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ORIGINAL PAPER

Developing an Active Emergency Medical Service System Based on WiMAX Technology

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Abstract The population structure has changed with the aging of population. In the present, elders account for 10.63% of the domestic population and the percentage is still gradually climbing. In other words, the demand for emergency services among elders in home environment is expected to grow in the future. In order to improve the efficiency and quality of emergency care, information technology should be effectively utilized to integrate medical systems and facilities, strengthen human-centered operation designs, and maximize the overall performance. The improvement in the quality and survival rate of emergency care is an important basis for better life and health of all people. Through integrated application of medical information systems and information communication technology, this study proposes a WiMAX-based emergency care system addressing the public demands for convenience, speed, safety, and human-centered operation of emergency care. This system consists of a healthcare service center, emergency medical service hospitals, and emergency ambulances. Using the wireless transmission capability of WiMAX, patients' physiological data can be transmitted from medical measurement facilities to the emergency room and emergency room doctors can provide immediate online instructions on emergency treatment via video and audio transmission. WiMAX technology enables the establishment of active emergency medical services.

Keywords WiMAX · Broadband wireless technology · Emergency medical service · Telemedicine · Active medicine

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Introduction

According to the official statistic report released by the Department of Household Registration,[1] elderly people account for 10.63% of total population and the ratio is increasing. The numbers suggest that the trend of aging society is formed and the demand for emergency medical services has dramatically increased.

Based on the statistics report released by National Fire Agency[2] (NFA), the number of emergency medical service dispatch climbed each year [1]. The number of people receiving emergency medical services reached 749,126 at a yearly growth rate exceeding 13.0%, as shown in Fig. 1 [1]. In cases requiring emergency medical services such as car accidents, peracute disease, general external wounds, fall injury, fainting, and so on, the percentage of incidences that needed emergency medical technicians (EMTs) to perform immedicate medical care reached 79% [1]. With the

[1] Department of Household Registration, Ministry of the Interior, Executive Yuan, R.O.C.
[2] National Fire Agency, Ministry of the Interior, Executive Yuan, R.O.C.

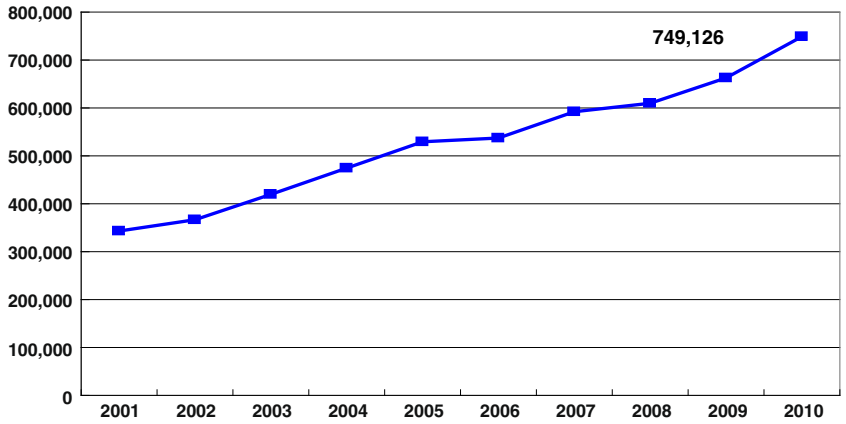

Fig. 1 Yearly statistics of people receiving emergency medical services (Source: National Fire Agency [1])

increasing percentage of elders in the future population structure, the demand for emergency medical services will dramatically elevate and the quality of the emergency medical services arises many concerns. For emergency medical services to be better organized and recognized, the Emergency Medical Services Act containing 58 articles was promulgated by President Ma on July 11th, 2007 [2], representing the improvement of national emergency medical treatment capability, the integration of emergency medical resources, and the implementation of the emergency medical services mechanism. The formulation of such an act will be the strong aid in improving the survival rate in emergency medical treatment and ensuring people's lives and health.

As the network technology advances from the stationary to the mobile, data transmission bandwidth and quality are also improving. The measures and results of emergency medical services can be further improved through the cooperation between the present network development and medical information systems/equipments, as well as the use of wireless communication technology for providing active emergency medical services.

The purpose of this study is to establish an integrated emergency medical service mechanism based on WiMAX (Worldwide Interoperability for Microwave Access) technology through the incorporation of the advanced technology and the development of information and communications technology (ICT) industry. The WiMAX wireless transmission systems installed in ambulances allow vehicles moving in high speed to transmit signals such as real-time audio/video and physiological data at high data rate for emergency room (ER) doctors to provide EMTs with real-time instructions in order to provide proper emergency medical treatments. As time is crucial to the emergency medical services, the fast and accurate emergency medical treatments supported by WiMAX technology should be able to make great differences in saving lives. WiMAX is capable of processing large data transmission demand in emergency medical service vehicles. The quality of emergency medical services and the survival rate can be improved by the integrated interface between emergency medical service system and medical equipments, as well as the user-friendly design for easy carrying and using of equipments. In addition, the real-time video transmitted from the ambulance will be recorded during the emergency medical services process and can serve as the evidence in case of medical dispute and therefore can suppress the occurance of medical disputes.

The integrated active emergency medical service system mainly consists of two parts. The first part is an active healthcare service system providing continuous monitoring of physiological conditions to members equipped with portable electrocardiography (ECG) devices which automatically transmit members' physiological data to the healthcare service center through the WiMAX network. The second part focuses on the establishment of WiMAX-based wireless transmission in emergency ambulances to support instant physiological data transmission and video conferencing between ambulances and ER. Through the integration of these two parts, this study realized the operation of an active emergency medical service system.

Literature review

Emergency Medical Services (EMS)

According to the statistic report released by NFA, the number of emergency medical services dispatches reached 918,882 in 2010 at an annual growth rate of 13.2%, as illustrated in Fig. 2 [1]. The curve of yearly dispatch statistics indicated the number of emergency medical services dispatch gradually climbed each year [1]. With the increasing demand, concerns arose for the quality of emergency medical services, especially for training of EMTs. When emergency medical instances take place, only qualified EMTs can perform emergency medical treatments.

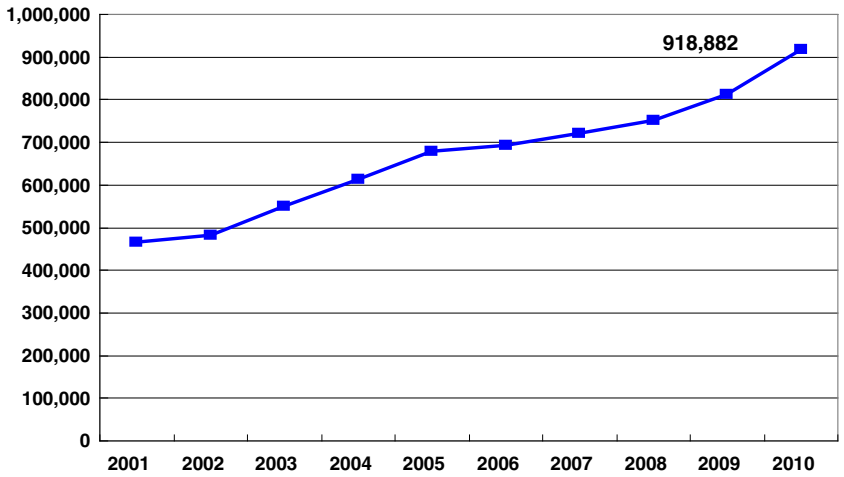

Fig. 2 Yearly statistics of emergency medical service dispatches (Source:National Fire Agency [1])

The responsibility of an EMT includes emergency treatments at the emergency scene and the subsequent, adequate medical care to maintain patients' vital signs during transportation to hospitals. There are three levels of technical certification of EMT, basic, intermediate, and advanced, and each level is authorized to give patients different levels of emergency treatments [3].

Time is crucial to the emergency medical services. The survival rate is dropped by 10% for every 1 min delay in treatment [4]. Emergency medical services have always been practiced under critical environment and emergency medical treatments have always been performed against the clock. Therefore, a well constructed and designed emergency medical services network is the key to improve the survival rate and save more lives.

Active medical service

Traditional medical services are passive. The by-request mode causes delay to treatment and influence its effectiveness. Active medical service, in contrast, combines various portable physiological measurement devices (including devices for body temperature, heart beat, cardiac scan, etc.) to actively monitor patients' physiological conditions. The patients' ECG devices are automatically linked to the system through WiMAX network, all physiological records are monitored by the healthcare service centers and the staff of the healthcare service centers can access the patients' medical records for reference. Any anomaly in a patient's physiological condition will trigger the monitoring system to give alarms and the staff of the healthcare service centers can therefore quickly response and provide timely emergency medical services.

Telemedicine is currently one application field of active medicine. Patients involved in telemedicine projects can use active medical devices to record and transmit their physiological data to distant healthcare service centers for daily monitoring and periodically for real-time discussion with doctors [5]. Through telemedicine, the quality of medical care service can be elevated by digitizing medical history data and sharing medical resources in order to lower the operation cost of medical system and break the geographic and time limitation, making distance no longer the cause for the medical resource difference in rural and urban districts [6, 8]. The experience in telemedicine can provide references to the application of active medicine in the emergency medical service system.

Hospital Information System (HIS)

In Taiwan, a Health Information Network (HIN) was established in 1995 for providing medical information transmission services to medical facilities and government institutions for national health and health insurance affairs, with the objectives to improve the service quality and efficiency of medical facilities, promote computerized medical services, construct national medical information network, and improve the quality of national health care [7]. The medical information system works upon the hospital arrival of the patient to the patient's discharge. During this time period, the information is processed by computers without excessive human intervention. The automated processes dramatically reduce the workload of administrative and medical staff, and further improve the usage efficiency of medical resources [6].

The applications of HIS include telemedicine, health education, digital medical image storage, electronic medical history, healthcare information system. Some functions of HIS can also be implemented into portable devices for transmitting medical data through wireless network technology in order to provide customized services to users. This allows portable devices to actively upload users' medical information to the healthcare service centers to provide more comprehensive medical services [9]. Active emergency medical services can be realized through the incorporation of the emergency medical alarm mechanism within such portable devices.

Integration of EMS and HIS

Efforts have been put to integrate EMS and HIS to help EMTs and ER doctors perform suitable and timely medical treatments on patients in emergency conditions [10–14]. The earlier attempt of hospital information sharing based on the World Wide Web (W3) by Issac et al. [10] aimed at the development of a cross-institutional data sharing mechanism. Such a web-based, cross-institutional system provided precious experiences regarding the challenges in data sharing and confidentiality [10].

Recent development in the wireless technology further supported data sharing in mobile and remote settings. For example, Kyriacou et al. [11] developed a telemedicine system which allowed the transmission of vital bio-signals and still images through GSM (global system for mobile communications) telecommunication network, satellite links, or telephony system. A consultation site with a multimedia database was equipped for storing and archiving patients' data [11]. Su et al. [12] applied 3 G (3rd generation) wireless mobile network in a medical emergency service network. In addition to the audio and video signal transfer between the ambulance and ER and medical record accessing from HIS through the 3 G wireless transmission, the GPS (global positioning system) function further gave ER the estimated time of arrival (ETA) so that the ER doctors could prepare in advance for receiving the patient [12]. In case that EMTs were unable to obtain the identities of patients, RFID-based systems provided assistance to quickly identify patients and therefore ER doctors could access patients' medical records as soon as possible [13, 14].

The works by Kyriacou et al. [11] and Su et al. [12] were developed in a rather limited setting in which patients' medical records were stored in the information system in a single hospital and the access to these records was limited. However, in this study, members' medical records were kept in the regional healthcare service center, making it possible to access the needed records from different ambulances and hospitals.

WiMAX technology

WiMAX is an innovative wireless broadband service technology with low cost and fast implementation time, which can be adapted to various applications such as internet surfing, image and data transition, visual surveillance, and on-line multimedia services [15]. One particular feature of WiMAX is the quality of service (QoS) support, which allows priority setting to different packets during data transmission [16]. The wireless data transmission through WiMAX is protected by strict AES-CCM (advanced encryption standard—counter with CBC-MAC mode) authentication and encryption technology to ensure the network security [17].

The advantages of WiMAX include long transmission range, high transmission capability, and QoS support [18]. These properties enable better service quality during real-time audio and video transmission and make WiMAX suitable for a broad range of applications including house care, telemedicine, camera surveillance, smart logistics, emergency ambulance, road safety monitoring, and mud-flows monitoring. The government in Taiwan began to actively support the development of WiMAX in 2005 through R&D subsidies, releasing operational frequency bands, implementing Mobile Taiwan Program, and international cooperation. The WiMAX development in Taiwan has built up strong basis and capacity for the development of 4 G (4th generation) communication technology [19].

Table 1 compares the characteristics of different wireless network technologies. In the comparison between WiFi and WiMAX, WiMAX is superior in transmission range, mobile internet support, as well as mobile phone support. In the comparison between 3.5 G (3.5th generation) technology and WiMAX, WiMAX has faster data transmission rate and supports mobile internet. In the comparison between the more recently-developed LTE (long term evolution) technology and WiMAX, LTE supports both mobile internet and mobile phone and has a higher data transmission rate than WiMAX.

Table 1 Characteristics comparison between different wireless technologies

	WiMAX	Wi-Fi	3.5 G	LTE
Peak download speed (bps)	46 M (802.1e)	54 M (802.11 g)	14.4 M	100 M
Signal strength	Good	Poor	Good	Good
Mobility	Support high speed moving	Fixed-point moving	Support high speed moving	Support high speed moving
Transmission distance	From several hundred meters to over 10 km	Within 200 m	From several hundred meters to several kilometers	From several hundred meters to over 10 km
MIMO (multiple antennas)	Yes	Yes	N/A	Yes
QoS	Yes	N/A	N/A	Yes
Authentication	Username & password or SIM card	Password	SIM card only	Username & password or SIM card

Source: Tatung Infocomm. Co., Ltd. [21]; Verizon Wireless [22]; this study

Despite of the slower data transmission rate than LTE, WiMAX is a more mature technology and is leading LTE in infrastructure and device development by approximately 2 years [20]. The support from the Taiwan government further facilitates the development of the WiMAX network. In addition, while WiMAX and LTE seem competing, these two technologies can be complimentary for different applications and the currently deployed WiMAX network can be transformed to LTE network in the future if needed [20]. Therefore, by choosing WiMAX technology, the active emergency medical service in Taiwan is expected to be more smoothly realized.

In the application of WiMAX in emergency medical services, the wide data transmission bandwidth of WiMAX enables the transmission of high resolution images for accurate diagnosis. The high mobility maintains the strength of the data signal during high speed moving of emergency ambulances. Using WiMAX allows real-time communications regarding patients' physiological conditions between emergency ambulances and hospitals.

System implementation

Panorama of the system

The key factor to emergency medical services is the time management. Even the time spent in notification process is crucial. Contrasting to the conventional way that people call 911 as emergency events take place and then wait for ambulances' arrival, the application of well-developed information technology and wireless network technology turns emergency medicine into active medical services. The medical treatment efficiency is much improved and patients can be further kept under continuous medical monitoring during transportation, increasing patients' survival rate. The procedure of the proposed active emergency medical service is shown in Fig. 3, with the circled numbers representing the operating sequence.

The procedure of the active emergency medical service is further explained in the following:

(1) Members of the active emergency medical service system carry portable ECG devices to measure and record members' physiological conditions, including blood pressure, heart beat, body temperature, etc. ECG devices also transmit instant medical measurement data to WiMAX mobile internet devices (MID);
(2) MID transmit the received physiological data to healthcare service centers through the WiMAX wireless network;
(3) The healthcare service center monitors members' health conditions from the received physiological data. If any abnormal physiological data is observed, medical staff will contact the member for confirmation;
(4) In case emergency conditions occur, the healthcare service center staff will call 911 to inform emergency service center for dispatching rescue team;
(5) Emergency ambulance will be dispatched for transporting the patient to hospital for medical treatment.

The emergency medical service system consists of three endpoints: Healthcare service center, emergency medical service hospital, and emergency ambulance, each with various duties. Jointly, the three endpoints form the comprehensive emergency medical service system. All three endpoints communicate with each other and transmit data via wireless

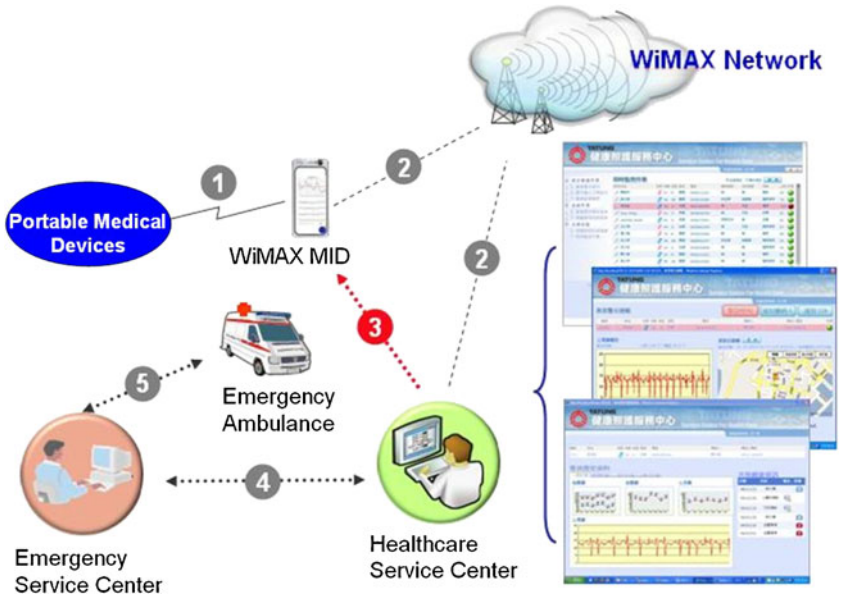

Fig. 3 Procedure of the active emergency medical service

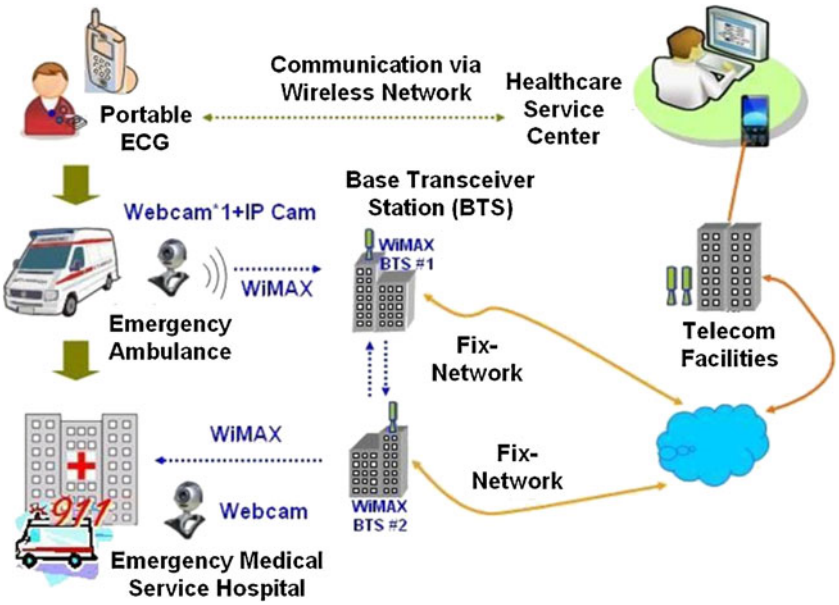

Fig. 4 Signal flow of the active rescue-report emergency medical service

network. As shown in Fig. 4, emergency ambulances equipped with WiMAX broadband wireless network technology evolves from conventional report-rescue mode into active emergency rescue-report mode. Patients' conditions are continuously monitored and reported to the emergency medical service hospital during ambulance transportation.

Following the requirements of the proposed system, the major equipments and transmission protocol used by each endpoint are chosen as listed in Table 2. Combining portable ECG transmitters and WiMAX provides the best solution for healthcare services and telemedicine, which enables 24/7 health condition monitoring and provide immediate emergency medical services within the shortest time.

Member end

The health of the elderly is of great concern with the increasing life expectancy and senior population. In order to ensure senior people in good health conditions, their physiological data need to be constantly monitored. At member end, four vital signs including respiration, body temperature, pulse, and blood pressure are measured by the one-lead ECG patch attached to the member, recorded by the portable ECG transmitter, and then transmitted to the MID via Bluetooth. MID transmits physiological data to the healthcare service center database for real-time monitoring as shown in Fig. 5. MID also displays real-time physiological readings and electrocardiography so that members can check their own health conditions.

Healthcare service center end

The healthcare service center is responsible for monitoring and recording physiological data received from ECG transmitters carried by members. The healthcare service center staff work in shifts on a 24-h basis for providing comprehensive healthcare to members. The service procedure carried out within the healthcare service center is shown in Fig. 6. The healthcare service center staff monitors the physiological

Table 2 Major equipments and transmission protocol used at each endpoint

Endpoints	Equipments	Transmission protocol
Healthcare service center	Computer with healthcare service system installed	Ethernet
Emergency ambulance	WiMAX Customer Premise Equipment	WiMAX
	Computer for receiving physiological data	WiMAX
	High definition WebCam	WiMAX
	Blood pressure and glucose meter (combo)	Bluetooth
	Digital temperature meter	Bluetooth
	ECG with transmitter	Bluetooth
Emergency hospital	Medical information system and computer with videoconferencing cameras	Ethernet
Members	Portable ECG with transmitter	Bluetooth
	Portable MID	WiMAX

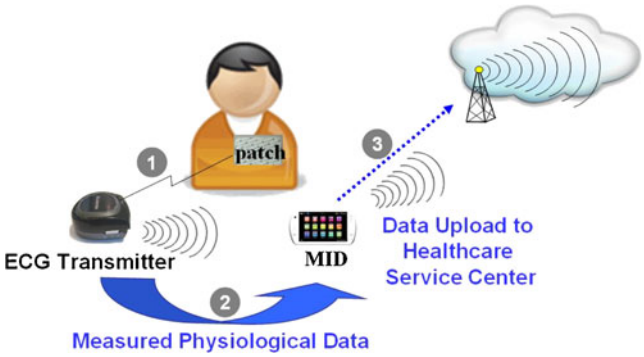

Fig. 5 Physiological data transmission at member end

data transmitted from the member end. All members' physiological data and GPS-based locations are recorded and stored in the database. When the system sends out an alarm signal for anomaly in a member's physiological data, the healthcare service center staff will contact the member via telephone to understand member's current physical conditions and try to find out the cause of the abnormal physiological data. If the member requires emergency medical services, the healthcare service center staff will contact the local emergency service center for requesting ambulance and inform the rescue team of the member's medical history and current health conditions as reference for suitable medical treatment and care during the emergency service.

Emergency ambulance End

The emergency ambulance plays a crucial role in the successfulness of emergency medical services. In addition to emergency medical equipments, emergency ambulances are also installed with WiMAX wireless transmission equipments and related digital medical equipments for achieving highly efficient emergency medical services. When an emergency ambulance is dispatched for rescue, the in-car WiMAX network system is activated. After arrival at the emergency scene, EMTs help the patient aboard the ambulance and replace the patient's portable ECG transmitter with the in-car

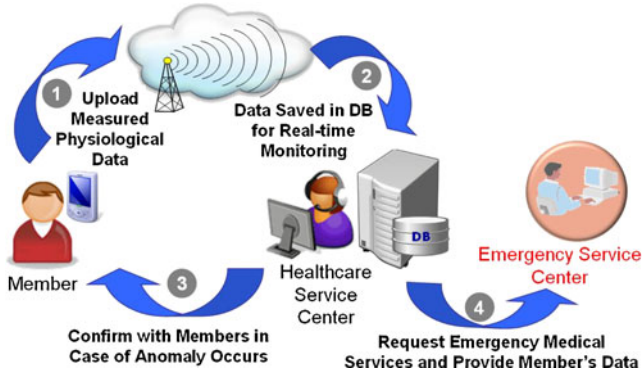

Fig. 6 Service procedure of healthcare service center

Fig. 7 WiMAX CPE

ECG transmitter. Medical equipments on the emergency ambulance are made digital to interface with the emergency medical service system. For example, the blood pressure and glucose meter and digital ear thermometer are equipped with digital wireless transmission function for automatically sending data to the system computer to avoid data errors caused by manual input. In addition, using touch-screen computer to activate digital medical devices for measuring physiological data allows EMTs to operate the system in a convenient and time-saving manner. The in-car laptop receives and transmits physiological data through the WiMAX network via a WiMAX CPE,[3] as shown in Fig. 7.

Figure 8 summarizes the interfacing among devices in emergency ambulances. The ECG patch attached to the patient sends physiological data to the ECG transmitter through the wire, and the ECG transmitter sends data to the transceiver via Bluetooth. The transceiver further transmits data to WiMAX CPE through a Cat5e cable. Digital ear thermometer, and blood pressure and glucose meter, and EMT's wireless headset are connected to a laptop computer through Bluetooth, and the laptop computer is connected to WiMAX CPE through a Cat5e cable. A high definition (HD) digital camera is set at the rear top inside the ambulance to obtain panorama view and wired to a video server which is connected to WiMAX CPE through a Cat5e cable. During operation, the laptop computer transmits received physiological data to the emergency medical service hospitals server through WiMAX CPE. A video conference will be setup between ER and the emergency ambulance, with the video signal directly transmitted from the panorama-view camera to ER through WiMAX using public IP to reduce the load of laptop computer in order to allow EMTs communicate with ER doctors with audio signal without laptop intervention. ER doctors can evaluate the patient's vital signs based on the received data and offer necessary instruction to EMTs.

[3] CPE: client premise equipment, a terminal that connects a client to a communication network

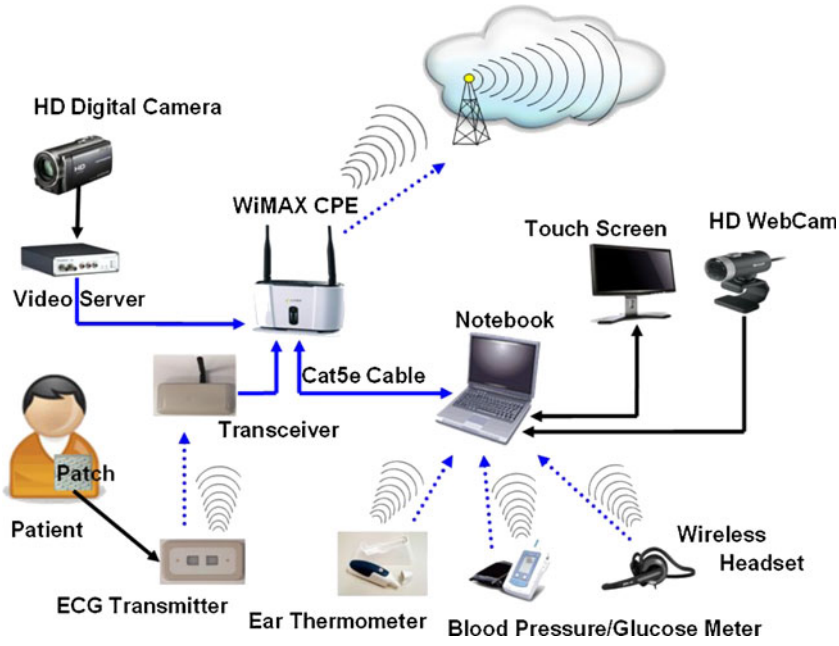

Fig. 8 Adaptive transmission between device inside the ambulance

In addition, another HD webcam is connected to the laptop for recording EMTs' movement and serves as the back-up camera for video conferencing. A touch screen is linked to the laptop computer for displaying system menu, video images, ECG charts, and various medial data, and allows EMTs to operate the system conveniently. To avoid power failure during emergency medical service processes, the emergency ambulances are equipped with uninterrupted power systems (UPS) for providing necessary electricity to keep all devices working during the ambulance transit, providing patients with additional protection.

Emergency medical service hospital end

The emergency medical service hospital plays an important behind-the-scene role. Hospitals carry out follow-up medical treatments after receiving patients from ambulances; with the WiMAX-based emergency medical service system, ER doctors are now able to communicate with EMTs through video conferencing and classify patients' conditions before hospital arrival (see Fig. 9). Moreover, ER doctors can give instructionw to EMTw based on the incoming physiological data and video images to perform emergency treatments during ambulance transportation, and prepare for timely and proper treatments after patients' arrival. If the patient's ID number is acquired, ER doctors can access the patient's medical record from HIS in advance for emergency treatment reference.

Data transmission through WiMAX

The use of WiMAX network for data transmission in the active emergency medical service system has two major concerns: network security and transmission bandwidth.

(1) Network Security

The network security of WiMAX is realized through encryption/decryption module and CA certificate au-

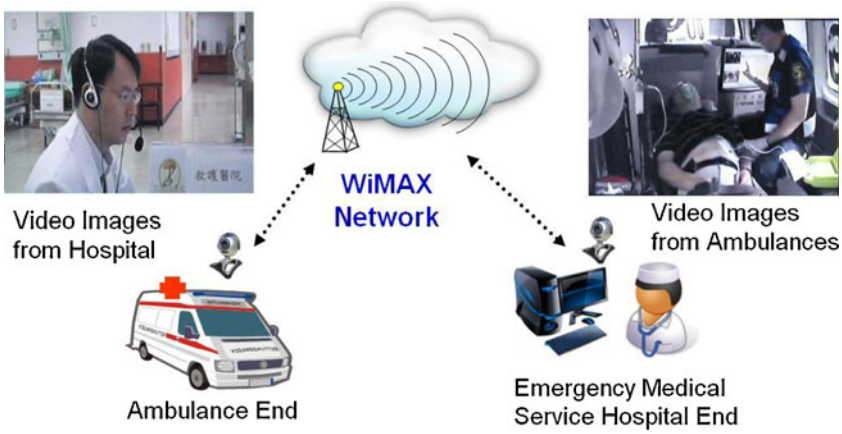

Fig. 9 Video conferencing through WiMAX between ambulance and hospital

Table 3 WiMAX transmission bandwidths of different system functions

Functions	Bandwidth for download and upload (bps)
Data transmission	607 K~25 M
HIS display	122 K~864 K
Video transmission	68 K~2.6 M
Live meeting	70 K or more
Powerpoint presentation sharing	54 K~113 K

thentication. The transmission between subscriber station (SS) and base station (BS) is protected by strict encryption and authentication mechanism. Different encryption and decryption algorithms are used for transmitting data with different security levels. Highly classified data are encrypted and decrypted using AES-CCM algorithm, whereas DES-CBC and AES-CTR algorithms are used for data with lower classified levels or even data for group broadcasting. In the member end, the system authenticates the user's identity with different measures including SIM card, number codes, username and password for ensuring the wireless network security.

(2) Transmission Bandwidth

The theoretical transmission bandwidths of 3 G and 3.5 G wireless network are 384Kbps, and 14.4Mbps, respectively. For WiMAX, the transmission bandwidth can be as high as 70Mbps, with a transmission range up to 30 miles. Although the 70Mbps transmission bandwidth is more theoretical than practical to WiMAX, for practical use, the data transmission rate of WiMAX is still far beyond what 3.5 G wireless network can offer, making WiMAX more advantageous in various applications. Table 3 lists the WiMAX transmission bandwidths of different functions required by the active emergency medical service system.

System operation and evaluation

System operation

Each member of the emergency medical service system constantly carries portable ECG transmitters. The ECG transmitters will automatically establish connection with the healthcare service center server and transmit the member's physiological data including electrocardiography, heart beat, body temperature, and so on through Bluetooth wireless technology to portable MID for the member to monitor his/her own health condition. The member's physiological data and GPS-based location will be transmitted from MID to the healthcare service center server through WiMAX and recorded for real-time monitoring. The monitoring system will access the member's personal information and physiological data from the server and display the data, as shown in Fig. 10. These data will be provided to the emergency medical service center when ambulance and rescue team are needed.

The portable ECG transmitters will measure patient's physiological data and alert the system in the situation of blood pressure swiftly dropping, heart beat rapidly raising, or other abnormal physiological data detected. The healthcare service center monitoring system will then send warning signals and alarms to remind staff to confirm with the patient about the anomaly and then report to the emergency medical service center, as illustrated in Fig. 11. In addition to the warning indicator in the Health Condition column, the row of the member's personal and physiological data will be marked by a transparent bar with color corresponding to a unique situation. For example, pink indicates the member is in life-threatening condition and needs immediate emergency medical service and yellow suggested the members has abnormal physiological conditions but is not in jeopardy.

When a critical physiological condition is detected, the warning sign and alarm will be triggered and the personal information regarding the members will be highlighted in

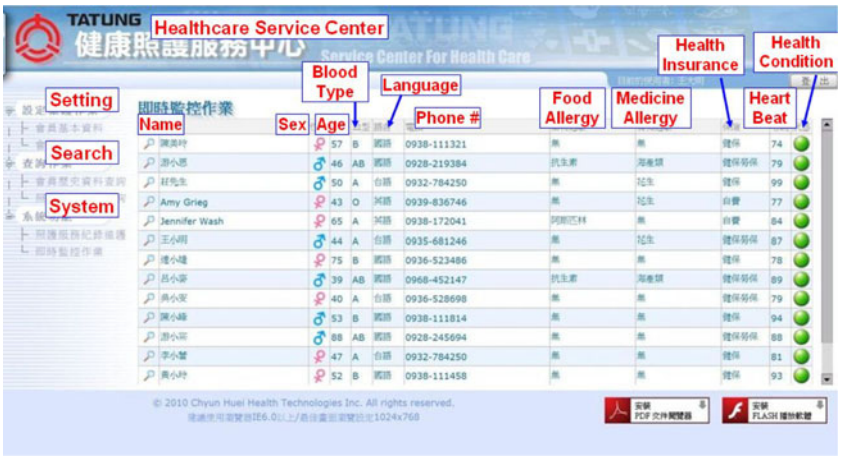

Fig. 10 Snapshot of real-time healthcare service center monitoring system

Fig. 11 Abnormal physiological condition warning

pink to suggest emergency medical services. The healthcare service center staff will click on the name of the members to enlarge the picture for more detailed information. The healthcare service center staff will attempt to contact the member by cellular phone through WiMAX to check if the member is still in conscious. If the staff is unable to reach the member, the situation will be considered emergency and emergency medical service center (911) will be contacted. The member's contact information and GPS-based geographic coordinates will be retrieved as shown in Fig. 12.

During the process of emergency medical service dispatch, the healthcare service center staff can make inquiry of the patient's health record and medical history, as shown in Fig. 13, and inform EMTs and ER about the medical records and things that requires extra attention.

When the patients is transferred into the ambulance, EMTs will use the ECG devices installed in the ambulance to continually monitor the patient's real-time physiological conditions, including electrocardiography, heart beat, body temperature, and blood pressure, and transmit the data through WiMAX to ER in the emergency medical service hospital for ER doctors to diagnose. In addition, video signal is transmitted from the ambulance to ER via WiMAX for real-time monitoring from ER, as shown in Fig. 14.

The ER doctor in the hospital can communicate with EMTs in the moving ambulance through video conferencing to instruct proper pre-hospital care and treatments on patients, as shown in Fig. 15. Before the ambulance's arrival at the emergency medical service hospital, the hospital can receive patient's physiological data including electrocardiography, body temperature, blood pressure, and heart beat, as well as information regarding visible wounds from the ambulance to prepare for necessary medical treatments in ER or arrange transfer to other hospitals.

System evaluation

The evaluation of WiMAX-based emergency medical service system is addressed from four aspects: emergency medical service mechanism, rescue time, medical equipments, and personal interview.

(1) Emergency Medical Service Process Flow

The current emergency medical service has the process flow shown in Fig. 16. When a patient experiences sudden illness and cannot contact the

Fig. 12 Emergency contact number and GPS location display

Fig. 13 Inquiry of patient's health record and medical history

emergency medical service center (911) on his/her own, the patient has to wait for others (family, friend, or people on the street) to find out the emergency condition and inform the emergency medical service center for dispatching rescue team. Such mechanism is passive and causes great delay before the rescue team can arrive at the emergency scene. In addition, EMTs can only perform basic medical treatments and report to ER the patient's basic physiological condition through audio means, making it difficult to maintain the patient's physiological status under critical conditions.

On the other hand, the emergency medical service system implemented by this study has a different process flow shown in Fig. 17. Whenever a patient experiences sudden illness, anomalies in physiological data will be directly send to the healthcare service center and trigger alarm. The staff of the healthcare service center will immediately contact the patient to confirm the patient's status. If the patient cannot be reached, the staff will immediately inform the emergency medical service center for dispatching rescue team. During ambulance transportation to ER, the system uses WiMAX to delivery real-time physiological measurement data and in-car video images to ER doctors for diagnosis and instruction to in-car medical treatments. The whole process is changed from passive waiting to active notifying and supporting.

Fig. 14 Real-time video transmitted from the ambulance via WiMAX

(2) Rescue Time

The emergency medical services process can be divided into five stages as illustrated in Fig. 18. The first stage starts as the patient is in sudden illness requiring emergency medical services, but is unable to contact 911 and requires aid from others. The second stage starts when the emergency medical service center takes the call and dispatches the rescue team. The third stage covers the arrival of the rescue team and the emergency treatments at the scene. The forth stage refers to the patient 's being transported to a nearby hospital. The final stage is the medical treatments within ER where ER doctors takeover the patient from EMTs. Time management in each stage is important to the survival of patients. Especially, the time period for a patient to wait for other's help and the rescue team's arrival is critical since the patient is the most vulnerable and unable to receive any help.

In current emergency medical services, the time of waiting for others to discover and notify 911 is unmanageable; in contrast, in the proposed active emergency medical service process, the step from anomaly detection to notification of 911 is active and takes only 2 to 3 min, much shorter than the time of waiting for others to discover the emergency condition. Moreover, in the forth step, the active transmission of the patient's in-car physiological measurements and video conferencing, jointly with the sharing of the patient's medical history between the healthcare service center and ER also save at least few tens of seconds for ER doctors to diagnose and prepare for

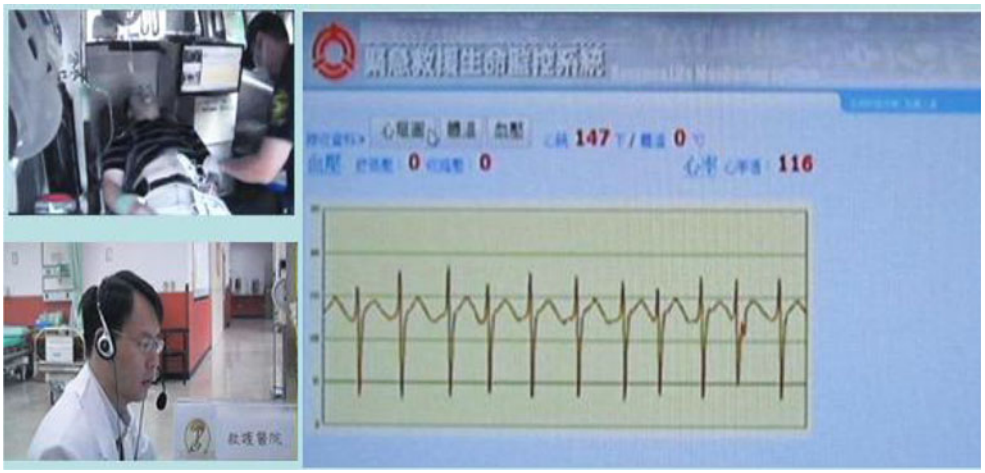

Fig. 15 Video-conferencing between EMT and ER doctors

subsequent medical treatments. In any emergency rescue incidence, more time saving means better chances for patients to survive. The proposed active emergency medical service system is advantageous in time management, as compared in Fig. 19.

(3) Cost

The cost structure of the active emergency medical service system can be mainly divided into two parts: equipment investment and salary, as analyzed in the following.

Table 4 lists the basic equipment and device requirements of the active emergency medical service system. The equipment investment in emergency ambulances will be the largest due to the large number of equipments and devices per ambulance and the large number of ambulances.

For human resource needs, the active emergency medical service system is designed to support 24/7 monitoring of members' physiological conditions. The healthcare service center staffs work on 3 shifts to cover day shift (08:00~16:00), night shift (16:00~24:00), and midnight shift (24:00~08:00), with each shift assigned with 10 healthcare staff, 2 managing staff, and 1 system manager. All staff are required to have basic medical skills and enthusiastic attitudes to actively handle members' medical emergencies. In addition, healthcare staff should have pre-job training to get familiar with the system operation, readings of physiological measurement, and standard operation procedure (SOP) of emergency medical services.

Based on the requirements to support the basic equipment operation and to satisfy human resources needs, the cost of the proposed active emergency medical service system can be calculated. The equipment and device cost to support basic operation at each endpoint is first listed in Table 5.

Table 6 further lists the estimated yearly cost for supporting the operation of the active emergency medical service system, with 3-year depreciation considered for all equipments. The equipment cost on

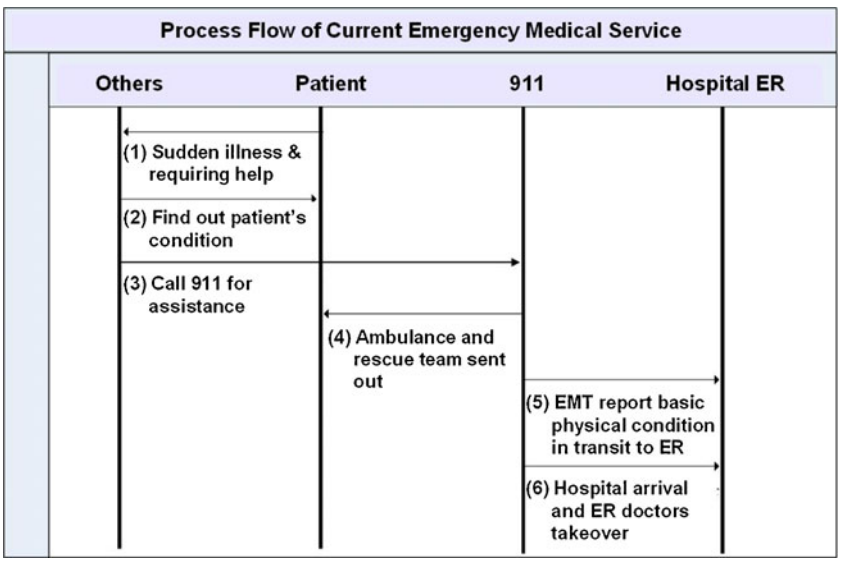

Fig. 16 Process flow of current emergency medical service

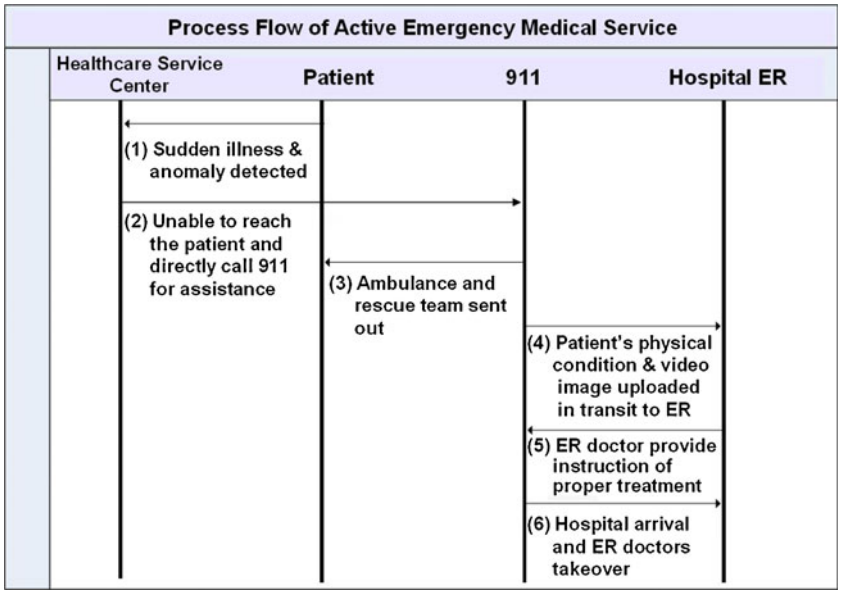

Fig. 17 Process flow of active emergency medical service

the members' side is assumed to be paid by members of the active healthcare services. The equipment cost for ambulances is the largest due to the number of equipments in each ambulance and the total number of ambulances. According to NFA, the total number of ambulances in Taiwan is 973 by 2010 [1] and therefore the total equipment cost for ambulances is $4,227,685 (USD). The cost for healthcare service centers is the second largest due to the large salary cost for dedicated staff. With four healthcare service centers distributed in Northern, Central, Southern, and Eastern Taiwan, the total salary cost is $1,992,000 (USD) and the total equipment cost is $18,680 (USD), and the total cost for healthcare service centers is $2,847,880 (USD) with rental and utilities. For the 128 hospitals in Taiwan, the cost is the $27,904 (USD) for adding system equipments. Finally, the total cost for supporting 1-year operation of the active emergency medical service system is $4,284,688 (USD).

(4) Personal Interview

One-to-one personal interviews were conducted to obtain users' feedback opinions regarding the construction of a WiMAX-based emergency medical service system. The interviewees include 5 members of instant physiological data monitoring service, 3 EMTs from the Penghu Island Fire Department, and 2 ER doctors from a local hospital on the Penghu Island. For members, the feedback opinions focused on the utilization of ECG devices and monitoring mechanism; for EMTs and ER doctors, the feedback focused on the operation of instant physiological data transmission and real-time video conferencing between ambulances in transit and ER. Table 7 summarized the feedback opinions from interviewees, including advantages, disadvantages, and suggestions. Overall, interviewees showed positive attitudes towards the implementation of the active emergency medical service system; however, system quality and stability are of great concerns.

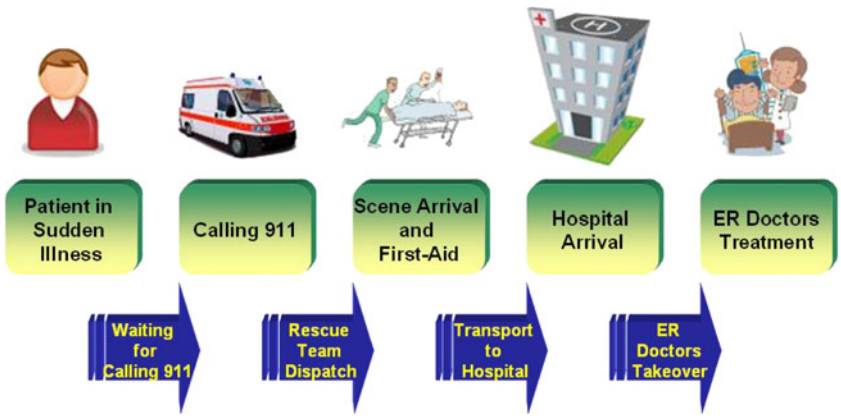

Fig. 18 Five stages of emergency medical services

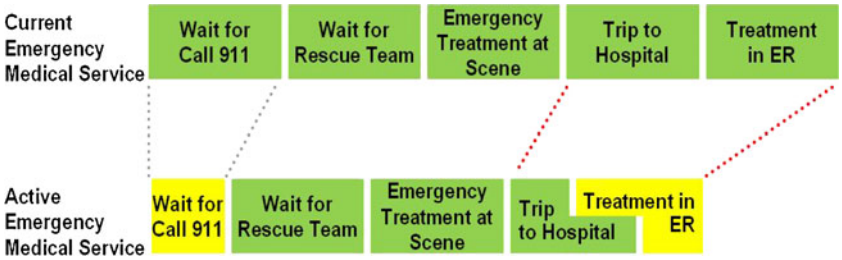

Fig. 19 Comparison of active and traditional emergency medical services

Conclusions and recommendations

This study designed and implemented a WiMAX-based active emergency medical service system. The system provides active emergency medical services through synchronizing the medical information, transmitting real-time physiological data and offer instant video conferencing between ER doctors and EMTs to understand patients' conditions and provide adequate medical treatments during patients' transportation to hospitals, with the aim to improve the current emergency medical services.

The main contributions of this study include:

(1) Achieving active emergency medical services through portable medical equipments monitoring and instant physiological data transmission.
(2) Through quick response to patients' abnormal physiological conditions and actively inform 911 for requesting rescue teams, the waiting time for rescue is shortened to 2 to 3 min.
(3) The automatic transmitting and recording of physiological data minimizes the errors caused by human intervention and saves the time for recording data.
(4) ER doctors can monitor the patients' physiological conditions and provide instructions for EMT to perform proper medical treatments through synchronized real-time in-car video and physiological data transmission from ambulances to ER.
(5) The application of user-friendly interface such as touch screens allows EMTs to carry out emergency treatment tasks in a convenient manner.
(6) The experiences of establishing the active emergency medical service system can be applied to both urban and rural regions.

Table 4 Equipment and device requirement at each endpoint

Endpoint	Item	Equipments
Member	1	Portable MID
	2	Portable Bluetooth ECG transmitter
	3	ECG patch
Emergency ambulance	1	Touch-screen monitor
	2	WiMAX CPE
	3	ECG transmitter
	4	Blood pressure and glucose meter
	5	Digital ear thermometer
	6	HD webcam w/720p wide screen
	7	Video Server
	8	HD video camera
	9	UPS
	10	Laptop computer
	11	Wireless headset (w/microphone)
Healthcare service center	1	Database server
	2	Personal computer
	3	Headset
Emergency medical service hospital (equipped in ER)	1	Personal computer
	2	HD webcam w/720p wide screen
	3	Headset (w/microphone)

Through the use of WiMAX technology, the ECG devices on the members' sides, the healthcare service center, emergency ambulances, and emergency medical service hospitals jointly formed a complete active emergency medical service system. The portable ECG devices with WiMAX wireless transmission capability allowed members who need constant monitoring of physiological conditions to continue their daily lives without significant interference from medical measurement facilities, realizing human-centered medical services. The overall performance of emergency medical services was improved with constant monitoring of members' physical conditions, active ambulance dispatch under emergency, and instant physiological data transmission and video conferencing to ER in ambulances.

The WiMAX application in this research is currently only for members of healthcare service center. It can be applied to the public such as the population that needs special care, the elderly, and patients with cardiovascular diseases. In the past, people who need special care must have nurses at their sides to prevent accidents from occurring under unattended situations, and therefore patients' activities are rather restricted. Through the active emergency medical service system proposed in this study, with the support of portable medical equipments and WiMAX wireless network technology, patients used to require intensive care can now live their daily lives like normal people. The patients no longer need to worry about being unable to reach for help during their travel when accidents

Table 5 Equipment and device cost at each endpoint (in USD)

Endpoint	Equipments	Price	Quantity	Subtotal
Member	Portable MID	335	1	335
	Portable Bluetooth ECG transmitter	335	1	335
	ECG Patch	10	1	10
	Subtotal			680
Emergency ambulance	Touch-panel screen	500	1	500
	WiMAX CPE	200	1	200
	HD video camera	835	1	835
	Camera support	90	1	90
	Video Server	280	1	280
	Laptop computer	835	1	835
	ECG transmitter	335	1	335
	Blood pressure and glucose meter	170	1	170
	Digital ear thermometer	50	1	50
	HD WebCam	85	1	85
	UPS	230	1	230
	Wireless headset	65	1	65
	Mechanical supporting parts	570	1	570
	Miscellaneous supplies	100	1	100
	Subtotal			4,345
Emergency medical service center	Database server	3,350	1	3,350
	Personal computer	535	1	535
	Headset	35	1	35
	Subtotal			2,440
Emergency medical service hospital	Personal computer	535	1	535
	HD WebCam	85	1	85
	Headset	35	1	35
	Subtotal			655

Table 6 Yearly cost of the active emergency medical service system (in USD)

Endpoint	Cost list	Price	Quantity	Subtotal
Member	Equipment Cost	–	–	–
Emergency ambulance	Equipment Cost	1,448	973	1,408,904
Healthcare service center	Staff Salary	12,000	120	1,440,000
	Manager Salary	16,000	24	384,000
	System Manager	14,000	12	168,000
	Salary Subtotal			1,992,000
	Computer Facilities	190	52	9,880
	Database Server	1,100	8	8,800
	Equipment Subtotal			18,680
	Network Annual Fee	4,000	4	16,000
	Office Rental	200,000	4	800,000
	Office Utilities	100	52	5,200
	Utilities and Phone	4,000	4	16,000
	Rental and Utility Subtotal			837,200
	Healthcare Service Center Total Cost			2,847,880
Emergency medical service hospital	Equipment Cost	218	128	27,904
Total				4,284,688

Table 7 Feedback from interviewees

Interviewee	Feedback
Members of physiological condition monitoring	Advantages
	1. Personal health condition is under constant caring.
	2. Small ECG devices have only small interference with daily lives.
	3. In case of emergency, the monitoring system indeed helps in informing 911 in the short time.
	4. With the help of constant monitoring on health conditions, patients can be physically and mentally more relaxed.
	Disadvantages
	1. ECG devices are only suitable for static activities.
	2. The signal transmission of physiological data is affected by the weather conditions.
	3. Charging of medical equipments and devices is troublesome.
Emergency ambulance EMTs	Advantages
	1. The instant video images and physiological data transmission does help to understand patients' conditions.
	Disadvantages
	1. Network transmission affects the image quality of instant video and the synchronization between audio and video signals.
	2. On-line instruction of emergency medical treatment is limited by the abilities of EMTs.
	Suggestions
	1. To overcome the darkness within the ambulance, increasing lighting in the vehicle is necessary.
	2. The fixed in-car video cameras do not support observation of patients' specific body parts. Additional mobile cameras are needed for better understanding of patients' detailed conditions and preparing for medical treatments in ER.
ER doctors	Advantages
	1. The transmission of physiological measurement data helps ER doctors in preliminary judgment.
	2. The fast WiMAX transmission helps in transmitting instant images in moving ambulance.
	Suggestions
	1. Maintaining stability and quality of WiMAX network transmission will help to improve the system stability and efficiency.

occur. They can regain their independence with the support of physical condition monitoring.

The limitations to this study include the following:

(1) To ensure WiMAX signal coverage while maintaining clear signal transmission, this study chose Penghu Island as the region of study to avoid signal interference in metropolitan areas.
(2) The subjects of this study were limited to EMTs of one rescue team under the Penghu Island Fire Department, ER doctors in one local hospital on the Penghu Island, and members of instant physiological data monitoring service on the Penghu Island.
(3) The installation of WiMAX transmission and digital medical devices in emergency ambulances was limited by the existing space arrangement in the ambulance.
(4) With limited research region and subjects, further studies may be needed to generalize results of this study to all regions in Taiwan.

Suggestions to future studies can be divided into several directions. Firstly, the current WiMAX-based active emergency medical service system can only provide limited physiological condition monitoring. How to incorporate more functions into the system and how to evaluate the effectiveness and efficiency of the incorporated functions is one key direction of future studies. Secondly, the alarm mechanism in the current system requires staff of the healthcare service centers to contact patients for emergency situation confirmation and to call 911 for ambulance request. Whether and how to develop a voice-message-based system, to reduce labor work and to improve efficiency form another direction.

Thirdly, this study chose WiMAX as the support wireless network technology to develop the emergency medical service system. With the future technology advancement, there may be other technologies, e.g., LTE, more suitable for the applications in this study. The shift from WiMAX-based platform to other platform may be one more important direction to work on. Overall, the efficiency and accuracy of the system should be considered first to ensure the benefits of patients using the developed systems.

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