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Ambulance Telemedicine Using Mobile Smart Devices Connected Through an LTE-A Network

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－ABSTRACT－

Background and Objectives：With the development of communications technologies, media transmitting could be possible in real time without having space and time limitations. In this study, we evaluate the feasibility of using mobile smart devices to exchange data between a moving ambulance and a hospital using LTE-A (long term evolution-advanced) network technology. **Materials and Methods**：In the evaluation, a server and monitoring system were used to link four mobile devices simultaneously via a commercial LTE-A network. The proposed system was designed to monitor the status of a patient being transported in an ambulance, using mobile smart devices communicating via a commercial LTE-A network, in real time without delays or video image break up. **Results**：This was achieved by decreasing image transmission overloads for each channel and increasing the compressibility of transmissions to the server. Based on these techniques, captured media could be transmitted without data loss using a bandwidth of 512Kbps. **Conclusions**：Collectively, the study demonstrates that efficient, real-time telemedicine in ambulance emergency scenarios can be realized by using mobile smart devices connected through an LTE-A network. **(J Clinical Otolaryngol 2016;27:112-120)**

KEY WORDS：Ambulance telemedicine · Communications technology · Emergency telemedicine · LTE-A network · Mobile smart devices.

Introduction

With advancements in communication network technologies, primary medical institutions have made continuous efforts to provide improved medical service for patients in tertiary medical centers, including small- and medium-sized hospitals, island health centers, and prison hospitals. These efforts rely on telemedicine technology to facilitate remote medical consulting programs.[1)] Telemedicine supports the delivery of high-quality medical services to patients in remote locations, using remote consulting and diagnosis methods via wired and wireless networks.[2)] In particular, for emergent patients in an ambulance, transmitting patient information to a hospital emergency room in real time is a key telemedicine feature.[3)]

Since the introduction of mobile telemedicine systems based on GSM (global systems for mobile com-

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munications), there have been significant research developments in this field.[3] In particular, live broadcasting of disaster scenes has evolved from fixed media transmissions into real-time transmissions of multimedia data.[4] To achieve this, reliable and stable encoding, transmitting, and decoding techniques are required to transmit multimedia data over various communications networks. Furthermore, to transmit additional information such as the location of the disaster, meta-frame support techniques are also necessary. In particular, conventional live broadcasting techniques such as satellite news gathering (SNG) and electronic news gathering (ENG) systems have limited mobility and are subordinated by outside broadcasts within satellite and microwave networks. To address this shortcoming, portable digital transmitting devices must be developed. In addition, to maintain network stability under failing or nonoperational wired or wireless networks, it is essential to develop a transmitting device that can connect to different networks simultaneously.

Increased broadband width and improved network service quality resulting from the development of third-generation (3G) communications systems has made it possible to provide higher quality telemedicine-based care.[5] Biometric data, along with high-quality pictures and video files, can be transmitted in real time over a 3 G network during telemedicine practice.[6] However, it was reported that applications using 3 G networks showed limitations that resulted in video and audio transmission delays, image break up, and significant decreases in captured image quality during emergency conditions in which rapid head movements occurred.[7]

In recent years, LTE-A networks have been widely established, propelled by the development of communications networks in general.[8] LTE-A is an ultra-high speed communications network with download and upload speeds of 1Gbps and 500 Mbps, respectively. Because LTE and LTE-A can support communications during high-speed transport (with a maximum speed of 500 Km/h), they are the optimal communications standards for telemedicine in ambulances.[9] Accordingly, in this study, wired and wireless transmitting devices were designed and tested to transmit live video data in real time through an LTE-A network, via several channels simultaneously. The server and monitoring systems were installed inside a hospital, and high-quality mobile devices were employed inside ambulances, to test whether live video data captured by the four mobile devices could be successfully transmitted to the server and monitoring system.

Materials and Methods

Instrument list for telemedicine system at Ambulance

SmartSee Server

The SmartSee Server transmits video and voice data, manages users who can connect from remote areas, and acquires location information. While the official announcement and message are being transmitted, connector binders can be controlled remotely.

Encoder

This device transmits improved-quality images by removing surrounding noise using beamforming techniques. For multichannel and multilateral communications, channels can be composed of up to 60 channels. The device supports full 1,080p HD pictures and can transmit audio in real time.

Recording server

This device records video and audio. It can save data from the encoder, and enables users to compare previously recorded video and live video.

Devices at remote area

To transmit live video data from remote areas, Android-based devices were used. The overall situation inside the ambulance and the patient's neighboring condition were captured with a camera on a smartphone (Galaxy S2, Samsung Electronics, Korea) connected to an LTE communications network. To transmit video of the patient's monitoring devices, an encoder interfaced with an LTE router was used.

Devices at situation room

The situation room contained several devices that facilitated communications with the ambulance, including a universal serial bus (USB) camera (to monitor the doctor), a USB microphone, speaker, an encoder, and a recording server.

Trunked radio service (TRS) terminal unit

Trunked radio service (TRS) is an advanced form of conventional personal radio system. Rather than using only one frequency for each user, which is standard in conventional mobile communications, multiple users can employ multiple common frequencies provided by a mobile radio relay station. Unlike conventional radio services, unoccupied channels can be searched for among several channels, and subsequently utilized ; this makes the TRS system very efficient. In particular, advanced digital TRS, which uses a digital communications framework upgraded from an analog type, provides improved security and excellent phone quality. Further, it allows group calls and high-speed data communications via combined voice and data transmissions. In this system, maximizing frequency bandwidth utilization is a primary feature.

Block diagram of total system design

A complete diagram of a telemedicine system using a multiple access control server is shown in Fig. 1. The wireless communication standards include LTE and LTE-A, while the wired communication standards include very high-data rate digital subscriber line (VDSL), asymmetric digital subscriber line (ADSL), and TRS. Because network characteristics vary according to the bandwidth of each communications network, authorized Internet Protocol (IP) address, and private IP address, telemedicine systems

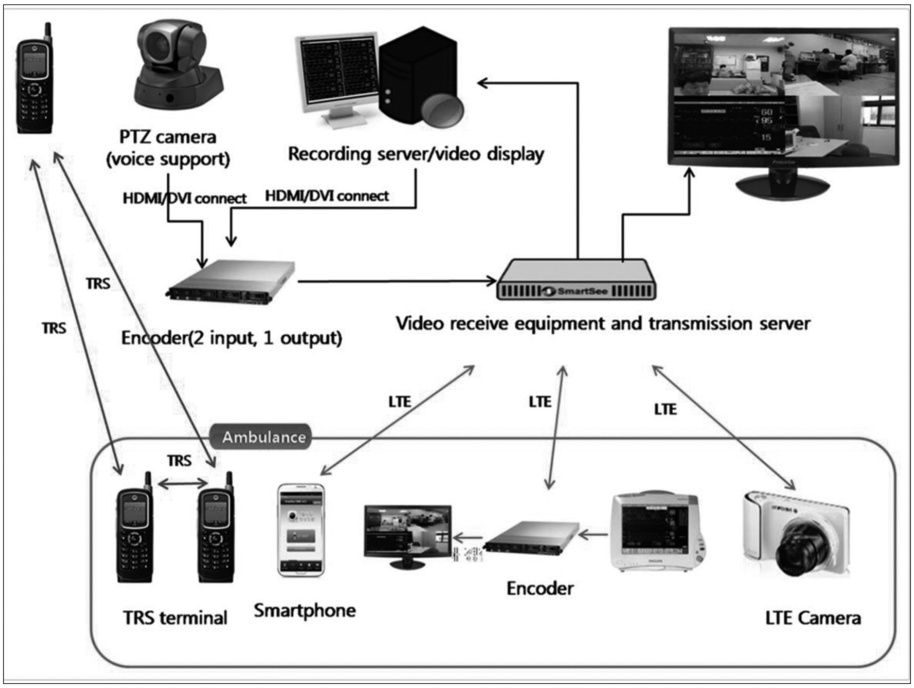

Fig. 1. Treatment process of telemedicine system.

must be properly designed to effectively service both the patient and medical team. The multiple access control server was designed to manage multiple patients and medical teams, according to contact lists and network characteristics. In the ambulance, LTE encoder networks can transmit a patient's biometric signal, as well as data from a smartphone camera or network camera. In the situation room, the receiving server can receive video information transmitted from an ambulance ; situation room instructions, necessary manuals, or related video can be transmitted to the ambulance via the server's USB camera. In addition, a recording server for video and an encoder for transmitting situation room video were installed in the situation room. For error-free voice communications, TRS terminals were utilized to facilitate communications between medical staff in the situation room and the ambulance. These terminals help to decrease delays in live video and voice data by using the LTE network in the ambulance ; they also provide increased security, stability, and voice quality.

Telemedicine application

This study used the SmartSee Disaster Management System (DMS), developed by BNP Innovation and DICS, as its remote control application. This application is available as a free download from the Google Play Store. Although this application is free, member registration is required for security reinforcement, and mobile device approval must be received from the server. The application was designed to provide two-way communications with maximum HD resolution through Android smartphones ; moreover, an exclusive management application allows the individual in change of the patient's care to control the screen. It can be used on Android-based smart devices, including smartphones and smart cameras connected to an LTE-A or Wi Fi network. This telemedicine application contains a menu, program settings, the patient's biometric signal monitor, the situation room monitor, the monitor for the patient on the ambulance, and a monitor for the primary patient information screen in the ambulance.

Design of video recording device

For real-time two-way communications, the international standard Session Initiation Protocol (SIP) is used. The camera operates as a SIP client and is registered to the SIP server to perform call-related functions. After each SIP client has been configured according to its SIP protocol, all multimedia data must pass through the media relay server during peer-to-peer transmission, to solve network address translation (NAT) issues and to ensure reliable transmissions. In addition, Real-time Transport Protocol (RTP) is employed to eliminate delays in two-way communications.

By employing the multimedia engine as software, camera video data is encoded using the H.264 codec; it is then packetized and transmitted to the remote terminal via network interfacing. Video data received from remote areas is decoded and displayed through an opposite process. Audio is also encoded and decoded in the same manner as video ; standard codecs, including G722, G77, narrow band, and wide band codecs, are used selectively.

Server and Monitoring system

When imaging devices developed for this study are connected to a network, IP information is sent to a Dynamic Domain Name System (DDNS) server whenever the IP is changed; the DDNS server then creates a database entry to record the changed IP information. The streaming server saves the encoded video and streaming captured video ; subsequently, the saved video can be linked with object tags to allow users to playback specific portions. This can be accomplished by receiving data from a client after the user's media player is activated. The server manages the IDs of the imaging devices being used at the remote site via internet; all technical data from these devices are saved to facilitate device management. In addition, information from the accessories installed on imaging devices, such as cameras and headsets, is saved and managed. The server's recording function records video when images are being transmitted from imaging devices, according to the current circumstances of the transmitting network; portions of this captured multimedia content can be selected and played back. A database containing information about the recorded media is maintained; this allows media to be searched according to the time and events of the emergency. During this experiment, a screen consisting of four channels was utilized, with the images from each media-transmitting device shown in each channel. The communication links were established using individual LTE networks, to prevent transmission delays. The allocated devices and functions for each channel are listed in Table 1.

The media server constructed for this experiment is designed to receive various media streams from inside the ambulance. This is accomplished by interfacing multiple transmitting devices and setting up multiple screens. In addition, the streaming of terminal data to smart phones, personal computers, and other similar devices is made possible via the web and by monitoring the accessed terminal's bandwidth. This allows media to be transmitted without image break up. As an expanded function, the size and type of the transmitted media can be converted to more appropri-

Table 1. Composition and function of 4 channel devices

Channel	Device	Circumstance	Function
1	USB camera, managed method, video	Situation Room	– Doctor gives instruction and demonstration to medical technician at ambulance via camera at control room server – Output manual or media to handle emergency condition
2	LTE supporting, network camera	Ambulance	– Capturing overall condition of inside ambulance by fixed camera
3	Encoder, LTE router	Ambulance	– Transmitting patient monitor screen to check patient condition via encoder to situation room in real time – Transmitting medias of medical devices such as ultrasonic wave, endoscope and etc. at ambulance to situation room in real time
4	Smart phone	Ambulance	– Small Camera (Smart Phone Camera) which is very handy to see patient condition in detail

Fig. 2. Individual screen configuration (Transmitting Biometric signal information via LTE communication network).

ately match the characteristics of the network and terminal. Moreover, the captured media can be recorded according to the characteristics of the site channel. A Digital Rights Management (DRM) security function was also added to manage access authority limitations; it is configured to manage various classes of users. It is possible to configure the control room monitor and the client's screen into an individual screen (Fig. 2), a 2×2 screen (Fig. 3), or a 1×3 screen. It is also possible to output screens that display content from up to four sets of media transmitting devices in real time. Moreover, media transmitted from devic-

Fig. 3. 2×2 Screen configuration.

Fig. 4. Output of Smart terminal screen.

es can be transmitted to other smart terminals via a web server (Fig. 4). In the situation room, three channels of media transmitted from an ambulance can be displayed and recorded if required. Recorded media can be played back (Fig. 5). Live conditions in the ambulance can be continuously recorded, even while recorded media is being viewed.

Results

In this study, a real-time multimedia transmitting system was implemented, using mobile devices developed for the study, as shown in Fig. 6. The system configuration is divided into terminal territory, network territory, server territory, and monitoring territory. Terminal territory utilizes applications developed for this study. Network territory provides access to wired, wireless, and satellite networks. Live media signals from smart devices can be transmitted to servers throughout the network and displayed on the situation room monitor in real-time, via decoding or transmissions to smart terminals from a web server, or both.

To test the functionality of transmitting devices, a server and monitoring system were installed inside a hospital ; in addition, one set of Galaxy cameras and two sets of smartphones were set up in the ambulance. The primary patient information screen in the ambulance, the closed screen containing the patient's condition or injured area, and patient biometric data such as heart rate and blood pressure were all cap-

Fig. 5. Recording and playback.

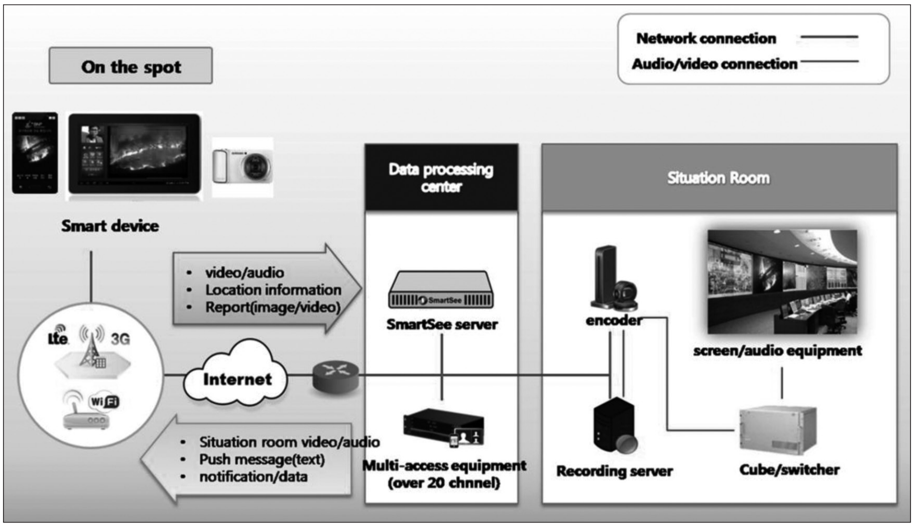

Fig. 6. Media transmitting system diagram.

tured and transmitted. During the test, the results of transmitting bulk-sized data using an LTE network were analyzed. After receiving media from a camera, it was encoded using high profile H.264 ; encoded data was divided into 1,324 byte units (which is smaller than the maximum transmission unit (MTU) and converted to RTP, then transmitted via an LTE module network. As a result of increasing the compression to high profile, the media was successfully encoded as 720p/20fps and transmitted using a network bandwidth of 512 Kbps without loss.

Discussion

With advancements in communication techniques, there have been increasing demands to develop platforms and mobile smart devices that can transmit and receive multimedia data from remote sites in real time. It has become possible to access many remote sites through wired and wireless IP networks, allowing access to audio data, video data, and site location information as ubiquitous properties. In addition, it has become possible to utilize meta-data, including biometric information, weather information such as atmospheric pressure, and vehicle information that is efficiently gathered using ubiquitous sensors.

For proper use of a telemedicine system, the medical data transmission and receiving processes must be stable, with no distortion or image break up.[10] Therefore, communications networks are one of the most important factors in telemedicine system applications.[2] Conventional telemedicine services have been limited to specific areas, and special equipment was often required. However, wireless communication networks such as wireless broadband internet (Wibro) and high-speed downlink packet access (HSDPA), both with ample bandwidths ranging from 1 Mbps and 3 Mbps, have been adopted by telemedicine systems. This has increased the quality of telemedicine services by stabilizing the transmission of medical information over wireless networks.[1,11] In other words, communications networks that can adapt to telemedicine services have been diversified, which facilitates remote diagnosis and proper treatment without time and space limitations.[1] In Korea, because mobile IP networks are widely commercialized, real-time transmissions of multimedia data are less affected by time and space limitations. As a result, applications have been expanded to various fields.[12] In particular, rapid data collection is very important when monitoring the status inside an ambulance during an emergency. In these cases, emergency telemedicine systems must be configured using three-dimensional and synthetic methods, based on multimedia data that can provide situational control in real time.[13-15]

In this study, a telemedicine system was designed to help support medical treatment by transmitting patient biometrics signals (via the patient monitoring device screen), video data, and image files captured by mobile devices at the emergency scene. The telemedicine network was configured using smart devices that are supported by high-speed internet networks such as Wi-Fi, HSDPA, WiBro, and LTE. To identify image break up and delay issues that may occur during mobile multimedia transmissions, actual testing was conducted using a moving ambulance.

In this research, video transmitting devices were adopted for live broadcasting of various emergency scenes. It was verified that a telemedicine system containing video servers and monitoring viewers could transmit telemedicine data reliably and stably in real time, using wired and wireless networks as well as satellite networks. Because these devices can interface with mobile devices such as smart phones and cameras, mobility was excellent because these devices can be easily transported. In particular, because multiple network connections are possible, other networks can be used if the primary network is not functioning.

Transmitting video via conventional 3G networks has limitations that can result in delays and image break up. However, in networks based on LTE-A, those limitations have been largely eliminated. In this study, rather than every device in the ambulance using one LTE network (as previous studies have done), each device uses a separate LTE network. This enhances live video broadcasting by partitioning the video data transmissions. In previous studies, custom-made devices had to be developed for each device to transmit biometric signals. In contrast, the encoder used in this study can transmit any type of biometric signal if a video output terminal is available. As a result, the system built for this study can transmit live video data, play back recorded data, and display digital output regardless of the adopted device type. As a result, the conditions of a patient being transported in an ambulance can be accessed rapidly and reliably at the destination hospital.

Conclusion

This system can effectively and reliably broadcast multimedia data from ambulances and emergency scenes, and can be instrumental in increasing patient survival rates. Using this system, hospital physicians can access the patient's condition in real time without distortions, thus helping the patient to receive medical treatment more rapidly. In addition, by reducing comprehension problems that may result from simple wired network communications, the treatment of emergency patients being transported by ambulance can be significantly improved. In addition to its role in ambulance telemedicine, the proposed system can be utilized in other medical situations where a patient's condition must be transmitted remotely.

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