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Provisioning of Medical Quality of Services for HSDPA and Mobile WiMAX in Healthcare Applications

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***Abstract*—Mobile healthcare, or m-health, is an evolutionary concept that provides both mobility and an 'always connected' healthcare functionality. The development of this concept depends on how best the available bandwidth in (HSDPA/HSUPA) and emerging (Mobile WiMAX) networks can be correlated with the relevant medical quality of services issues. In this paper we address and discuss some of these issues and challenges. We also provide an example of a bandwidth demanding application to verify such provision mechanisms.**

I. INTRODUCTION

In recent years large number of mobile healthcare systems has been applied to different healthcare applications. The concept of mobile healthcare or m-health is originally defined as 'mobile computing, multimedia, medical sensor, and communications technologies for healthcare' [1].

Since, then the research and advancements beyond 3G (4G) domain of emerging wireless and network has not been paralleled with similar pace in the areas of mobile healthcare. In particular, these emerging wireless communications and network technologies need to be further validated and tested especially from the concept of medical quality of services (m-QoS). These issues become paramount in bandwidth demanding medical applications such as real-time ultrasound video streaming systems that 4G systems advocate. The concept of m-QoS is defined as the 'Augmented requirements of critical mobile health care applications with respect to the traditional wireless Quality of Service requirements' [2,3]. In general the provision of end-to-end medical quality-of-service (m-QoS) will become an important factor in future WiMAX and HSDPA/HSUPA network systems and their acceptability for bandwidth demanding mobile healthcare applications. More recently, the IEEE 802.16e (Mobile WiMAX) is such standard that aim to provide broadband connectivity to mobile users in a wireless metropolitan area network (WMAN) environment, especially with the necessary flexibility required for bandwidth demanding healthcare applications. This system has great potential in different mobile healthcare applications that required higher operational data rates, clinically acceptable remote diagnostic quality and potentially cost effective solutions [6].

In this paper we present such application with bandwidth demanding medical diagnostic requirements and study these requirements from the HSDPA and WiMAX connectivity perspectives. It is well known that the advances in real-time medical imaging diagnostic systems correlated with the mobility domain of these emerging network technologies can provide breakthrough solutions to remote medical imaging services with potential and substantial cost savings, efficient healthcare delivery and improved diagnostic accuracy. For example, remote robotic ultrasound and medical imaging is one of the new technologies that can offer such advantages, and provide a suitable platform for medical experts who want to perform skilled diagnosis from expert clinical centre to a remotely located patient. In recent year such examples has been introduced. One such example is the robotic -OTELO (mObile- Tele-Echography using an ultra-Light rObot) system that has been originally developed as a part of an EU-IST funded project [4]. The system is a fully integrated end-to-end mobile tele-echography system for remote population of patients that are not served locally, either temporarily or permanently, by medical ultrasound experts. It comprises a fully portable tele-operated robot allowing a specialist sonographer to perform a real-time robotised tele-echography to remote patients. Fig. 1 shows the main operational blocks of the system over 3.5G /WiMAX communication networks. Further details of this system and related work are described elsewhere [4, 5].

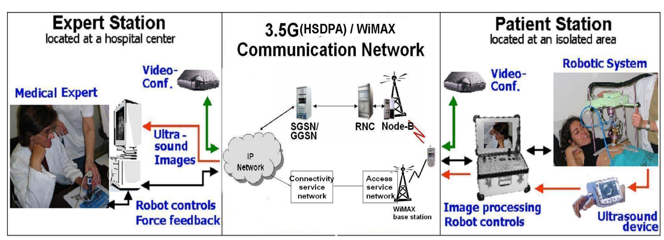

Fig. 1. The OTELO Mobile Robotic System over 3.5G (HSDPA) / WiMAX communication network

This paper is structured as follows; Section 2 we present a summary of the medical quality of service concept and in section 3 we present the architecture and implementation issues with some preliminary results of implementing the concept in simulated HSDPA network and also discuss the application in mobile WiMAX systems. Finally section 4 presents ongoing work in this area and the conclusions of the paper.

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II. Medical Quality of Services and Rate control adaptation

A. Medical Quality of Services

The main quality of service metrics in video streaming environments are summarized in the utilization, packet loss, end-to-end delay and delay jitter.

These QoS metrics need to be guaranteed by the delivering network in order to provide satisfactory wireless multimedia services [6,7]. In order to validate the concept of m-QoS defined above, we assume that for such new category and based on the considered bandwidth demanding m-health application, extra bounds and functional metrics need to be added to the traditional QoS metrics outlined above. Table I shows an example of m-QoS metrics for the teleultrasound streaming application in the OTELO system. The functional bounds reported are specified by earlier clinical evaluation studies of such system , where abdominal ultrasound scanning was considered [5]. The bound on the video quality are reported in terms of the classical peak signal-to-noise ratio (PSNR) metric and in terms of the structural similarity (SSIM) index, a quality assessment method focusing on the structure similarity between the original and the distorted image [8].

The functional bounds described above are specified by the clinical evaluation during the real implementation of the OTELO system [4, 5 & 12].

In order to validate the m-QoS concept we need to address the following wireless QoS issues augmented with the metrics reported in Table I:

1- Utilization: The main two data types that can be transmitted simultaneously by the OTELO Patient station (Figure 1) are the ultrasound streaming data and the robotic control data. However, due to the low generated data rate by the robotic control data of 5-6 kbps, we consider here the Ultrasound streaming data only. To achieve an optimum utilization within the available bandwidth, this data needs to be within the available bandwidth with good link utilization. This is implied in the image quality index and the frame rate metrics shown in table 1. In the rate control algorithm we assume link utilization factor as the constraint of how far we increase or reduce the image quality and the relevant frame rate to occupy the available bandwidth optimally.

2- Packet loss: Transmission impairments, such as packet loss, will impact differently on the medical experts perception depending where the loss occurs within the video clip. Measuring the average packet loss cannot predict the impact on an expert viewer's perception since packet loss can produce a wide range of different qualities [8]. Therefore packet loss effect is implied in the image quality index metrics shown in table 1.

3- End-to-End delay: this is an important issue that is explicitly identified in table 1. In general video streaming applications one-way delay should be < 5s. However for this m-health application the end-to-end delays (two-ways) should be < 350 ms.

4- Delay jitter: This is implicitly implied in the arriving frame rate metrics above in table 1. The recommended delay jitter for normal video streaming applications is within 2 s. This is also acceptable for the current medical platform.

B. Q-USR Control Algorithm

In order to match the resulting data rate with the network available bandwidth, there must be a trade off between the m-QoS requirements. Rate control can be used to control sending rate of the ultrasound data in a way that satisfy both the network requirements in terms of the available bandwidth and satisfy the medical QoS requirements. It should be noted that different network technologies might implement rate control in different levels, such as hop-to-hop level or network level. Nevertheless, for inter-networks involving multiple networking technologies, it is common to rely on rate control performed by the end-hosts application layer [9].

TABLE I
MEDICAL QUALITY OF SERVICE (M-QOS) FOR A MOBILE ROBOTICS TELE-ULTRASONOGRAPHY SYSTEM (OTELO)

m-QoS metrics	Functional bounds
Image quality (PSNR) – QCIF 176X144	> 36 dB
CIF 352X288	> 35 dB
Structural SIMilarity (SSIM) Quality Index	> 0.9
Frame Rate – QCIF 176X144	> 5 fps
CIF 352X288	> 7 fps
End-to-End Delay	< 350 ms

In this paper we use the Q-USR rate control algorithm, introduced in earlier work by the authors [3]. The rate control policy of wireless video streaming is regarded in this algorithm as a discrete-time MDP problem. The congestion in the network would trigger the transition of the system state such that the rate controller of the video streaming is executed. The congestion in the network is sensed via the encoder buffer occupancy as shown in Fig. 2. Network congestion will trigger the transition in the system state (buffer state).

As shown in Fig 3, the feedback information that the (Q-USR) controller requires is the channel rate (CR), the Arrival Frame Rate (AFR) and the image Quality Index (QI). In this case we use the Peak Signal to Noise Ratio (PSNR) as the quality evaluation index. The feedback information is received by the network feedback analysis block and fed the output CR to the encoder buffer management in order to calculate the buffer occupancy (*Bo*) which will be used as the state of the environment in Q-USR control algorithm. The (AFR) and the (QI) parameter are used by the Q-USR block as rewards to obtain the resultant optimal actions that will be used by the encoder to adapt its rate. The encoded image streams pass through the encoder buffer and then packetized and delivered via UDP transport protocol to the lower IP based layers.

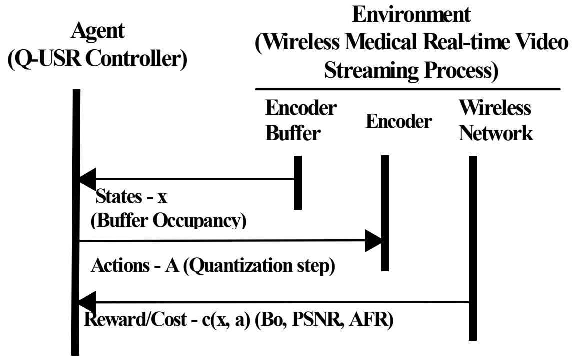

Fig. 2. Architecture of the (Q-USR) algorithm in the application layer on a mobile network.

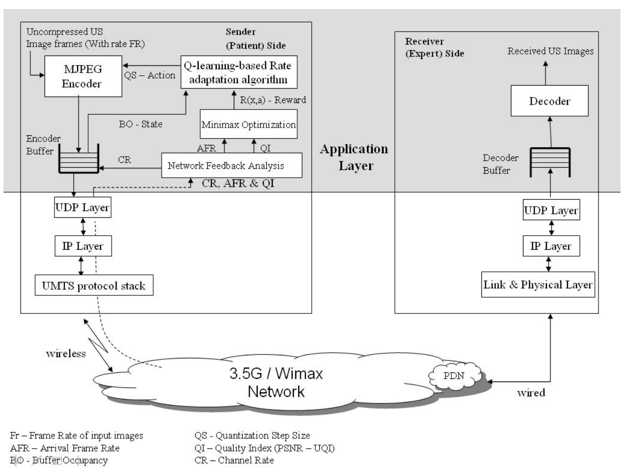

Fig. 3. shows the Q-USR algorithm and state model. It shows the timing sequence between the Q-learning controller and the wireless medical video-streaming environment in terms of the states, the actions and relevant reward.

III. Implementation and Results

A mobile experimental test bench is designed and developed to measure the End-to-End m-QoS system performance when transmitting the ultrasound image streams under the Q-USR controller functionality as described in section II. The relevant interface software and algorithmic implementation was carried out using LabVIEW^{TM} and MATLAB^{TM}. The HSDPA network connectivity using the Vodafone/UK system was used for the experimental data transmission with a data rate of 1.8 Mbps on the downlink and 384 kbps in the uplink. The experimental ultrasound scanner data stream used is at a rate of 13 fps and resolutions of QCIF (176X144) pixels, which has been acquired using a video card and fed to the laptop at the patient station. The acquired images were encoded using H.264 encoder based on the JM 12.3 AVC test model software. However, due to the mismatch between the generated rate at the encoder/decoder and the available communication bandwidth we use the encoder/decoder buffer management's structure, as shown in Fig. 3. The buffer size (Bs) is assumed to be twice the average frame size. With this implementation of encoder buffer model, we ensure that decoder buffer underflow will not occur, since it occurs when all the bits corresponding to a given frame are not present in time to be decoded.

Since the channel capacity depends on the number of users, the experimental tests were carried out at different real 3.5G network loading conditions especially at peak working hours. Fig. 4 shows the average throughput of the ultrasound stream (US) captured from the expert (robotic) end. This average throughput is achieved by transmitting ultrasound image streams with a PSNR of (37.75 dB) and an average frame rate (9.3 fps). Fig. 4. shows that generally the average throughput was approximately 62 kbps. These results are within the minimum m-QoS requirement for the OTELO system given in table 1.

Fig. 5. Indicates that the achieved data rate (for PSNR of 37.75 dB and frame rate of 9.3 fps) is within the bandwidth capability of the uplink 3.5G link of approximately of 360 kbps. The experiments to test the 3.5G uplink bandwidth capability were done by continuous uploading of files with large sizes and measuring the average throughput achieved at the receiver.

The Q-USR controller adapts the sending rate according to the available bandwidth. In this work the available bandwidth was measured based on measuring the average throughput for the ultrasound stream over time at the receiver using the bottleneck capacity estimation described in [10]. The measurement of this average throughput is then sent from the expert station to the patient station. At the patient station the current average throughput is predicted via Linear Predictive Coding (LPC).

Fig 6 shows the delta time (time difference between two consecutive packets) of the received ultrasound image stream. The packet size used for the packetization of the ultrasound images is 300 Bytes the number of packet used for this analysis is 300 packets. Form Fig 6 the average delta time can be calculated as 0.12 sec with standard deviation of 0.063.

The time delay for the expert side to request the ultrasound images are measured at 0.07sec, which was based on the transmission of 16 Byte robotic control data. The average time for the packet to reach the expert end is 0.12±0.063 sec. Therefore, the total End-to-End time delay of the system can be calculated as 0.253 sec which is within the acceptable medical requirements for robotic diagnostic quality that are quantified by 0.350 sec, as shown in table 1.

The delay variation (Jitter) across this system's link is considered a key factor for the reliable real-time medical ultrasound stream reception at the Expert station. As shown in Fig. 6 the average delay jitter is 0.063 (which is the standard deviation of the delta time).

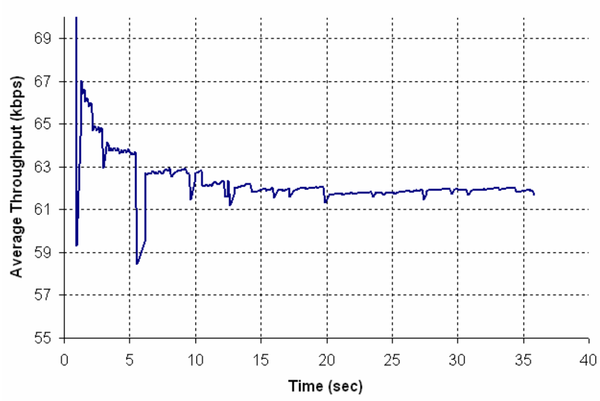

Fig. 4. Average 3.5G throughput of the received ultrasound streams at PSNR (37.75dB) and Frame rate of (9.3 fps).

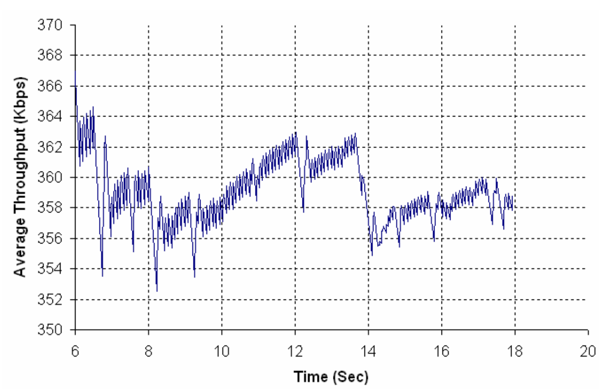

Fig. 5 The 3.5G-uplink bandwidth capability.

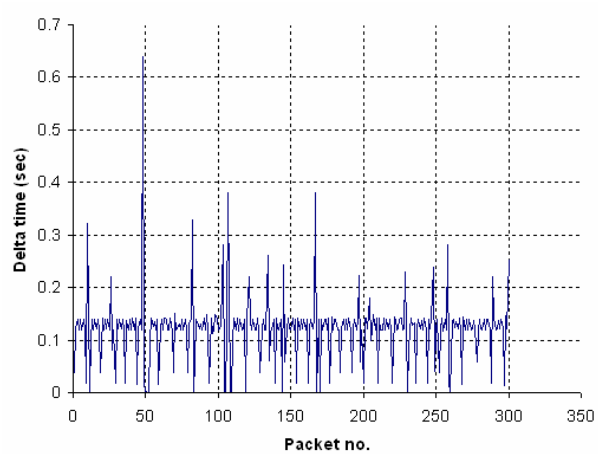

Fig. 6. Performance of the packet delay at the Expert end.

Ongoing work is currently underway to test the same experimental set-up and algorithmic approach for the IEEE 802.16e Mobile WiMAX test network. The preliminary results show the successful implementation of such algorithmic approach in both network architectures. Similar results where obtained using IEEE 802.16e system connectivity. The worst case scenario is considered when the user is at the cell edge. For example, the cell edge rate is expected to achieve 1-2 Mb/s for downlink and 300-400 kb/s for the uplink [11]. Further studies are also underway to further test and integrate the subjective and objective medical imaging quality measures of earlier work [12] with the current proposed optimized rate control strategy and the proposed network connectivity architectures.

IV. Conclusion and Future Work

In this paper we presented some of the provision issues of medical quality of services and their implementation issues in emerging HSDPA and the potential implementation of mobile WiMAX healthcare networks. The experimental results has shown the successful implementation of the Q-USR control algorithmic approach presented earlier for a bandwidth demanding medical ultrasound streaming application. Further work is currently ongoing to design and test these concepts for comparative HSUPA/ m-WiMAX networks and their comparative performance analysis issues.

The need to tailor made encoding and compression standards for such medical applications that can provide higher quality of service issues are also ongoing.

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