J. Biomed. Eng. Res.
Vol.26, No.5, 301-307, 2005

Telemedicine for Real-Time Multi-Consultation

Hye J. Chun[1], HY Youn[1], Sun K. Yoo[1,2,3]

[1] Dept of Medical Engineering, Yonsei Univ. College of Medicine, Seoul Korea,
[2] Center for Emergency Medical Infprmatics, Yonsei Univ., Seoul Korea
[3]Human Identification Research Center, Yonsei University, Seoul Korea
(Received June 22, 2005. Accepted August 11, 2005)

Abstract: We introduce a new multimedia telemedicine system which is called Telemedicine for Real-time Emergency Multi-consultation(TREM), based on multiple connection between medical specialists. Due to the subdivision of medical specialties, the existing one-to-one telemedicine system needs be modified to a simultaneous multi-consulting system. To facilitate the consultation the designed system includes following modules: high-quality video, video conferencing, bio-signal transmission, and file transmission. In order to enhance the operability of the system in different network environment, we made it possible for the user to choose appropriate data acquisition sources of multimedia data and video resolutions. We have tested this system set up in three different places: emergency room, radiologist's office, and surgeon's office. All three communicating systems were successful in making connections with the multi-consultation center to exchange data simultaneously in real-time.

Key words: Multi-connection, Multimedia telemedicine, Simultaneous data sharing, Multi-consultation

INTRODUCTION

Many kinds of telemedicine system supporting multimedia data are being developed with the advance of computers and communication technology. Some of the examples of multimedia telemedicine system are: 1) a web-based telemedicine system supporting the transmission and display of video and still image data of a patient [1] and 2) a multipurpose health care telemedicine system supporting those of bio-signals and still images [2]. The former system was tested on the Internet and the latter system was tested through GSM, satellite links, and POTS (Plain Old Telephony System). Likewise current researches on multimedia telemedicine systems focus on a one-to-one communication between a doctor and a patient in different kinds of network environment.

However, due to the subdivision of medical specialties, an expert consultation from more than one medical doctor is required for a proper treatment of a patient.

This study was supported by a grant of the Korea Health 21 R&D Project, Ministry of Health & Welfare, Republic of Korea (02-PJ3-PG6-EV08-0001).
Corresponding Author: Sun K. Yoo, Ph.D.
Dept. of Medical Engineering, Yonsei University College of Medicine, Sudaemoon-Gu Shinchon-Dong, 134, Seoul, 120-752, Korea
Tel. 82-2-2228-1919 Fax. 82-2-363-9923
E-mail. sunkyoo@yumc.yonsei.ac.kr

Under a serious emergency situation, the emergency medical technician has difficulty in taking care of the patient alone. An advice from a corresponding subspecialist is needed for a pertinent treatment. Since all the needed subspecialists cannot be available in the emergency room all the time, a multimedia telemedicine system based on a multiple connection can be used effectively to realize the multi-consultation between the medical specialists. The existing telemedical diagnosis service is usually one to one based and this does not allow more than two surgeons to diagnose the patients at the same time, and hence it is not efficient in an emergency situation.

In this paper, we present a multimedia telemedicine system using multiple connections to provide the mutual consultation of the subspecialists. The system is implemented to enable the simultaneous sharing of the patient's multimedia data. Therefore the synchronization of the multimedia data is considered most important when designing the system. For the synchronization of the data, we minimized the data transmission delay by letting the user to choose appropriate data sources, compression methods, video frame rate, and video resolution. Also, a clinical experiment was performed to show the efficacy of the system in a real medical environment. We set up the system at Shinchon Severance Hospital's emergency room, the office of radiologist and surgeon to experiment the efficient communication of the three subspecialists in diagnosing the emergency patient.

MATERIAL & METHOD

Hardware

TREM (Telemedicine for Real-Time Multi-Consultation) system consists of two major terminals: patient's terminal and monitor's terminal. A computer in patient's terminal acquires the multimedia data and transmits them in demanded format depending on the network bandwidth supported. Computers in monitor's terminals receive the transmitted data and decode the data to display them on the screen. Pentium-IV with 512 Mbytes RAM and 2.4 GHz clock is used as the transmitting computer in the patient's terminal. The external units interface to the transmitting computer through the PC add-on-boards and interface connectors; RS-232C, USB, and PCI. A desktop PC was used in wired network condition for monitor's terminal, and a notebook computer was used in wireless network to make use of the mobility. The asymmetrical hardware complexity where the patient's terminal is more complex than the monitor's terminal because all the external equipments are needed at the patient's site, while only a computer connected to the network is required at monitor's site for consultation [2]. This asymmetrical hardware complexity is an advantage to a system with multiple receivers.

In the system, there is an additional terminal named multi-consultation center (MCC). It functions as a router, which sends patient's data to the member of the consultation group. In order to join the multi-consultation, the patient or the medical specialist must make a connection with the MCC. The MCC will gather the data needed for the consultation and send them to the consultation group members. Other than the simple transmission of received data, MCC performs a negotiation between the data quality and the transmission delay according to a given network bandwidth. Specific process of the negotiation is described in the next section.

The full-quality camera (VCC-4: Canon Co.) captures the motion video with the user-selective spatial and temporal resolution through video capture board (ATI Radeon 9000, ATI Technologies Co, Canada) with PCI interface.

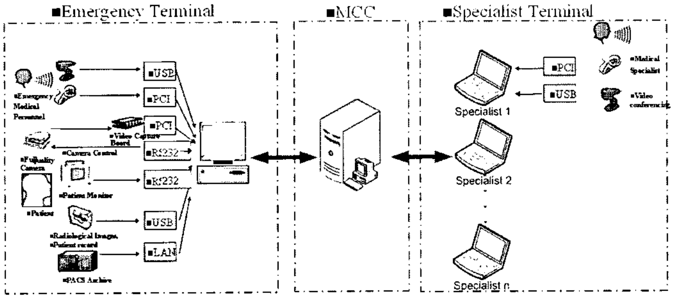

Fig. 1. Hardware Architecture

The dedicated device (KTMED Co.), specially designed to acquire bio-signals from the patient monitor, transmits measured patient data using wireless RF transmitter. The RF receiver converts analog data to digitized data and transfers them to the terminal computer through RS-232 serial interface. It samples the bio-signals (ECG, BP, respiration, and SpO_2) with 300 Hz and 12 bits resolution, and acquires the text string every 30 seconds for other bio-data (SpO_2 value, temperature, systolic pressure, diastolic pressure, and heart rate). The LAN (Local Area Network) card (100 Mbps Ethernet) through PCI interface or the WLAN (Wireless LAN) card (11Mbps) makes the connection with either the PACS network or the WAN (Wide Area Network).

Software

The software configuration is based on the realization of multi-consultation over network. Windows Socket 2.2 is used to construct the API function for socket communication. Visual C++ 6.0 is used to design the software modules of TREM as COM (Component Object Module) objects. The modules control and display audio/video streaming data using DirectX framework (including DirectShow and DirectDraw).

Multi-Consultation Center (MCC)

MCC functions as a router during the operation of the TREM system. Computers in patient's terminal or monitor's terminal must make a connection with MCC if they want to join the consultation. MCC will receive the data from a patient's side and transmit them to the monitor's side. Besides transferring of the data, MCC performs a specific function as a negotiator. When a terminal makes a connection with MCC, MCC checks the available network bandwidth between them and adjusts the appropriate video resolution and frame rate (Fig 3(a)). This is to realize the synchronization of the multimedia data at best effort. By using appropriate data format chosen according to available network bandwidth, we can minimize the delay that can be fatal in a patient treatment.

In the transmission source, video resolutions and frame rates supported by the video acquisition source is enumerated so that after MCC checks the network bandwidth it can choose the parameters among the enumerated values (Fig 2). The enumerated values are sent to MCC and stored in a form of table with the corresponding network bandwidth. MCC searches the table and send the parameters appropriate for the bandwidth to the source application, using message.

After finishing such parameter setting process, MCC will receive the patient's multimedia data of the adjusted format from patient's terminal and transmit them to the monitor's terminals. MCC can also show the state of the connected or unconnected terminals as shown in Fig. 3(b).

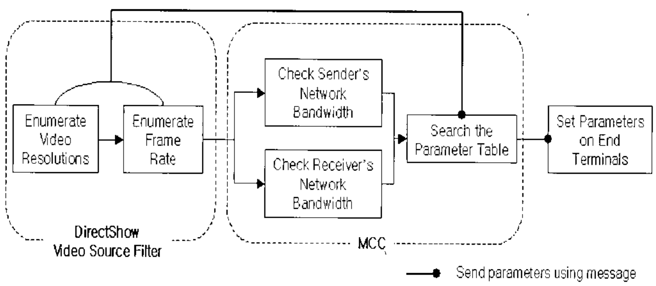

Fig. 2. Function of MCC (Multi-Consultation Center)

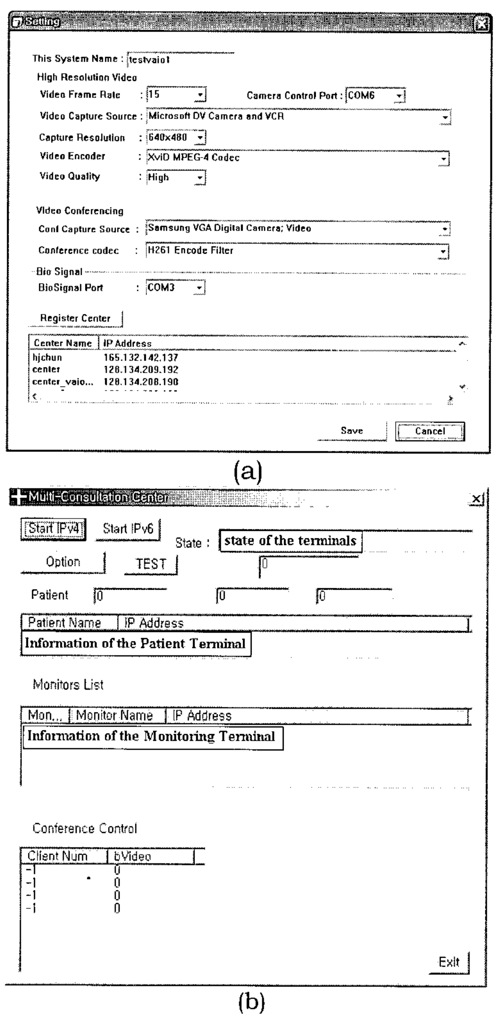

Fig. 3. (a) Selecting Data Format, (b) MCC

Communicating Terminals

Both the patient and monitor's terminals display four modules: high quality video, video conferencing, biological signal, and radiological image. Patient's terminal acquires the multimedia data of a patient to display and transmit them to MCC at the same time. Monitor's terminal receives the data from MCC and displays them on the screen. When exchanging data through MCC both terminals can select which data acquisition source, compression method, video frame rate, and video resolution they are going to use (Fig. 3). Before choosing any parameters, MCC will check the available network bandwidth between the end terminal and MCC as described in the previous section. Using these formats, multimedia data can be captured and compressed to compromise the network bandwidth.

Test Network Configuration

When a medical specialist is away from the hospital, he or she is most likely to use one of the high-speed Internet connections in order to be connected to the hospital's local network. Therefore we chose ADSL (asymmetrical DSL) and VDSL (high-data-rate DSL), two major high-speed Internet connections deployed in Korean housing segments, as the test network of the designed system. In addition, to verify the system mobility, we tested the performance of TREM when using wireless LAN (WLAN) based on the IEEE 802.11b standard (Fig. 4).

In the aspect of mobility WLAN is located between the 3G CDMA service and the wired broadband service, enabling easy and high-speed Internet access through a notebook PC or PDA. Also besides public WLAN, home WLAN service is very promising since Korea has a sufficient number of houses wired to high-speed Internet. Table 1 shows the properties of the tested network services.

Table 1. Properties of Broadband Services

Network Connection	Maximum Speed (down/up)	Main Target Area
ADSL	2~8 Mbps / 640 kbps	Housing Areas
VDSL	13~50 Mbps / 3~13 Mbps	Apartment Complexes
WLAN	11Mbps	Home, Hotspot, SOHO

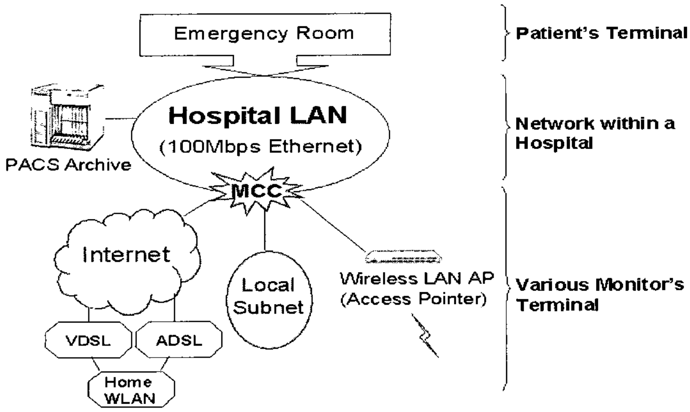

Fig. 4. Test Network Configuration

Experiment

Technical Experiment

The technical experiment of TREM was constructed to make a connection between three terminals using different kinds of test networks (Fig. 5.). The system for monitor's terminal was set up in three different computers for each location, and MCC was set up in a notebook computer near the patient. These four systems were connected using ADSL, VDSL, and WLAN each supporting the maximum speed of Table 1. We used MPEG-4 and H.261 for the compression of high quality video data and video conferencing data respectively. The spatial resolution of the high quality video was fixed in 640×480, and the frame rate varied from 5 frames/sec to 30 frames/sec.

The amount of high quality video data being transmitted per second was measured in four different frame rates. With this parameter we can adjust the appropriate frame rate depending on the available network bandwidth of the given network. [3,4]. Also, we measured the delay time of the high-quality video display in different spatial and temporal resolutions. This delay time includes encoding, transmission, and decoding process of the video data. By measuring this parameter we can check the synchronization of the multimedia data shared among the communicating terminals. The delay in bio-signal transmission is ignorable since TREM has a special buffering management scheme for signal display. It is designed to give a fixed amount of intentional delay so that the signal can be displayed without any stop or disconnection. Therefore regardless of the transmission delay, the signal will be displayed evenly. Unlike the signal data, video synchronization depends on the encoding/decoding process, thus by adjusting spatial/temporal resolution of the video data we can control the delay of the video display.

Clinical Experiment

To show the clinical operability TREM was tested in examining two patients: a patient with a penetrating injury in cranium and a patient with deteriorated mentation. In such examination a multi-consultation from a radiologist, a neurosurgeon, and an emergency physician is required for a pertinent treatment of a patient. TREM was set up in the emergency room of Shinchon Severance Hospital, the office of a radiologist and a neurosurgeon to diagnose emergency patients.

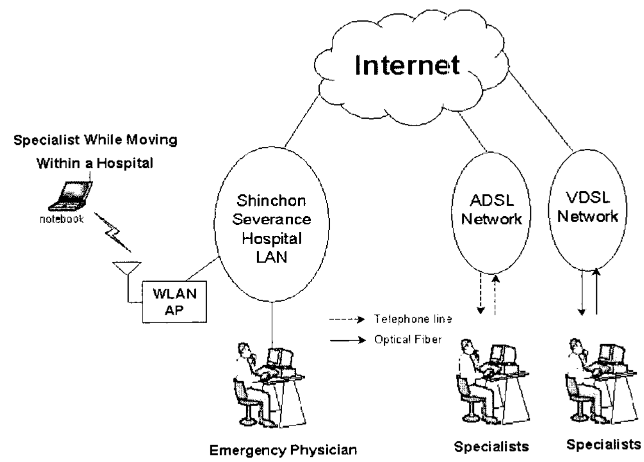

Fig. 5. Testing Environment in Shinchon Severance Hospital

RESULTS

Technical Result

Before performing any experiment using commercial high-speed Internet connections, we checked the actual average speed of each network. We mainly checked the speed between 17:00 and 24:00 since during this time of the day most specialists are away from the hospital and likely to use commercial high-speed Internet to be connected to TREM. The result is as shown in Table 2.

From Table 2 we can see that the actual average speed of the high-speed Internet is less than the theoretically guaranteed speed shown in Table 1. Also these speeds may vary according to the number of network users at the time. Therefore we tried to appropriate the system performance according to the minimal guaranteed speed.

Table 2. Actual Average Speed of the High-Speed Internet

	ADSL	VDSL	WLAN
17:00 ~ 19:00 (Down/Up)	3.8Mbps/529kbps	20.8Mbps/803.4 kbps	1~2.5Mbps
20:00 ~ 24:00 (Down/Up)	5.9Mbps/592kbps	7.81Mbps/6.01Mbps	

Table 3 shows the data rate of the high quality video stream using MPEG-4 compression method with different frame rates (5 frames/sec to 30 frames/sec) and spatial resolutions (320×240, 640×480, 720×480). From the table we can see that the data rate increases proportionally to the frame rate and the spatial resolution. When sent in the frame rate of 30 frames/sec and the spatial resolution of 720×480, the data rate of the video stream was approximately 6Mbps. This amount of data can be successfully transmitted in VDSL. However, it cannot be transmitted successfully in ADSL since it surpasses the average speed of the network. Hence the reduction of the frame rate is required to compromise the available network bandwidth.

Likewise with these data we can assume that there will be performance degradation such as greater delay of the video signal if TREM is operated over low speed network with high quality video support. To minimize the degradation appropriate frame rate and spatial resolution of the video needs to be considered along with the given network environment.

Comparing the result in Table 3 with the actual bandwidth supported by network in Table2, high-quality video less than 15 frames/sec, 720×480 can be successfully sent using ADSL. Likewise video less than 10 frames/sec, 720×480 can be sent using WLAN, and the full quality video of 30 frames/sec, 720×480 can be transmitted using VDSL. To verify the synchronization of the video data we measured the time delay of the video display when transmitted in the optimum format derived from Table 3. The result is as shown in Table 4.

Table 3. Data Rate of the High Quality Video Stream

	5 frames/sec	10 frames/sec	15 frames/sec	30 frames/sec
320×240	167 kbps	304 kbps	384 kbps	650 kbps
640×480	315 kbps	582 kbps	771 kbps	1.28 Mbps
720×480	1 Mbps	2.2 Mbps	3.1 Mbps	6.1 Mbps

As shown in Table 4, when transmitted in an optimum video format of the provided network environment video display will be operated with less than 3 second time delay. The relation between the quality of the video, system performance and the required bandwidth is shown in Fig. 6. When the network bandwidth is decreased the intersection point with the performance graph changes as shown in the Figure. Based on this intersection point, we can decide the optimum quality of the video data to send.

Table 4. Time Delay of the Video Display

	1 Patient's erminal	1 Patient's erminal + 1 Monitor's rminal	1 Patient's Terminal + 2 Monitor's erminals
15 frames/sec 720×480 ADSL	No delay	1~2 sec	2~3 sec
10 frames/sec 720×480 WLAN	No delay	2~3 sec	3 sec
30 frames/sec 720×480 VDSL	No delay	2 sec	2~3 sec

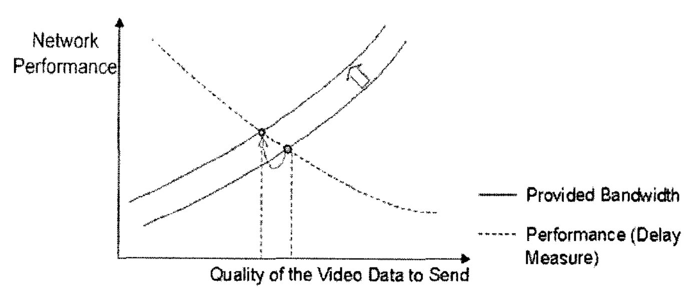

Fig. 6. Relationship between the Bandwidth, Video Quality, and Time Delay

Therefore by adjusting the quality of the video data according to provided network bandwidth, we can use TREM with minimal performance degradation. In the beginning of the connection the quality factors of the video data will be set by MCC. Based on these factors video can be encoded and decoded in appropriate format.

Clinical Result

Emergency physicians examined the mental and physical state of a patient, who had fatal penetrating injury in cranium and contacted a neurosurgeon who stays in his office with a desktop PC equipped with TREM (Fig 7 (a)~(e)). The neurosurgeon was able to examine the patient's physical state remotely with the high-quality video and the bio-signal transmission. The radiologist can examine the exact anatomical location of the damage based on the patient's x-ray image obtainable through the PACS system. The radiologist gave his opinion about the patient's status with the radiological image data. Through this multi-consultation the emergency physician could obtain expertise of a neurosurgeon regarding the patient's internal brain injury, and with the comment from the radiologist emergency physician could minimize the damage to losing the sight of one eye. Therefore with TREM, three specialists (emergency physician, neurosurgeon, and radiologist) were able to have a multi-consultation of an urgent patient and give more prompt and exact diagnosis.

Fig. 7. The actual running of TREM in Severance Hospital: (a) Neurosurgeon, (b) Emergency Room (Penetration Patient), (c) Radiologist, (d) Emergency Room (Deteriorated Mentation Patient), (e) MCC

Secondly, an unconscious patient arrived at the emergency room. The emergency doctor examined patient's condition and reported a drowsy mental state to the radiologist. The radiologist advised CT scan and diagnosed a small amount of subdural hemorrhage of the patient, and gave a direct comment to a neurosurgeon. The neurosurgeon and the emergency doctor could successfully make a management plan about the patient's treatment. Since the detection of a subdural hemorrhage requires a very close observation and an experience of handling similar patients, a comment of a radiologist can be crucial in deciding the patient's treatment.

As demonstrated in the previous experiments, TREM enables a simultaneous multi-consultation between more than two specialists improving the decision making process of a patient care. It helped decreasing the possibility of misdiagnosis.

DISCUSSION

TREM is a multimedia telemedicine system to enable a multi-consultation between different specialists. It consists of two kinds of end terminals and an MCC, which acts as a router. Every end terminals joining the consultation make a connection it to exchange data (Fig 4). MCC also controls system performance by deciding the format of the sharing data along with provided network bandwidth.

According to the Korea Network Information Center (KRNIC), the number of high-speed Internet connections, based mainly on digital subscriber line (xDSL) and cable (CATV), surpassed 10 million by the end of 2002 [5]. This corresponds to more than 70 percent of households and almost coincides with the 80 percent penetration of personal computers. Based on this statistics we assumed that the specialist is likely to use xDSL high-speed Internet connection when he or she is away from the hospital. Therefore we performed a technical experiment measuring the performance of TREM in different kinds of networks. By measuring the data rate of high-quality video in different resolutions, we could find out the optimum video resolutions for each test networks and also derived the relationship between video quality, provided bandwidth, and system performance (Fig 7).

Since all the communicating terminals that want to join the multi-consultation should be connected to MCC, it has to send the same data repeatedly as the number of system user increases. This will cause a bottleneck problem between MCC and the commercial Internet when there are more than two receivers or the data rate of the network is not high enough to deliver all the required data.

In order to supplement this defect of the TREM system, we should use a multicast protocol supported by the network router [6]. If we use the multicast protocol, we can group the receivers according to the data they want to receive. This way instead of sending the same data to every receiver repeatedly, the MCC can send the data to the group router, and then the router will distribute the data to its group members. Therefore the load of MCC can be considerably decreased even when there are many receivers. Also the data rate of the network does not have to be high, for the router takes care of the transmission pace of the network.

Despite of the network burden TREM is designed based on multi-connection instead of multicast for two major reasons: compatibility with the existing infrastructure, reliability of the data transmission. In order to support multicast there has to be multicast-enabled routers that connect the multicast source and the group members, but we cannot guarantee that all the routers in the commercial Internet support multicast. By using multi-connection scheme TREM can exchange data through any kind of existing infra network [7]. The deployed high-speed Internet is expected to meet the required high bandwidth due to the replicated data transmission. Also, multi-connection based TREM can assure the reliability of the transmission by using TCP (Transmission Control Protocol) where UDP (User Datagram Protocol) based multicast cannot.

CONCLUSION

To show the system operability we conducted clinical and technical experiments in Yonsei Medical Center network. Being able to give patients a multi-consultation of required subspecialists in a limited time, emergency doctors could give the patient more exact and prompt treatment. It was possible to transmit high-bandwidth medical multimedia data in a limited network bandwidth without any performance degradation.

Future work will be focused on network performance test between multicast based system and multiple unicast based system.

REFENCES

[1] C. Logatis, P. Fontelo, C. Sneiderman, M. Ackerman, S. Uijtdehaage, C.Candler, S.Stensaas, S.Dennis, "*Webcasting Videoconferences Over IP: A Synchronous Communication Experiment*", Journal of the American Medical Informatics, Mar/Apr, pp.150-153, 2003.

[2] S. Yoo, S. Kim, N. Kim, Y. Kang, K. Kim, S. Bae, M. Vannier, "*Design of a PC-based multimedia telemedicine system for brain function teleconsultation*", International Journal of Medical Informatics, Vol. 61, pp.217-227, 2001.

[3] B. Levine, J. Crowcroft, C. Diot, J. Garcia-Luna-Aceves, J. Kurose, "*Consideration of Receiver Interest for IP Multicast Delivery*", IEEE INFOCOM, pp.470-479, 2000.

[4] T. Oh-ishi, K. Sakai, K. Kikuma, A. Kurokawa, "*Study of the Relationship between Peer-to-Peer Systems and IP Multicasting*", IEEE Communications Magazine January, pp.80-84, 2003.

[5] Korea Network Information Center, http://www.krnic.or.kr

[6] C. Diot, B. Levine, B. Lyles, H. Kassem, D. Balensiefen, "*Deployment Issues for the IP Multicast Service and Architecture*", IEEE Network Jan/Feb, pp.78-88. 2000.

[7] L.Orozco-Barbosa, A. Karmouch, N.Georganas, M. Goldberg, "*A Multimedia Interhospital Communication System for Medical Consultations*", IEEE J. SAC Vol. 10, pp.1145-1157. 1992.