3G Mobile Communications For Wireless Tele-Echography Robotic System

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ABSTRACT

A 3G wireless solution for the OTELO system—a wireless tele-echography robotic system is introduced in this paper. Based on the analysis and understanding of the OTELO functional modalities, the IP Multimedia Subsystem (IMS) is introduced in the 3G wireless solution to the OTELO system. The OTELO system architecture identified for OTELO functional modality is illustrated. Quality of Service (QoS) issues for tele-robotic control and tele-echography image transmission are also discussed.

Keywords: 3G mobile communications system; tele-echography; tele-robotic; mobile telemedicine

1. INTRODUCTION

It is well known that ultrasound echography is a popular easy-use non-invasive method for routine examinations in hospital in different diagnostic settings. Ultrasound imaging in Medicine can be used to evaluate the degree of emergency for patients. However the main drawback of current ultrasound techniques is that the quality of the examination highly depends on the operator's specialised skills, skills that are lacking in most health centres, especially in many small medical centres, isolated sites, or rescue vehicles. In some cases, no appropriate well-trained sonographer can be found to perform the first ultrasound echography from which the emergency level can be evaluated[1].

Because of this concern, a fully integrated end-to-end mobile tele-echography system that will bring population groups preventive care support is studied and developed in the OTELO† project. OTELO is a dedicated, portable ultrasound probe holder robotic system, associated with new communication technologies, which will reproduce from afar the expert's hand movements during an ultrasound examination. Although being manipulated by a non-specialist on the remote site, the slave system will bring, in real time, good image quality back to the expert site, where force feedback control will be combined with virtual reality for the rendering of the distant environment.

As the Third generation (3G) mobile radio networks like Universal Mobile telecommunications System (UMTS) is now being launched, and will support bit rates of up to 144kbit/s in rural areas, 384kbit/s in hotspots and up to 2Mbit/s in indoor scenarios that is much higher than presently available in second-generation cellular systems, UMTS is considered as a wireless communication solution for OTELO system, see Ref[1] and the reference therein. In comparison with satellite or ISDN, 3G wireless communication technology can provide a cheaper and more convenient mobile medical service for the OTELO system[2].

In this paper, the user and medical service functional requirements for OTELO wireless communication system are described in section 2. The OTELO UMTS wireless structure identified for OTELO functional modality is illustrated and QoS issues for OTELO medical service is discussed in section 3. Future research issues are also described in section 4.

2. OTELO FUNCTIONAL MODALITIES

The operation of OTELO system is subdivided into the following functional modalities:

2.1 Medical diagnostic Procedure

In the OTELO system, a medical consultation session starts by the medical expert at the master site communicating in video and voice format with the remote patient at the isolated slave site. The expert may also adopt wired (ISDN,
ADSL or LAN) or wireless access (UTRAN) means if available.

During this phase, the correct positioning of the probe by voice comments to the isolated operator is first calibrated, and the probe will be allocated in parallel to the robot main axis (perpendicular to the skin) that is used as the reference position to start moving the robot.

As soon as the probe is well located the “video conference image” can be interrupted and the isolated slave station sends the first echo images (real time high resolution sequences). The following sequential scenario’s can then be used:

1) If as expected the organ to be visualised appears on the echo image, the expert switches to high resolution echo images and uses the distant robot to adjust the probe orientation on the patient and to find the appropriate incidence needed for the diagnosis.

2) If the desired organ does not appear on the image, the expert asks the operator to translate the probe holder system (“left, right, up, down”) without patient-probe video control until the expected organ appears on the echo view. Then he continues the sequence as described above.

3) If the image of the organ cannot be reached by the previous translations, the expert will asks the assistant at the slave station to reposition the probe via the video conference system (back to the beginning of the sequence).

All views (real time dynamic sequences) will be stored at the master station (namely, expert centre) first, and then the expert can determine if the images need to be stored on the image data server, which is located somewhere on the internet or intranet, for either on-line or off-line co-operative work with other medical experts.

2.2 Robot Real Time Controls

Since the change in orientation of the robot probe must be done in a continuous mode, and the velocity of these movements must be adjustable from the operating centre, the robot feedback control data is very sensitive to time delay. Current research shows that a time delay of less than 20ms is acceptable for the teleoperation of a robot over the Internet[3]. It is important to promise a constant data rate for robot feedback control, if the robot control data is sharing the bandwidth with other types of data, such as videoconferencing images, etc. about 50% of the connection bandwidth should be assigned to robot control to keep the control loop active.

In comparison with TCP, connectionless protocols such as UDP, RTP (Real Time Protocol) or E-UDP (Enhanced UDP) are suggested for adoption to provide quicker and safer data delivery.

2.3 Ultrasound Images

Echographic images coded with DICOM (Digital Imaging & Communications in Medicine) standard as well as JPEG-LS, JPEG-2000 will be used in OTELO. The size of the medical images varies from 256x256 pixels up to 512x512 pixels while the gray level of each pixel can be saved up to 16 bits. The lowest data rate acceptable to medical experts is 210kb/s.

During the beginning of the examination, when the expert is searching for a specific examination area (liver, kidney...), a high quality ultrasound image sequence is not required. An image with 20 gray levels could be sufficient at this stage to ensure that the received images can be considered to be of acceptable quality by the expert.

During the second phase of examination, when the organ of interest has been found (e.g. heart observation), sequences of high-resolution ultrasound images will be needed. It is then necessary to consider reversible compression techniques (e.g. Wavelets-LZH) that would bring high quality images to the expert.

As the ultrasound images are mostly transferred from the robot probe or image data server to the master, an asymmetric channel is applicable.

2.4 Ambient Information

This information mainly deals with the ambient video and audio information and patient’s reflex and video feedback to the OTELO video operation during the medical diagnosis procedure.

The time delay between the slave probe motion (remote controlled probe) and the reception of the video image from the slave station at the expert centre should be as close as possible to 300 ms. The suggested frame rate for video transmission is 15 frame/s to minimum 1 frame/s. Color or B/W video will be chosen in transmission.

Interactive compression standards, H.263 or MPEG-4 will be used to transmit the real-time video. (MPEG-4 coding involves nearly 5sec delay although providing good quality image).
3. UMTS WIRELESS COMMUNICATION SOLUTION FOR OTELO SYSTEM

3.1 System Architecture

In this section, a UMTS mobile communication solution is proposed to provide the OTELO medical service with appropriate QoS. The IP Multimedia Subsystem (IMS), which has recently been developed in UMTS release R5[4] as an extension to the existing Circuit Switched (CS) and Packet Switched (PS) domains, is introduced in the solution to support the OTELO medical service. The configuration of the system entities, which consists of mobile terminal, UTRAN radio access network, GPRS evolved core network, the specific functional elements of the IP Multimedia Core Network (IM CN) subsystem, and OTELO application server (OTAS), is illustrated in Figure 1.

The medical service offered by the OTELO system is a value-added service (VAS) for the mobile network operator. The OTELO Application Server (OTAS) is the main element to control this medical service via S-CSCF, especially for the QoS control while transferring the OTELO data package.

The Internet is a conglomeration of networks utilizing a common set of protocols. IP protocols are defined in the relevant IETF STD specifications and RFCs. The networks’ topologies may be based on LANs (e.g. Ethernet), Point to Point leased lines, PSTN, ISDN, X.25 or WANs using switched technology (e.g. SMDS, ATM)[5]. The OTELO Medical Data Server (OMDS) in the Internet Network is a medical database that stores the ultrasound medical images, patient profiles and other relevant medical data.

CSCF is in charge of session handling and mobility management. It delegates the service control on behalf of the mobile end-user through a single IP Multimedia Service Control (ISC) interface to OTAS and is comprised of three main areas[4]:

- The S_CSCF (Serving CSCF) is the main point for session control within the home network. It holds user data (downloaded from the HSS), terminates the call/session signaling from the mobile terminal (Ue) and interacts with the applications and services area via the ISC interface.
- The I_CSCF (Interrogating CSCF) interrogates the HSS during mobile terminated communications setup, to determine the S_CSCF catering for the mobile
- The P_CSCF (Proxy CSCF) is closely linked to the GGSN and performs bridging of the signaling between the terminal (Ue) and the S_CSCF, the proxy is also involved with bearer confirmation, decision, policy and charging aspects during the session.

The network’s central database Home Subscriber Server (HSS) is an evolution of HLR with the inclusion of additional user data to cater for the IM aspects, and provides subscription and mobility data to the service control entity CSCF and also supplies information for the SGSN.

The IM Media Gateway (IM-MGW) acts in similar way to the circuit switched area, providing the transcoders and interconnection with legacy networks PSTN. As with the OTELO system, the medical expert may also communicate via ISDN, IM-MGW is necessary in this situation.

The MGCF is applied in the same way as for wired VoIP networks in providing IP specific call/session signaling to legacy network signaling conversion (e.g. SIP to ISUP).

Figure 1. System architecture of the UMTS wireless communication solution for OTELO system (bold lines: interfaces supporting user traffic; dashed lines: interfaces supporting only signaling; twin lines: reference point)

Here, the OTELO Master Station could link from either the
IP Multimedia Network or from ISDN/ADSL or UTRAN. Figure 1 only illustrates the situation where it links from the IP Multimedia Network.

As the ultrasound images are mostly transferred from the robot probe to the OTELO Master Station, the air Interface Uu between the OTELO Slave Station and the RNC bears an asymmetric traffic load. The ultrasound image, ambient video & audio steam and robotic control feedback data are transferred over the uplink channel, while only the latter three types of data are transmitted over the downlink channel.

3.2 QoS Issues for OTELO Medical Service

The UMTS R5 architecture is a layered architecture with a clean split between bearer (e.g. SGSN, GGSN), session (e.g. P-CSCF, S-CSCF) and service level. UMTS QoS is based on hierarchical bearer layers, as

![QoS Architecture of UMTS](image)

Table 1: UMTS QoS classes[6]

<table>
<thead>
<tr>
<th>Traffic class</th>
<th>Conversational class</th>
<th>Streaming class</th>
<th>Interactive class</th>
<th>Background class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conversational RT</td>
<td>Streaming RT</td>
<td>Interactive best effort</td>
<td>Background best effort</td>
</tr>
<tr>
<td>Fundamental characteristics</td>
<td>Preserve time relation (variation) between information entities of the stream</td>
<td>Preserve time relation (variation) between information entities of the stream</td>
<td>Request response pattern</td>
<td>Destination is not expecting the data within a certain time</td>
</tr>
<tr>
<td>Example of the application</td>
<td>voice</td>
<td>streaming video</td>
<td>Web browsing</td>
<td>background download of emails</td>
</tr>
</tbody>
</table>

RSVP protocol is used to signal the requested IP QoS end-to-end from a client to a router network and further to a remote host. The request is per flow and therefore it is claimed to be poorly scalable for backbone networks. The reservation is done separately for upstream and downstream directions with Path and Resv messages. The Path message is sent from the sender and it includes the traffic characteristics. The Resv message is sent from the receiver and it makes the actual resource reservations along the path.

As we mentioned above, the OTELO Master Station may either link from the IP Multimedia Network or through the ISDN/ADSL or through UTRAN.

The situation in which a laptop at the master side connects to the Slave Station using RVSP is a typical example of end-to-end QoS scenario 4 that 3GPP specified. (Scenario 4: IP Bearer Service Manager in the User Equipment, end-to-end QoS with IP layer signaling, Gateway GPRS Support Node is RSVP aware.) RSVP here is used to signal end-to-end the required QoS and is sent over the radio interface[7].

For the end-to-end scenario in which both the OTELO master station and slave station access through UTRAN, no end-to-end RSVP solution is available in 3GPP, at least so far. This is primarily because RSVP would introduce an overhead on the radio interface, and raises scalability problems when used in backbones both in terms of bandwidth and processing power. In this scenario, to provide quality control for OTELO medical service there is a need to involve the session layer (SIP/SDP) and coordinate bearer and session layer. The way to setup the session is based on the principles of interleaving session and bearer level signaling. Since this scenario is not foreseen to occur frequently, we leave the discussion to later papers.

### 4. FUTURE RESEARCH DIRECTIONS

In order to evaluate the proposed UMTS wireless solution for the OTELO system, and find the cheapest and most convenient communication solution among 3G mobile
communications, satellite communication and fixed wired ISDN, the following studies should be carried on:

1). Software simulation and performance evaluation of the Uu air interface with asymmetric traffic overload added to its uplink and downlink channel
2). Elaboration of the proposed UMTS wireless solution OTELO system to determine the final system architecture
3). Analysis of system communication time delay, and optimal method for tele-robotic control
4). Software simulation and QoS model evaluation of the 3G OTELO system

5. CONCLUSIONS

Due to the increasing popularity of ultrasound with GPs and the setting up of a peripatetic radiographer-based community services by many hospitals, the movement of using modern information technology to provide ultrasound services via wireless link, both in real-time and stationary mode, between primary care clinicians and specialists at some distances from each other is assured.

This paper proposed an UMTS wireless solution for OTELO system, an end-to-end tele-echography system that integrated a dedicated portable ultrasound probe holder robotic system with new wireless communication technologies. Based on the analysis and understanding of the user and medical service functional requirements, the IMS is introduced in the solution to support the OTELO medical service. The OTELO UMTS wireless structure identified for OTELO functional modality is illustrated, and end-to-end QoS control for tele-robotic control and tele-echography image transmission are discussed. The ongoing work is currently underway to implement the system using the Vodafone 3G testing network in UK.

6. REFERENCES

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