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The Next Generation of Mobile Computing for Hospitals

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ABSTRACT

Mobile computing in the broadest sense is when multiple communications devices work together within an environment, unhampered by equipment limitations, distance, or interference. As computer and networking devices are put into smaller and smaller envelopes, their workplace usefulness increases. These mobile devices offer the potential of increasing the quality of healthcare services by making better use of hospital resources, including improved communications among medical and support staff, and increased patient monitoring. This paper depicts several hospital scenarios in order to conceptualize the planning and design of future mobile networks, taking into consideration patient care, management thinking, and technical issues.

MOBILE NETWORKS

One can easily imagine a sophisticated hospital environment where many of the staff are actively using Personal Digital Assistants (PDAs) to communicate with each other and to record patient data into the hospital's information system. Similarly each patient wears a miniaturized mobile monitoring device which broadcasts medical readings to the nurse's central station (Morton and Bukhres, 1997). But these new technologies also provide a challenge for management: how best to administer hospital resources using 24/7 communications, with their more accurate and timely information, and potential for superior logistics (Evanshwick, Swan, and Smith, 1995). Simply stated, the challenge is to plan and build a mobile network providing Quality of Service (QoS) computing so the outcome is QoS patient care (Adis, 2003).

The transition to mobile pervasive computing is already taking place in hospitals and other healthcare environments. If the technical transition is allowed to occur in an unstructured manner, similar to the first introductions of PCs and networks, this can negatively impact the hospital environment. Mobile computing only adds value to the degree that it improves patient care, management support, and the overall work environment. Optimally, management's transition to mobile computing must take place in stages, based on the strengths and weaknesses of current mobile systems and their middleware operating systems. There are initial tradeoffs in designing, building, and implementing a mobile system. One of the best ways to come to grips with these issues is to conceptualize these tradeoffs through analyzing various common hospital scenarios (Bardram and Christensen, 2004). The remainder of this paper looks at various next generation scenarios, analyzing them from three perspectives: patient care, management, and the technical issues. This exercise allows stakeholders to take the first steps in conceptualizing mobile computing within a QoS patient environment.

TRADEOFFS

The roadmap to mobile computing, and to a superior hospital environment, is initially a series of managed tradeoffs (Banavar, 2000). In order to gain mobility one trades a fast full featured desktop PC for a significantly slower and less robust mobile client. Using a mobile client generally means having a smaller display panel, a battery as a power-source, an antenna rather than high speed Cat 5 wiring, limited storage for programs, less memory for caching documents, and a slower CPU for needed tasks like encryption and compression.

Another tradeoff is having to move away from a known model of client server computing, with its established middleware and solid communications, to new model of computing. This new model has to take into consideration the possibility of lightweight and limited functionality of both clients and servers. These mobile client/servers may have a limited broadcast range and the inability to handle sophisticated audio and video communications. Furthermore, mobile middleware has to take into consideration events occurring within the hospital work environment, such as interference generated from hospital equipment, interrupted work sessions, and the movement of patients, medical staff and equipment from one transmission zone to another.

Mobile middleware has the task of balancing these tradeoffs in a 24/7 communications environment. It does so by monitoring the mobile network and providing compensatory services such as data compression for light weight nodes. It can also manage communication faults and irregularities with reconnection services, and can secure the environment with encryption (Capra and Mascolo, 2001).

While these are some of the technical tradeoffs, there are also management tradeoffs. Probably the most obvious one is that the hospital medical and administrative staff have to accommodate themselves to working on small, PDA type, mobile equipment. A larger though more invisible issue for management is patient privacy and overall data security. Broadcast transmissions are more vulnerable to hackers within range of the signal and therefore data encryption and user authentication are essential middleware services (Morton and Bukhres, 1997). From an information technology perspective, this is a period of transition. Computing staff will be required to support old systems while implementing mobile computing. To perform this dual mission, financial resources and timelines need to be mapped against management directives. An example of this would be funding a technical help desk with sufficient staff and test equipment to support a mobile environment which may be initially less stable and more prone to cause problems (Esler, 1999).

Yet for management there can be no tradeoffs in providing patient care in a secure QoS environment. This means that the mobile communications can never deteriorate to the point where wait time, integrity of transmission, and security negatively impact the patient care environment. Management must be aware that the critical components in mobile computing are fault tolerant systems, with 'intelligent' middleware (MosquitoNet, 2003). Management thinking also needs to address workflow issues that take advantage of the new mobile environment, while introducing safeguards to guarantee QoS (Campbell, 1997), (Rohrer, 2003).

HOSPITAL SCENARIOS

The following hospital scenarios depict a series of common patient-driven events that occur in a hospital. The initial purpose of these scenarios is descriptive, showing how mobile devices can be incorporated into patient care and hospital services. This leads to the main theme which is to analyze the managerial and technical issues needed for QoS patient care.

Scenario 1: Emergency Room

An ambulance arrives with a sick individual. The patient is registered, assigned a temporary room and an attending doctor. The registration staff enter the data in a traditional networked computer, which forwards the appropriate information to the healthcare data server. This server functions as both the medical data program and the patient accounting program.

In addition the staff provide the patient with an electronic bracelet, an updated equivalent of the traditional wrist bracelet. This device contains data storage and a transceiver for transmitting and receiving information. Besides name and demographics, the electronic bracelet contains information for the attending physician, and has storage capacity for medical diagnosis and treatment plan.

After the patient examination, the doctor orders appropriate medication and schedules an initial treatment as well as further tests for the patient. She enters all of this into her mobile PDA and the data is then transmitted to the healthcare server, which records the information and schedules tests and treatments. The patient information is then forwarded through the traditional network to workstations in the assigned medical sections, including the pharmacy. In addition, the healthcare server broadcasts certain essential medical information to the patient's electronic bracelet.

Scenario 1 Analysis: Emergency Room

Patient Care: The electronic bracelet allows critical medical information to reside with the patient. Having critical data always with the patient is a safeguard to ensure a match between the bracelet information and any medication or treatment. (Scenario 2 details how this matching works.) There is also less chance for a transcription error, since the attending physician enters the data herself into her PDA, which then broadcasts the information to the healthcare server (Ancona, 2000).

Management: Overall work flow is more easily managed by early knowledge of the patient's treatment plan. Resources such as CAT scanners, operating rooms, recovery centers can be scheduled with this information. Furthermore, the billing information for the patient's account is entered concurrently with the treatment. No longer does the updating of the patient's accounts occur as an after fact.

Technical: Mobile devices are becoming smaller and less expensive all the time, with memory cards storing large amounts of data. Since mobile communications lack the reliability of traditional cabled networks, the middleware must guarantee transmission or alert the users of system faults (Object Management Group, 2000). Furthermore the database system found on the server must regularly compare its patient data against the data in the electronic bracelets, to ensure that both are concurrent. One way to do this is to have the server regularly send a copy of critical bracelet data to the attending physician for review and confirmation. This would be an electronic equivalent of checking the patient's medical chart.

Scenario 2: Test Results

The patient has taken a series of tests to determine his condition. One of the tests shows an irregular cardiogram reading. The healthcare server downloads a high priority message to the attending physician, as well as downloading the results to her PDA. The heart specialist on call is also alerted and sent the results.

Through messaging back and forth the two doctors decide to meet in one of the conference rooms to discuss the problem. By checking the schedule of conference rooms through their PDAs, it is straight forward to choose one that is free. During the meeting, they beam the cardiogram results found on their PDAs to an electronic white board. In this way they can both see and discuss the cardiogram. From this collaboration, they decide that the medication needs to be changed, further tests taken, and additional treatments given. They immediately alert the patient's nurses. Both physicians use their PDA to update the system with the changes. Additionally the attending physician decides she wants to discuss the results with the patient. Since the patient's electronic bracelet acts as a global positioning locator (GPL), he can easily be found, whether he is in his temporary room, a new room or in any of the medical sections of the hospital.

Scenario 2 Analysis: Test Results

Patient Care: Through collaboration there is a shortening of the time needed for diagnosis and implementation of any new medical treatment plan. It is easy to locate the patient and keep him updated as to the status of his condition. Again the system updates the electronic bracelet with the necessary changes.

Management: Collaboration is the core of any improved healthcare logistics (Goldberg, 1997). Workflow is improved because the chief participants can use appropriate collaboration software to schedule meetings and services. Messaging confirms the time and place to meet and resolve patient care issues. In this instance the doctors choose a meeting room which has a white board with mobile client capabilities. This visual aid is a useful collaboration tool in their discussion.

Technical: The GPL is part of the patient's electronic bracelet, as well as part of the doctors' PDAs. The mobile system uses this GPL feature to track and locate patients and staff throughout the hospital. The GPL feature is integral to providing optimum communications by discovering the location of the mobile clients, and having the middleware change their broadcast zone as they travel.

The middleware supports collaboration software for scheduling and overall workflow. It also supports the collaboration process by tracking the features found in each mobile device (Mohan, 2000). For instance, it knows the limited functionality of the doctor's PDA, particularly the small size display panel. Therefore the system middleware modifies the cardiogram's medical data to more easily display on the PDA. When the cardiogram data is shown on a large electronic white board, the middleware modifies the data set to take advantage of the large screen format. This is possible because the middleware's object repository contains the interface and characteristics of each client.

Scenario 3: Patient Discussion

The doctor's electronic search discovers that the patient is in his newly assigned room. As she is walking to that area, she sends a brief message to the patient's nurse to join them for the discussion. During the meeting, the doctor uploads patient data from her PDA to the television in the patient's room and shares the data and the diagnosis with the patient and nurse. The doctor also can get on to the Internet and point out some healthcare sites for the patient to explore from his bedside PDA.

Scenario 3 Analysis: Patient Discussion

Patient Care: The patient is continually informed about his condition through discussions and the use of appropriate media. By signing on to Internet healthcare sites, the patient can become a better participant in his own care.

Management: Text messaging, voice mail, video displays and other communication media permit a greater range of collaboration among staff.

Technical: Global positioning is based on the radio frequency ID (RFID) of each bracelet. The server uses the transceivers within the hospital to determine the patient location. In this instance the transceiver locates the patient in his room. Similarly, any resource that has a RFID can be located, whether it is an individual's PDA or a piece of medical equipment (Finkenzeller, 2003), (Want and Russell, 2000).

Scenario 4: Medication

Later on in the day the nurse's PDA alerts her that it is time to give the patient his medication. The medication comes from the newly altered treatment plan which the doctors have recently prescribed. The patient name, room number, medication and dosage appear on the nurse's PDA screen. The electronic tag on the medication is automatically matched against the data on her PDA for accuracy. On returning to the room, the data on the patient's electronic bracelet is automatically matched against the electronic medication tag. If there is any discrepancy the PDA immediately notifies the nurse, and sends a message to the attending physician. In addition the nurse's PDA automatically sends a message to the healthcare server for error tracking and rectification. Assuming in this instance that there are no discrepancies, the nurse administers the medication, and enters into her PDA the transaction completion codes (time /date and health care provider) that signify that the medication has been administered. Once the medical transaction has been completed, the PDA forwards one segment of the data to the healthcare server that is monitoring the progress of the patient, and a second segment to the accounting program that is maintaining the patient medical bill. The accounting program also contains a database for managing medical inventory, which is similarly updated based on resources used by the staff.

Scenario 4 Analysis: Medication

Patient care: Multiple precautions are in place to ensure that the correct medication and dosage is administered to the patient (Doug, 2002). This has the potential of significantly reducing manual inspection errors. Similar features exist for medical services such as matching the patient with any scheduled treatment.

Management: Tracking of medical errors is an important component of improved patient care in a number of areas. Firstly, the potential to cause patient injury through administering incorrect medication is lessened. Secondly, insight into workflow issues and potential weaknesses in the delivery of patient care are highlighted. Tracking of patient treatments and medications similarly increases the accuracy and timeliness of patient billing.

Technical: Backup tracking systems are called for in the case of electronic tag malfunction or transmission failures. This means that the hospital's mobile system has fault tolerant capabilities, with procedures for replicating services. Also a system has to be in place for the safe recycling of electronic bracelets and tags for new assignments.

Scenario 5: Mobile Monitoring

The patient has several mobile monitoring devices attached to him. Some of the devices are composite in that they perform more than one task. For instance, a device can monitor pulse and temperature at the same time, and then transmit the data to a central monitoring station. These miniaturized devices save the patient from feeling that he is wrapped in wires, and in general make him feel more comfortable. If the patient is in transit from one area to another for treatments and services, the mobile devices can still alert the medical staff of a problem while he is being moved in his wheelchair or trolley bed. As the patient approaches the service department, his electronic bracelet uploads his medical chart on to their monitoring workstation. If the assigned treatment doesn't match the patient, the staff member's PDA sounds an alarm, and the event is recorded on the health care server.

Scenario 5 Analysis: Mobile Monitoring

Patient Care: Mobile monitoring devices add comfort and provide in-depth readings. The patient has a sense of security knowing that his condition is being monitored 24/7.

Management:. The patient's treatment in each service department is continually matched against data from his electronic bracelet and healthcare server. This safeguard assures the patient that the medical staff is fully aware of his medical condition and treatment plan. Any discrepancies are immediately indicated as well as recorded for further follow-up. Management can also track any recurring problems in delivery of patient care, and resolve workflow issues.

Technical: As the patient moves through the hospital there may be areas where communications are non-existent because of geographic barriers or equipment interference. An example may be in elevators, or in areas using high voltage equipment. The technical staff must regularly complete an environment scan, pinpointing areas where there are poor or no communications. The staff can then resolve these communication faults by adding additional transceivers, modifying equipment, and changing transmission bandwidth.

In addition, over time mobile equipment becomes dated, and can become incompatible with the current mobile network. These issues can be resolved through the adoption of communication and interface standards for the mobile equipment as well as for the middleware.

Scenario 6: Visitors

Each visitor is given an electronic tag that transmits a radio frequency ID. This tag serves as a geographic locator, and thereby informs the security staff of visitors in prohibited areas. The staff also have electronic tags or PDAs to show their location throughout the hospital, which helps in marshaling resources in case of an emergency. In addition to the GPL function, the signals emitted by electronic tags serve as code for opening electronic doors in secure areas. The hospital uses this function to secure prohibited areas from unauthorized access.

If visitors need to be reminded that their time allocation is up, or if there are any other visitors who are waiting to see the patient, then the electronic tag can be activated and produces a beeping sound.

Scenario 6 Analysis: Visitors

Patient Care: Visitors and visiting hours are an integral part of patient care. Scheduling and tracking of visitors becomes more straightforward, and more manageable.

Management: Electronic tags provide a theft deterrent and safeguard against malicious damage by securing areas to those staff members who have an appropriate level of clearance. For instance narcotics may be stored in a secure area of the hospital pharmacy, and access to that area may be strictly limited to certain pharmacy staff. Similarly if equipment and supplies have embedded tags, then the resources have a built in RFID trigger for monitoring against theft (Ryan, 2002).

Technical: The more electronic tags, bracelets, PDAs, and devices with RFIDs, the greater the burden on the mobile system and middleware. The more tasks that the middleware has to perform, from tracking patients to opening doors, the greater the potential stress on the system. The design must be robust and have the ability to scale as new tasks and components are added.

In order to safeguard against future incompatibilities, the hospital has to follow accepted industry standards for RFIDs, interface, and communications protocols. This ensures that the mobile system is able to perform an increasing number of tasks, and can scale to accept the concomitant new hardware.

Scenario 7: Patient Privacy and Information Security

Hospitals, like other institutions, face the threat of hackers attempting to infiltrate their network, causing damage and loss of confidential information. Mobile transmissions, with a broadcast range of hundreds of meters, potentially open up a new set of trap doors for hackers.

Scenario 7 Analysis

Patient Care: The patient expects information privacy, and the hospital is mandated to provide system security.

Management: The adoption of hardware and software security standards helps protect the mobile system from hackers. An example of this would be PDAs which have enough processing power and memory to be able to meet industry level encryption standards. Furthermore, management needs to be proactive in employing security consultants to update the hospital's long range technical plan (Brewin, 2003).

Technical: The middleware has to continually update codes, passwords, and electronic tags, to create a more difficult environment for hackers. As hardware devices become more powerful and mobile communications protocols become more secure, these updates can be transmitted over the mobile network (Birman, 1996).

CURRENT AND FUTURE GENERATIONS

Some of these next generation scenarios may become possible in the near future based on the recent advances of mobile computing technologies. In order to grasp how fast mobile technologies are changing, and to underscore the timeframe for management and technical planning please refer to Table 1 below.

Protocols	Wi-Fi 802.11	WiMax 802.16	802.11e	802.11i
Speed	54 Mb/sec	10 Mb/Sec		
Distance	300 ft	30 miles		
Audio-Video Streaming	No		Yes, QoS Prioritizing	
Security	Subset of Advanced Encryption Standard			Advanced Encryption Standard

Table 1: Wireless Protocols.

Table 1 shows the popular Wi-Fi 802.11 protocol and some of its most important features. Its speed, distance and relative security make it a very strong choice for today's wireless network. In addition there are several other planned protocols which will be implemented to support and extend Wi-Fi, strengthening its distance and imperviousness to noise (802.16), its security (802.11i), and allowing prioritized streaming of audio and video data (802.11e). These features are a small but significant step on the road to the next generation of ubiquitous wireless computing.

CONCLUSIONS

The future of hospital computing is built on understanding the technical direction of mobile computing and conceptualizing the QoS issues facing its work environment. Table 2 summarizes this approach to planning and design by using the three categories of QoS Patient Care, QoS Management, and QoS Technical. These three categories were chosen to emphasize the multiple perspectives needed in the planning and design process. QoS Patient Care focuses on the issues that concern the well-being of the patient. It has a broad impact range, from the delivery of health services to the more personal ones of informed participation in medical decisions, and protection of confidential health information. The QoS Management category deals with administrative issues such as policy/standards, timely billing and scheduling. It also involves the organizational dimension of workflow and collaboration. Finally the QoS Technical category focuses on system issues from performance monitoring, upgrades, and security to training and problem resolution.

Overall, these three QoS categories help conceptualize the planning and designing of mobile computing in a QoS hospital environment from the perspective of its principal stakeholders (Killijian, 2001). This becomes another important step in the visualization of the future work environment.

QoS Patient Care	**QoS Management**	**QoS Technical**
Quality Delivery of Care	Collaboration	24/7 Mobile Computing
Privacy	Security Procedures	Middleware Security Services
Informed Participation	Policy / Standards	Performance Monitoring
Integrated Patient Monitoring	Timely Billing	System Scaling / Upgrades
Safety Checks for Medications and Procedures	Scheduling and Workflow	Training /Problem Resolution

Table 2. Planning and Design Issues

Few would argue that the next generation of wireless computing has the technical and logistic features to transform most business environments. If Table 2's guidelines are read broadly, then the criteria for successful implementation in most settings are spelled out. The reason for this is that the QoS wireless concepts are equally valid for the implementation of business solutions across many different business sectors. The QoS wireless techniques and guidelines are in fact driven by the needs and expectations of its business stakeholders.

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