A Next-Generation Mobile Telemedicine Testbed Based on 3G Cellular Standard

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Abstract

The digital cellular network can play an important role in mobile telemedicine applications. Since the network gradually evolves from the second generation (2G), such as GSM, to the third generation (3G), a testbed based on the 3G cellular standard is proposed for the next-generation mobile telemedicine. The 3G-based testbed (12.2 kbps ~ 2 Mbps) has higher and wider data transmission rates than its 2G version (up to 9.6 kbps). Thus, more medical services can be designed and tested using this new testbed. To demonstrate the usefulness of the testbed, we deign a simple telecardiology system as an example. The experimental results show that the proposed testbed has the potential to evaluate and improve the quality of service (QoS) for mobile medical applications using 3G cellular standard.

1. Introduction

Wireless and mobile telemedicine systems provide a new way for health care delivery. Due to the ubiquity and low cost of the cellular phone, the current second generation (2G) digital cellular network can play an important role in telemedicine applications, where high mobility and low cost are essential [1]. The 2G traffic and the number of users are still increasing. However, its data rate is limited - a single channel data rate with a GSM telephone is 9.6 kbits/s or kbps. To increase the data rate for broader services, the cellular network gradually evolves from 2G to the third generation (3G).

The 3G system can provide mobile users with a high-speed Internet access, video and many other communications services, including a mobile medical service. The International Telecommunication Union Radio Communication Standardization (ITU) has developed a concept known as IMT-2000 (International Mobile Telecommunications – 2000) for 3G systems and called for proposals in radio transmission technology by June 1998. Among all proposals for IMT-2000, wideband-code division multiple access (W-CDMA) is the most promising candidate for 3G wireless access due to its numerous advantages and its state as being standardized in the 3rd Generation Partnership Project (3GPP)[2-5]. For the development of mobile telemedicine, the mobile telemedicine system design based on GSM was recently addressed in [6,7]. However, no study to date has addressed the functionality issues of the 3G-based mobile tele medicine system. These issues will be the main theme of this paper.

The rest of this paper is organized as follows. In Section II, we address the design and modeling issues of the 3G-based telemedicine testbed. In Section III, in order to demonstrate the usefulness of the testbed, we deign a simple telecardiology system as an example and present its simulation results. Finally, a conclusion is given in Section IV.

2. Next-generation mobile telemedicine testbed

A 3G-based mobile telemedicine testbed is shown in Figure 1. The testbed and its related models are simulated using SystemView by ELANIX® software and the associated Entegra's 3G design libraries on a PC-based Pentium III computing environment [8,9]. The detailed description of the system blocks and the associated sub-blocks with relevant simulation modeling details are described in [3-5,9]. Only a brief description of the main design modules is given here for completeness.

The key functions performed in the transmitting path in a 3G signal processing structure are the signal input, channel coding, interleaving, rate matching and modulation. The receiver blocks are essentially the reverse of the transmitter blocks. Since this testbed is based on 3GPP FDD (Frequency Division Duplex) mode standard, its data traffic channel has five rates, 12.2, 64, 144, 384, and 2048 kbps, to be selected according to the required medical service [5,9]. The transmitted medical data include video data, audio signals, medical images, and physiological signals, such as ECG and blood pressure, obtained from the patient in a moving vehicle. This basic 3G-based telemedicine testbed is comprised of the following generic cellular blocks: (1) Data encoder; (2) Transmitter; (3) Cellular channel model; (4) Receiver; and (5) Data decoder. A brief description for each modular block is given next.

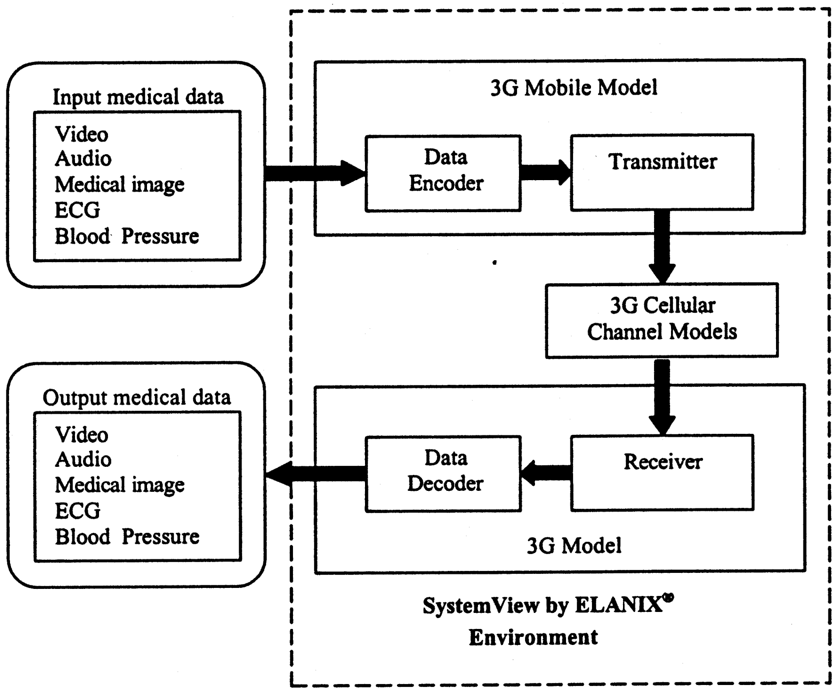

Figure 1. The 3G-based mobile telemedicine testbed.

2.1. Data encoder

This block consists of several subblocks, including channel encoder, rate matching, and interleaving. The medical data sources are digitalized first. The digitalized data can then be compressed if necessary. The resultant bits are channel encoded or multiplexed frame-by-frame and the frame length is 10ms. First, it is attached by CRC (Cyclic Redundancy Check) code for the error check at the receiving end. For channel coding, note that 3GPP systems typically use a 1/2 or 1/3 rate convolution encoder for low rate data, such as audio or vital signal processing, and a 1/3 Turbo encoder for high rate data, such as video data. Next, the inter-fame interleaving is performed, followed by the rate matching. The rate matching is used to match the number of bits to be transmitted to the number of bits allowed for a single frame. The 2nd interleaving performs intra-frame interleaving and the data field is formatted with various overhead fields to create a wideband code-division multiple access (W-CDMA) frame required for the 3GPP FDD mode structure.

2.2. Transmitter

This part includes spreading, scrambling, and modulation. The spreading modulation scheme is the dual channel QPSK. Each mobile unit has a dedicated physical data channel (DPDCH) to deliver traffic data and a dedicated physical control channel (DPCCH) to deliver control data. Two channels are I/Q multiplexed. For data spreading, OVSF (Orthogonal Variable Spreading Factor) and a long or short random scrambling code are used for channelization and scrambling, respectively. The modulated output is a complex envelope signal.

2.3. Cellular channel model

For the complex baseband simulation, besides basic additive white Gaussian noise (AWGN) channel, three optional channel models can be selected to simulate the desired realistic cellular channel conditions such as in urban, rural, outdoor to indoor and pedestrian, or indoor office environments. These models provide several useful static channels derived from the 3GPP standards. For example, the Rayleigh fading channel provides various parameters such as the mobile user velocity and produces a fading channel with complex output for a complex input signal. The moving channel sets up a two-path channel, with the first path fixed and the second path moving in a sinusoidal fashion. The birth-death channel provides a two-path channel where a channel path "dies" and reappears immediately with a new delay [9].

2.4. Receiver

This modeling block is used to despread, descramble and demodulate a 3G signal. For the multipath propagation caused by natural obstacles such as buildings, hills, and so on, it is necessary to use a Rake receiver in order to recover or collect the energy of all paths. Basically, a Rake receiver is a collection of multiple correlation receivers. According to the required system performance, standard 3G design procedures, and the compatibility with medical data specifications, smart adaptive antennas and multiuser detection are options in the 3G standard.

2.5. Data decoder

This block decodes the various fields of channel traffic. Each W-CDMA frame is decoded. The data field of each frame is deinterleaved and the resulting main data field is then rate recovered. The rate recovered data field is deinterleaved again, and then decoded using a convolution decoder with the Viterbi algorithm Next, it is decoded to check frame errors by the CRC decoder, and its CRC attachment is removed. According to the resultant bits from the decoder, the reconstructed medical data or signals can be retrieved.

3. A design example and its results

3.1. An example: Mobile telecardiology

To demonstrate the usefulness of the testbed, we deign a simple telecardiology system as an example. As a basic requirement for the mobile telecardiology system, the ECG signal must be sent from an ambulance or a patient's home to a cardiology expert at a remote site. Thus, in our experiment, several 10-min segments of ECG signals from the MIT/BIH arrhythmia database are sent over the testbed to study the feasibility of the system. Moreover, for the 3G-based testbed itself, we choose 12.2kbps rate as the data traffic of the testbed channel because this should provide enough bandwidth for clinical ECG real-time telemedical transmission. A 1/3 rate convolution encoder/decoder is selected for the ECG data, since the lowest data rate of the 3G channel bandwidth (12.2 kbps) is used.

3.2. Results

In this section, we present the performance results of the mobile telecardioloy system based on the testbed. For the ECG test data in our experiment, Record 100, 101, 111, 117, 200 and 208 from the MIT-BIH arrhythmia database are used. All data are sampled at 360 Hz with 11 bits/sample precision. Typical ECG resultant bits (10-min long) are fed to the transmitter or mobile unit of our mobile telecardiology system. The system performance is evaluated at the receiving end of the testbed under different channel distortion conditions, where only AWGN is considered. The signal-to-noise ratio (SNR) is used to quantify different distortion conditions. Due to the page-length limitation of the paper, only the results of Record 117 are shown below. Given the SNR of 4, 6, 8, and 10 dB, the corresponding bit error rate (BER) performance is shown in Table 1. From Table 1, we found that as SNR increases, the corresponding BER decreases substantially.

Table 1. BER performance for various SNR levels.

SNR (dB)	4	6	8	10
BER	6.51×10^{-2}	8.82×10^{-4}	$<10^{-5}$	$<10^{-5}$

Typical waveforms of the original and the reconstructed ECG signals at the receiver for 4, 6, and 8 dB SNR levels are, respectively, shown in Figure 2. When SNR = 4dB, the ECG signal transmission essentially fails and most portion of the reconstructed signal in Figure 2 (b) is beyond recognition. When SNR = 6 dB, although the major part of ECG signal in Figure 2 (c) is reconstructed normally, a few bit transmission errors do cause the sparse impulse-type noises. It may lead to an erroneous diagnosis and the reconstructed signal can not achieve acceptable clinical or diagnostic quality. At SNR = 8 dB, the BER is less than 10^{-5} and most characteristics of the received ECG waveform in Figure 2 (d), such as P wave, QRS complex, and T wave, can be preserved with good quality. The results for SNR = 10 dB are similar to the 8-dB case. Therefore, given BER < 10^{-5}, the mobile telecardiology testbed shows successful transmission of the ECG data under consideration. The results for other ECG records are similar to the Record 117 case.

4. Conclusion

In this paper, a testbed based on the 3G cellular standard is proposed for the next-generation mobile telemedicine. The testbed is designed and implemented using a commercially available communication system design tool. To demonstrate the usefulness of the testbed, we deign a simple telecardiology system as an example. In our experiment, ECG segments are sent over the testbed to study the feasibility of the system. Given that BER < 10^{-5} at the receiver, most characteristics of the received ECG waveform can be preserved with good quality. However, when SNR = 6 dB, a few bit transmission errors do cause the sparse impulse-type noises, which may lead to an erroneous diagnosis. This

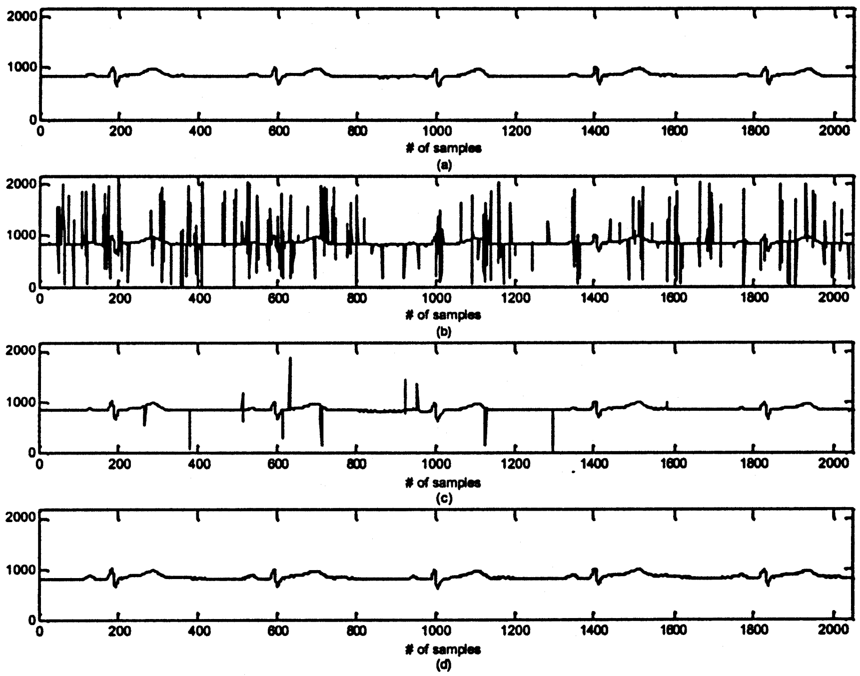

Figure 2. Typical ECG waveforms obtained in the testbed. (a) an original signals; the reconstructed ECG signals of (a) at the receiving end given (b) 4; (c) 6; and (d) 8 dB SNR level.

information is useful for a system designer. For example, he can try to suppress the noises by some post-processing techniques or remove them almost completely by an ARQ (automatic repeat request) technique with an allowable delay. Of course, he can also choose a high enough SNR if the power budget is not a problem.

To sum up, the proposed 3G-based mobile telemedicine testbed has the potential to evaluate and improve the quality of service (QoS) for many mobile medical applications, including the simple telecardiology system discussed in this paper.

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