BSN) will now use ring formation with the cluster head as coordinator of the sensors and this will communicate to the nearest mesh node [13]. In this way, we can increase the number of patients, assuming that we follow the Zigbee [12] technique. This schematic can be extended for the entire hospital, comprising many wards. This agent based routing architecture has been validated in SunSpot Sensor using JADE-LEAP[14,15]

## 3. Implementation of Intelligent agents based routing using JADE - LEAP

We have seen so far about the working of the agent based hierarchical scheme and also about the agent based routing in wireless body sensor networks. We have validated the agent based routing in wireless body sensor networks with the Sunspot emulator [14, 15]. Now we will consider only the patient monitoring activity and explain in details as how the agents have been developed using JADE-LEAP [5, 6] agent development kit to replicate the nurse, which is a basic requirement for our envisaged global scenario. We have developed four main agents, viz., the nurse agent, the sensor agent, the database agent and the ward boy agent, the functionality of these would be discussed in this paper. We will now give a brief overview of technologies used for implementing these agents.

We will now describe the functioning of the four agents developed viz., the nurse agent, the sensor agent and the database agent as shown in Figure.3. The sensor agent will be running in the J2ME [16] environment as depicted in the screen shots below. The sensor agent will be in sleep mode when it is started waiting on the nurse agent to wake him up with a request for temperature. The sensor agent will get this temperature from the patient that is generating random temperature that may be produced by a patient with the Influenza virus as an example. The Nurse agent will get its parameters from a Gui that will be presented to the nurse agent. These parameters include setting the range for what the nurse chooses as normal range for the patient, how often the temperature should be collected and when to start collecting the data. The data received is checked for abnormalities (thresholds specified by the doctor/nurse – policy based decisions) of three consecutive temperature readings. If there are abnormalities – physiological parameter going above the upper threshold or going below the lower threshold, an alarm is triggered for the nurse agent to take an appropriate action. Every set of temperature reading collected by the nurse agent will be sent to a database agent that will enable storing the readings in an appropriate database and then initiate the ward boy agent to intimate the concerned doctor. We now present the algorithm developed and the results.

### 3.1. The Algorithm

*The Sensor Agent algorithm:*

- Start the Sensor Agent
- Register the sensor Agent in Directory Facility [DF] of Jade

- Get the temperature from patient and send to nurse agent
- Suspend the sensor agent until the next request for temperature

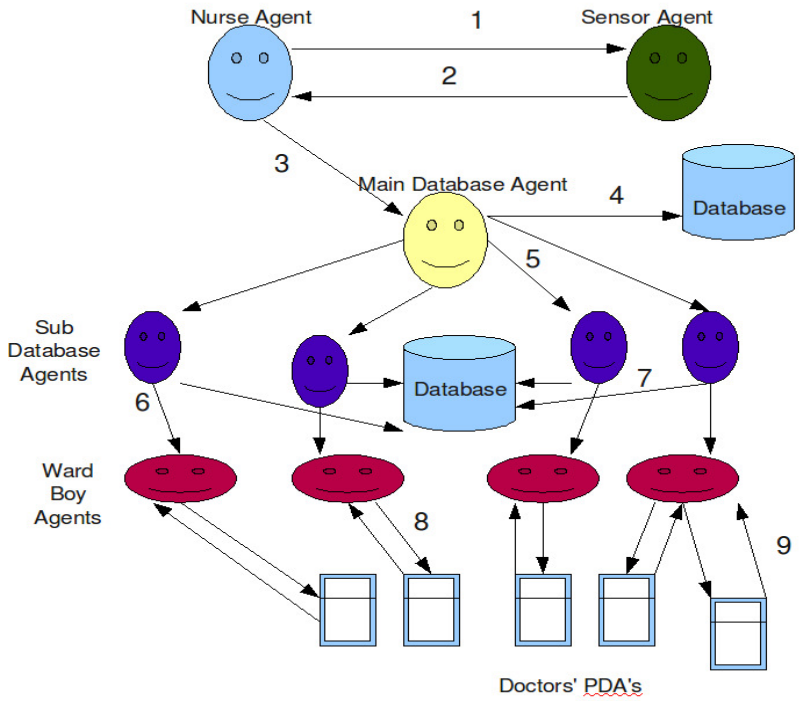


Figure. 3 Intelligent agent interaction in patient monitoring

*The Nurse Agent Algorithm:*

- Start Gui to get Sensor Agent parameters
- Input schedule for the request of temperature based on how often this data is required
- Input the Upper and Lower range for temperature
- Input schedule when the Nurse Agent should begin collecting data.
- Input how often temperature should be collected.
- Start Sensor Agent
- When request is activated based on the above parameters, check Directory Facility for Sensor Agent
- When sensor agent is found send the request to sensor agent for temperature data.
- Suspends behaviour and wait for reply from Sensor Agent.

- When temperature reading is received, update array with temperature reading and time

- When there are 3 consecutive temperature readings out of normal temperature range, trigger a visual and sound alarm

- Search the directory facility for database agent .When found, send 5 temperature readings with times of temperature taken , the date and the sensor id to the database agent for storage

- Reschedule the request for temperature based on the given parameter

- At the end of Simulation a time vs. temperature graph would be created

*The Database Agent algorithm:*

- Doctors or other medical personnel will set the bands for temperature monitoring – policy based.

- Database agent will execute a cyclic behaviour to wait for messages from Nurse Agent with data set of 5 temperatures, Date, Time and Patient ID/Sensor ID(Each Sensor ID will be set based on Patient's ID)

- When the temperatures are received, the Main Database Agent will update database and spawn Sub-Database agent and give him the 5 temperature readings and patient ID.

- The Sub Database agent will run temperature monitor software that will check to see the range that the most temperature readings fall into. This range will determine the doctor(s) to contact. Sample Ranges that could be set are (based on policy):

  Band1: 95-100: **Duty Doctor**

  Band2:93-95 and 100-102: **RMO**

  Band3:90-93 and 102-104: **Chief Doctor**

  Band4: Less than 90 and More than 104: **Consultant**

- If two values fall in one band and 2 other fall in another band then both doctors are contacted along with other doctors that are below their hierarchy to avoid conflict.

- If three consecutive values fall in one band, then the doctor associated with that band will be contacted, along with all the other doctors below their hierarchy.

- If two values fall in one band and remaining three fall in other bands, then the concerned doctor contacted with the other doctors that are below their hierarchy.

- After Sub Database Agent runs the temperature monitoring software, depending on the type of doctor returned to be contacted. The Sub Database agent will connect to the database and check the roster to see the group of doctors matching the doctor type that the patient is assigned to and who is also on duty.

*The Wardboy agent Algorithm*

- The Sub Database will now spawn a Ward Boy Agent, give him an appropriate warning message which will include the Ward boy id & time created, patient's id, Temperature, time, date and which group of doctors to deliver the message to.

- This Ward Boy agent will now migrate to the Main Access Point where he can see the doctors phone and then send the information to the concerned doctors and wait for a specified amount of time for replies from doctors.

- When all replies are confirmed, the Ward Agent will now confirm these replies to the Nurse Agent and then terminate itself.

- If there are any failures, or particular doctors take too long to reply, the ward boy agent will check which doctor's phone was not contacted and try the next level doctor and wait for another specified amount of time.

- If no doctor is contacted (rare/worse case scenario), then agent will report to nurse that no doctors are responding to the message and Nurse would have to take an appropriate action.

## 4. Results and Conclusion

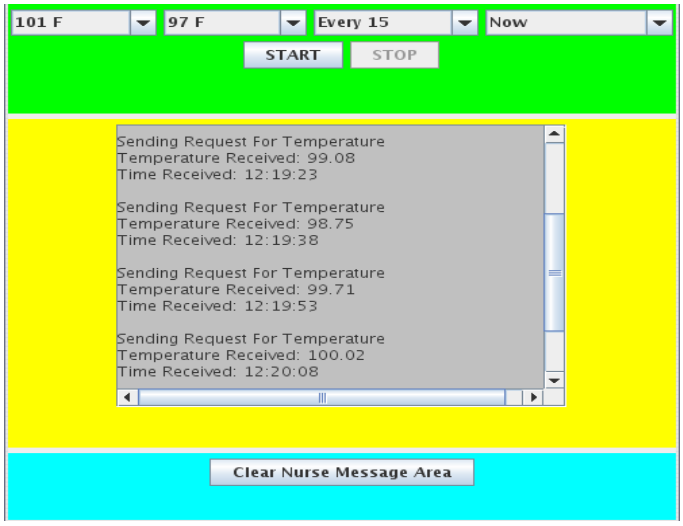


Figure 4. Nurse gent

The implementation and validation of intelligent agents for monitoring the temperature viz., the Nurse Agent and the Sensor Agent was done using JADE-LEAP development kit for a single patient from the point of our research study [16]. As mentioned only the body temperature parameter has been considered for our simulation study. The same technique can however, be extended for 42 patients as zigbee network [12] can support 255 active nodes. We now show the results on how the temperature monitored be delivered to the concerned doctor with the temperature bands set fixed based on policy. The results of the implementation are shown as sample screen shots for temperature monitoring. Figure.4 shows the nurse agent which requests for temperature from sensor Agent (which is shown in

Figure.5). We here have replicated the job of a nurse by means of Nurse Agent for monitoring one physiological parameter viz., body temperature.

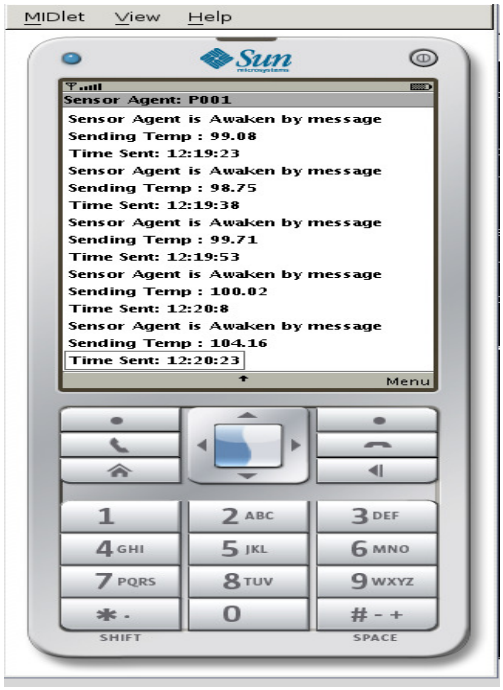


Figure 5. Sensor agent

Figure.6 shows the GUI of main database agent .This one would be started and stopped by medical personnel like the nurse or so. As describe above in our database agent algorithms, we set (policies) the temperature bands for each doctor to be contacted. For duty doctor and Consultant we have set the temperature band as Upper threshold (U-Threshold) and Lower Threshold (L-Threshold) like 95 to 100 and less than 90 to more than 104 respectively. Now for Resident MO, Chief Doctor we got two bands: one below the normal human body temperature (93-95) and other above the human body temperature (100-102). The one band below the human body temperature is been shown as Lower Upper threshold (LUT) and Lower Lower Threshold (LLT). Similarly other band above the human body temperature is shown as Upper Lower Threshold (ULT) and Upper upper Threshold (UUT). Now the band values are set for each doctor to be contacted and database Agent started.

Also these band values are subject to change by the hospital staff. Now that the database agent is created, the values recorded in database by nurse agent are monitored by a sub database agent to decide on which doctor is to be contacted. In this case we have five temperature readings viz., 96.1, 97.2, 99.6, 103.0, and 90.0 and these are shown in Figure. 7 graphically. From the graph we can clearly see that 3 temperature readings fall in the duty doctor band. Now based on this the ward boy agent would migrate to the access point and check for the duty doctor's phone agent. Then the Ward boy agent would send the Wardboy agent id, time created, Patientid,

temperature, time and date recorded to that duty doctor as shown in the sample Figure.8.

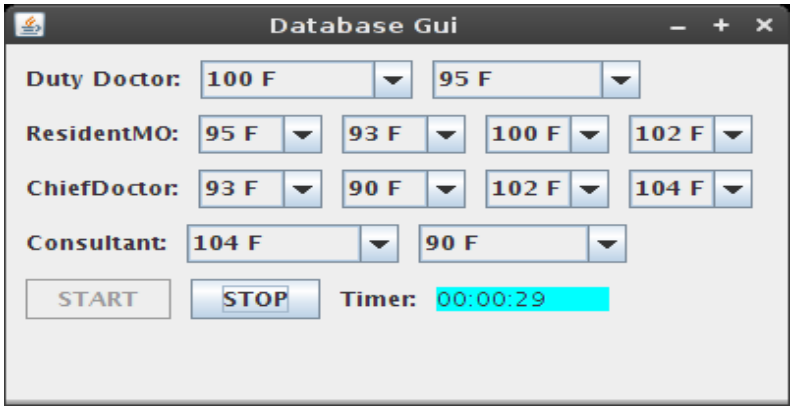


Figure 6. Database agent – started

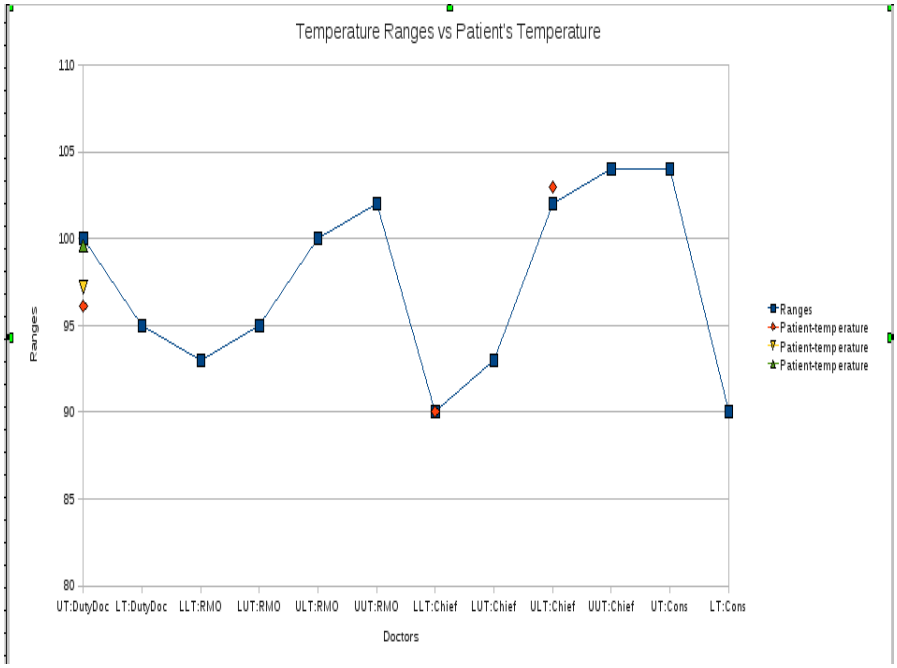


Figure 7. Band – temperature graph

Now that the temperature is received by the duty doctor the duty doctor responds to nurse agent through the wad boy agent as shown in Figure. 9. Also shown in Figure.10 all doctors fail to reply and in that nurse manually goes to call the doctor available.

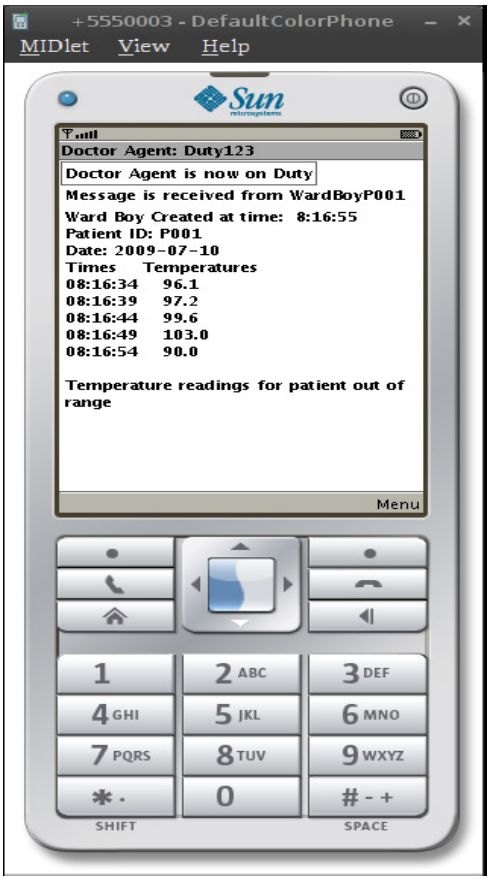


Figure 8. Wardboy agent – communicating to the duty doctor

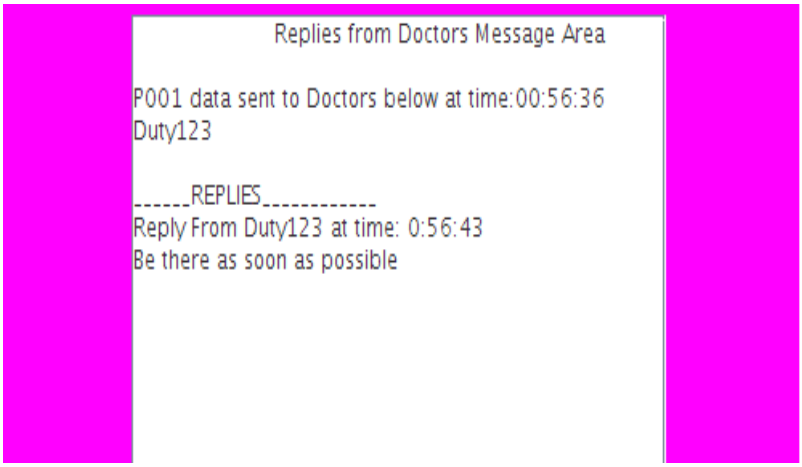


Figure 9. Duty message sent- Nurse Agent

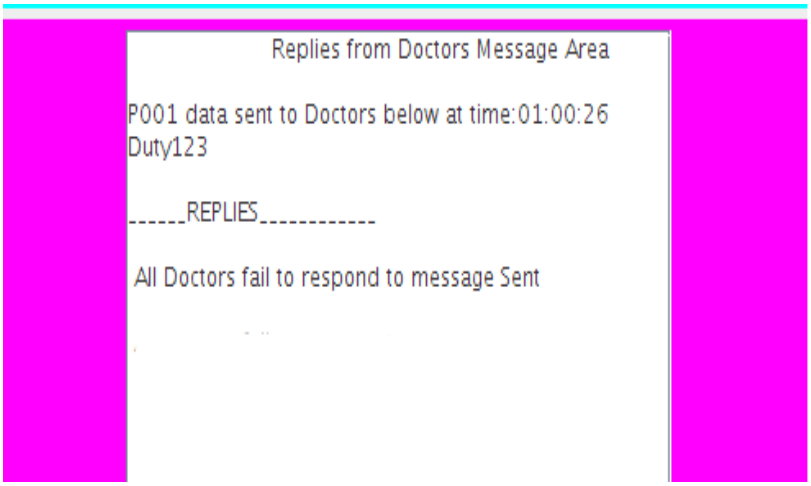


Figure.10 No message received-nurse agent

Consider a second scenario in which the ward boy agent would migrate to the access point to see which doctor's phone agent is up? Then the agent would send the message to the Resident MO, chief doctor with a copy to Duty doctor too who is below in hierarchy to avoid conflict. It also shows that consultant is also up but we need not have to send to him as the temperature is not in that range to be contacted. This show in Figure. 11

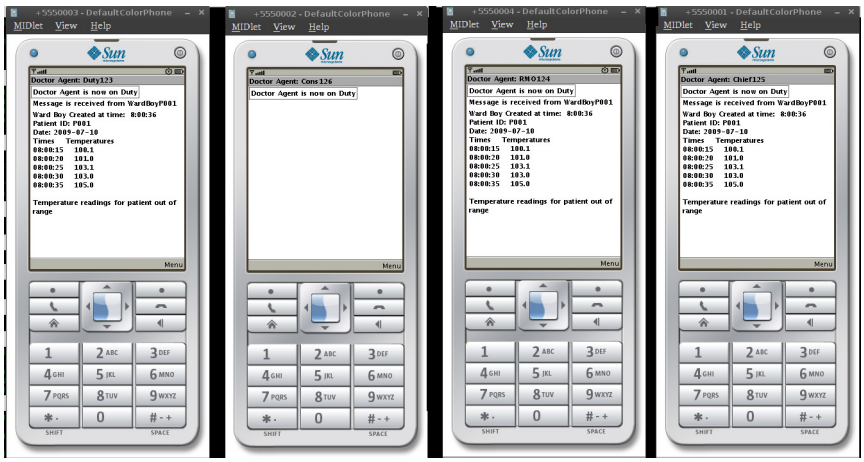

Figure.11 Wardboy agent – communicating
to RMO and Chief Doctor

In the third scenario 3 temperature readings fall in one band - Resident band. In this case, the ward boy agent will send temperature readings to RMO and a copy to Duty Doctor. The temperature readings are as follows: 100.1, 101.0, 101.2, 103.0, and 89.0. This is shown in Figure. 12

Any system is susceptible to human error. So we here have taken measure to see to it the temperatures are entered properly and also there is no overlapping in temperature bands and

also lower threshold values are not bigger than higher threshold. A scenario where lower threshold value entered is bigger than higher threshold and so database agent creation is failed which is shown as error message in Figure. 13.

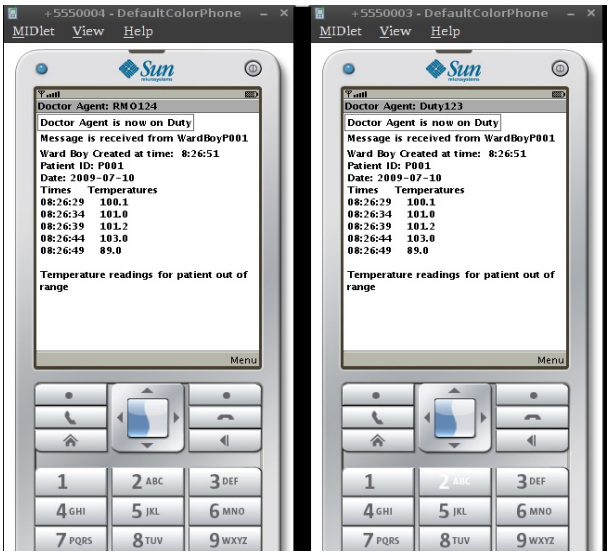


Figure 12. Wardboy Agent – Communicating to RMO and Duty Doctor

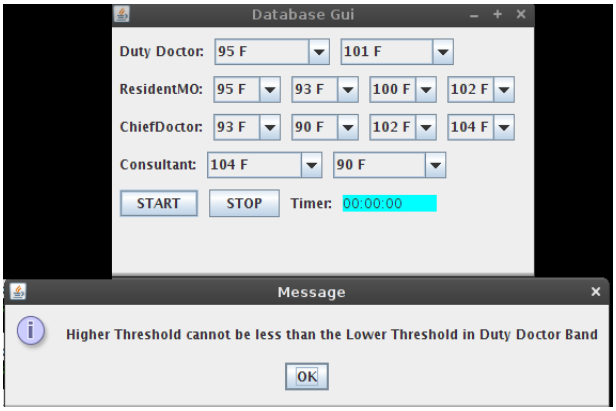


Figure 13. Database agent- error message

For such healthcare applications, we normally employ a human nurse to collect say, the body temperatures and record them periodically and inform the doctor. But with the wireless sensor devices coming up out of research, we recommend employing them to sense the body temperature or for that matter any physiological parameter using appropriate wireless sensor device and deploy agents, as described in this paper, to collect the physiological parameters periodically and record them in a database or issue an warning alarm, as the case may be. We here have replicated the job of a nurse by means of Software agent for monitoring one physiological parameter viz., body temperature. The physiological parameter readings are intimated to doctor concerned by means of Ward boy agent by means of setting bands in temp.

The result outputs of our research have been shown as screenshots to bring home the applicability of the scheme proposed. In future we propose to work on sending the acknowledgment for message received by doctor's PDA to nurse agent.

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