Mobile Telemedicine Systems Using 3G Wireless Networks

a report by
Yuechun Chu *and* **Aura Ganz**

Multimedia Networks Laboratory, Department of Electrical and Computer Engineering, University of Massachusetts

Motivation

A mobile telemedicine system provides a platform for data acquisition from numerous instruments and its harmonious transmission and delivery to healthcare providers through 3G-based wireless networks. Because this system can be used in any geographical area in which 3G networks provide coverage, it offers significant hope in reducing mortality and morbidity as well as presenting monetary savings. Below are a number of scenarios that benefit from the use of 3G-based wireless networks.

A teletrauma system can provide continuous realtime voice, video, and medical data input between an ambulance and a level I trauma center. This system benefits pre-hospital trauma care, especially in situations where long transport time or multiple transfers are involved. Such a solution can improve the quality of trauma care, expediting the evaluation and management of injured victims, thereby increasing the chances of timely and appropriate actions.

A mobile remote patient telemonitoring system allows a healthcare provider to continuously monitor a patient's physiological data regardless of the patient's location. The only constraint imposed on the patient's location is that it needs to be covered by a 3G wireless network. Therefore, the telemonitoring system allows the patient to sustain near normal lifestyle, positively impacting the patient's recovery, as well as improving the patient's quality of life.

Such a system includes a small portable hand-held device, such as a mobile phone or personal digital assistant (PDA), which relays the information collected from sensors to the healthcare provider using a 3G-based wireless network.

A wireless telemetry system used in disaster or mass-casualty scenarios can support, control, and monitor patients in relatively large areas by delivering patients' vital signs and medical information to remote medical facilities. Such a system supports the trauma team to effectively treat mass casualty events with limited resources, reducing mortality and morbidity.

Overall, mobile telemedicine systems using 3G networks offer numerous advantages:

- facilitate immediate exchange of information with remote mobile sites such as ambulances;
- enable better utilization of limited healthcare resources (e.g. physician specialists);
- allow patients to remain in their communities and maintain a normal lifestyle;
- reduce the hardships (physical and economic) associated with travel (for patients or physicians);
- enable early diagnosis, intervention, and treatment in certain events (trauma); and
- avoid unnecessary transportation to tertiary care facilities.

Challenges

This section introduces the challenges that face the development of such mobile telemedicine systems using 3G wireless networks. The general design challenges faced by all telemedicine systems such as billing, usability, and regulations, etc., are not dealt with.

Limited and Fluctuant 3G Link

Current commercially available 3G links, such as the Verizon code division multiple access (CDMA) wireless data service, provide data rates of up to 153Kbps. However, the actual throughput of such cellular wireless links is fluctuant, with an average throughput of around 70Kbps. Therefore, the implementation of mobile telemedicine systems over such a link requires special considerations.

Transmission of Bandwidth-hungry Medical Information

System developers should keep in mind the rich nature of the medical information that needs to be transferred from the patient to the healthcare provider. Such data, as well as the operating environment, can be different for various medical scenarios. Many applications may require bandwidth-hungry data such as images or realtime video. The telemedicine systems must manage this data and perform necessary

Yuechun Chu is pursuing a PhD degree in the Department of Electrical and Computer Engineering (ECE) at the University of Massachusetts, Amherst. Her research interests include wireless telemedicine systems, wireless multimedia applications, architectures, and protocols for wireless networks with quality of service (QoS) guarantees and ultra wideband (UWB) networks. She received her MSc degree in electrical engineering from the University of Science and Technology of China in 1999.

Aura Ganz is an Associate Professor and Director of the Multimedia Networks Laboratory at the ECE Department, University of Massachusetts, Amherst. She has published a book, *Multimedia Wireless Networks: Technologies, Standards and QoS*, and authored over 150 peer-reviewed publications. Dr Ganz is a senior member of Institute of Electrical and Electronics Engineers, Inc. (IEEE) and a member of the IEEE Engineering in Medicine and Biology Society (EMBS).

transformations to ensure the smooth transmission through the low-speed and fluctuant 3G link.

Simultaneous Transfer of Different Media Streams

Telemedicine systems often transmit different types of streams simultaneously, such as realtime video, images, vital signs, or other readings from medical sensors. Depending on the medical demands, the transmission requirements for different media types are quite varied. It is critical to establish policies to coordinate, prioritize, and compress the diverse media streams to eliminate distortion of multimedia content or choking of some applications. Such policies are especially important in situations involving the limited and fluctuant bandwidth of 3G links.

Mobile Telemedicine Projects

With the emergence of cellular networks, a number of systems used cellular phones to transfer vital signs (e.g. electrocardiogram (ECG) and heart rate). Some telemedicine systems used PDAs to monitor patients' status. Several projects transmitted critical care medical information, such as multimedia data, over cellular networks.

A wireless telemedicine project was developed for ischemic stroke. The system was based on proprietary hardware that can aggregate and manage simultaneous transmissions of data over multiple cellular lines (2~8 GSM cellular lines), allowing a video transmission rate of around eight frames per minute. The British Lancashire Ambulance project transmitted vital signals over one cell phone line and slow-scan images over another line at frame rates of 15 pictures per minute. The EU's study, AMBULANCE, based on the experience of Telemedicine projects, and its successive projects were able to transmit patients' biosignals or image sequences using available Global System for Mobile communications™ (GSM) phone lines. The results show that their image transmission rate is one image (size 2.5–3KB) every three to five seconds and the percentage of ECG transmission interruption reaches 27%.

The mobile telemedicine projects described above focused on exploiting the possibility of transmitting patient information through commercial wireless links, rather than improving the transmission efficiency. Their usefulness is often limited due to their poor performance in terms of very low frame rates and high interruption rates. Those systems did not tackle the critical issues of limited and constantly changing bandwidth of a 3G wireless network. Such issues severely limit the possibility of transmitting simultaneous transmissions from multiple medical sensors/instruments along with bandwidth-hungry interactive video applications, causing errors and loss of potentially critical information.

Mobile Telemedicine Systems Developed at Multimedia Networks Laboratory

In this section, two mobile telemedicine systems are described that were designed and prototyped in the author's laboratory. In addition to providing solutions to all the challenges posed by 3G wireless networks described above, the development of these systems was guided by the following design guidelines:

- easy-to-use interface – the system should provide simple interfaces for the health provider;
- controllability – the system should support remote control functions. The healthcare provider should be empowered with the ability to control the media content according to medical specialties or his/her personal preference. For example, the health provider is allowed to control ECG sample rate, video frame rate, and image quality, etc.;
- device adaptability – the system should meet the capabilities of the computing device (e.g. laptop, PDA or mobile phone) on which it runs;
- media adaptability – the system should provide support for different medical data, such as vital bio-signals, images, video, and patient information; and
- modular design – the system should have a modular design so that it allows for the development of a roadmap for growth that can accommodate future generations of functionality.

Next, two mobile telemedicine systems are described that were developed in the authors' laboratory – a teletrauma and a telepatient system.

Teletrauma System

The teletrauma system, which effectively delivers trauma-patient information to a remote hospital, comprises two units – trauma-patient unit and hospital unit. The trauma-patient unit, which may reside in an ambulance, is implemented on a laptop or tablet PC. Through connected devices such as vital signs monitoring, portable ultrasound, and video camera, the trauma patient unit collects patient's information, processes it (e.g. compresses the information), and transmits it over 3G wireless link. The information traverses the wireless link as well as the Internet and is delivered to the hospital unit, which is implemented on a PC connected to the Internet. Thus, the

physician has access to visual information such as ECG waveform, medical images, and realtime video.

The hospital unit is implemented on a desktop computer located in the trauma center. After receiving the data from the trauma-patient unit through the Internet, the hospital unit properly presents the vital signals (ECG), medical images, and video to the physician. When receiving the information, the hospital unit decompresses the information according to the media types.

The trauma-patient unit collects the patient information and then multiplexes, transforms, and transmits it to the hospital unit. The system performance bottleneck is determined by the limited data rate of the wireless link. Because the trauma-patient unit transmits multiple multimedia streams over the wireless link, this unit reduces the amount of information by compressing the media before transmission such that the amount of data can fit into the limited wireless link. Because the three media streams are transmitted in parallel, it is inadmissible for one medium to occupy the link and impede the transmission of others. For example, ECG requires a relatively small portion of the bandwidth compared with video and images. However, when ECG is transmitted in parallel with the image and video, these two bandwidth-hungry streams will dominate the link and even cause congestion. To minimize the effect of congestion, different transmission methods are applied to different streams. Reliable transmission control protocol (TCP) is used for ECG and images to guarantee their transmission integrity. Based on video's realtime requirements as well as its tolerance to frame loss (i.e. a few frame losses are usually acceptable to viewers), user datagram protocol (UDP) is considered a suitable transmission protocol. However, because UDP uses simple datagram with no congestion control, a frame rate adjustment policy has been developed.

TelePatient System

The TelePatient system enables healthcare providers to monitor patient's information 24/7. The system uses a PDA as a gateway to the healthcare provider to transmit vital bio-signals as well as medical image files. Additionally, the system allows controllability by the healthcare provider.

The TelePatient system involves two networks – a wireless personal area network that contains the medical data acquisition units and a wireless network for transmission to a healthcare provider. The PDA, henceforth medical digital assistant (MDA), serves as a gateway between these networks. All the medical data collected by the medical acquisition units passes through the MDA to the healthcare provider. The MDA, along with the acquisition modules, form a portable patient area network that can be carried anywhere. The MDA obtains medical data from the medical data acquisition unit and multiplexes, transforms, and transmits the data to the healthcare provider. The MDA is dual-homed, i.e. it has two communication interfaces for the two independent networks. The main challenge facing the MDA design and development is the fact that the CDMA wireless link offers limited and variable bandwidth. Also, it must act on the data to suit the healthcare provider's preferences. However, the PDA platform has constrained resources and this makes the task more difficult. The following modules have been developed at the MDA:

- User Profile – this allows the healthcare provider to tailor TelePatient to particular scenarios.
- Parameter Control – these are healthcare provider controlled parameters, such as changing the ECG measurement frequency.
- ECG/Pulse/SpO2 Module – handles communication with the ECG/Pulse/SpO2 acquisition unit and the healthcare provider.
- Image Module – obtains the image, and suitably transforms the image based on doctor preferences and underlying link, and then sends the resulting transcoded image to the healthcare provider.

At the healthcare provider side, a health provider unit provides an easy interface for doctors to view the medical data, send text messages, and control parameters to acquire medical data.

Summary

3G wireless networks are of great importance for telemedicine due to their broad geographical coverage and widely deployed infrastructure, which significantly expand the telemedicine system's reach. This article has analyzed the challenges faced by the mobile telemedicine systems and provided a number of design guidelines that should be followed by the system designers. Using commercially available 3G wireless data services, two mobile telemedicine systems have been demonstrated that follow the proposed design guidelines. These systems can simultaneously transmit multiple types of medical information using 3G wireless networks. To overcome the most challenging factor of the limited and fluctuant bandwidth of the wireless link, for each system a software architecture that differentiates, prioritizes and transforms the medical data was implemented, such that critical data is delivered reliably, efficiently, and with high quality. ■

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