A NOVEL LOW COST TELEMEDICINE SYSTEM USING WIRELESS MESH NETWORK

E. Supriyanto[1], H. Satria[2], I.H. Mulyadi[2] and E.H. Putra[2]
[1] Faculty of Biomedical Engineering and Health Science
[2] Faculty of Electrical Engineering
Universiti Teknologi Malaysia

ABSTRACT

Telemedicine promises an improvement of health care service quality in rural, urban, dense and mobile areas. In order to implement the telemedicine in these areas, a low cost telemedicine system with acceptable quality for medical data transfer is required. This paper discusses simulation and implementation results of a low cost telemedicine system including wireless medical interface and communication infrastructure. A simulation has been done to investigate the network quality of service. The infrastructure has been also implemented using low cost 5.8 GHz transceiver for backhauls and low cost 2.4 GHz transceiver for clients. Test result shows that the low cost telemedicine system is able to do real time communication between patient and medical staff with medical data rate up to 2 Mbps. It shows that the low cost telemedicine sytem using wireless mesh network can be implemented in remote area with acceptable medical data transfer quality.

1. INTRODUCTION

Telemedicine is an emerging technology which combining telecommunication and information technology for medical practice. It gives a new way to deliver health care services when the distance between doctor and patient is significantly away. Telemedicine can deliver health care services to the patient even in remote area.

Pavlopoulos et al. (1998) has presented an example of telemedicine advantage with implementation on ambulatory patient care at remote area. Another application has been done by Sudhamony et al. (2008) for cancer care in rural area. High technology telemedicine application in surgery has already been developed by Xiaohui et al. (2007).

Currently, the telemedicine uses available wired and wireless infrastructures. Telemedicine infrastructures with wired network have been proposed by Al-Taei (2005) using Integrated Service Digital Network (ISDN), Asynchronous Transfer Modes (ATM) by Cabral & Kim (1996), Very Small Aperture Terminal (VSAT) by Pandian et al. (2007) and Asymmetric Digital Subscriber Line (ADSL) by Ling et al. (2005). Telemedicine has also been implemented in wireless network using Wireless LAN (WLAN) proposed by Kugean et al. (2002), Worldwide Interoperability for Microwave Access (WIMAX) by Chorbev et al. (2008), Code Division Multiple Access (CDMA) 1X-EVDO by Yoo et al. (2005), General Packet Radio Switch (GPRS) by Gibson et al. (2003) and 2G Groupe Spécial Mobile (GSM) by Pavlopoulos et al. (1998).

Each infrastructure has its own obstacle, in particularly when they are implemented in a remote area. For example, Asynchronous Transfer Mode (ATM) and Multi Protocol Label Switching (MPLS) had some mobility and scalability limitation, even both networks provide high Quality of Service (QoS) and have stability on delivering data (Nanda et al., 2007). The fragility of 3G UMTS network for telemedicine has been explored by Y. E. Tan et al. (2006), where the implementation costs are high and does not provide enough QoS. Comparison of available network infrastructures and technologies for telemedicine system are summarized in Table 1. It can be shown that based on cost, data rate and mobility, the optimal solution for telemedicine system is Wireless Mesh Network (WMN).

In order to investigate the quality and the possibility of using WMN as a telemedicine infrastructure, a simulation of data communication in WMN using NS2 network simulator has been done. Besides, the infrastructure and the medical data interface have been also developed and tested. This is required to create a low cost telemedicine system that has an acceptable quality of service.

Table 1 Comparison of available network infrastructures/technologies for telemedicine system

infrastructure/ technology	bit rate (Mbps)	investment cost*	operational cost	user device cost	mobility
Fiber Optics	2,550,000	H	M	VH	No
ATM	155	VH	H	VH	No
ADSL	8	H	M	M	No
ISDN	0.128	H	M	M	No
VSAT	4.09	VH	M	VH	No
GPRS	0.115	H	L	L	Yes
EDGE	0.256	H	L	L	Yes
3G UMTS	0.512	H	M	M	Yes
HSDPA	3.6	VH	M	M	Yes
WMN	54	L	VL	L	Yes
WiMAX	54	M	VL	L	Yes

Note:

$$\text{*investment cost} = \frac{\text{cost of investment}}{\text{number of user node that can be serviced}}$$

VH = very high, H=high, M=medium, L=low, VL=very low

2. MEDICAL QUALITY OF DATA AND SERVICE

An application example of telemedicine system can be seen in Fig. 1. It involved patients and doctors that are equipped with medical data assistant (MDA). The MDA acquires the medical data using Medical Data Interface (MDI). MDI retrieves medical data from various medical devices. Typical medical devices are electrocardiography machine (ECG), Doppler instrument, blood pressure monitor, ultrasound machine and stethoscope. The MDA are connected through wireless router and transceiver for data transmitting between patient and doctor. Two-way communication between patient and doctors is supported by camera and microphone. All of patient medical data are continuously recorded inside the server for diagnostic purposes.

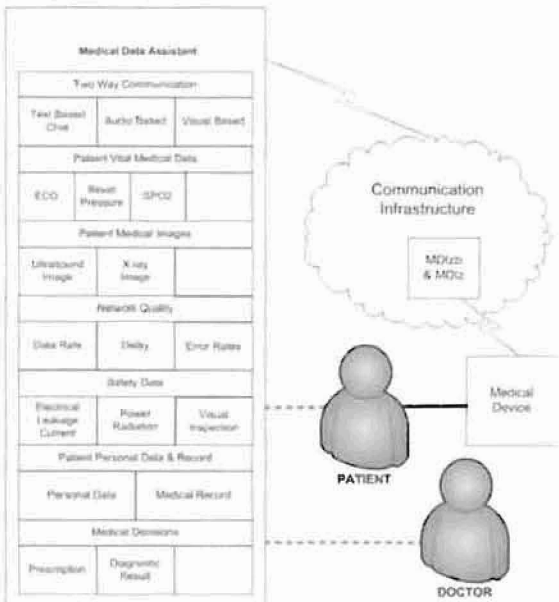

Fig. 1 An application example of low cost telemedicine system

For this application, the minimum data rate for acceptable (good) quality and excellent quality are listed in Table 2.

Table 2 Desired output data rate

devices	data rate good	data rate excellent
ECG	2 kbps	12 kbps
Doppler Instrument	40 kbps	160 kbps
Blood Pressure Monitor	1 kbps	1 kbps
Ultrasound Machine	100 kbps	400 kbps
Camera	100 kbps	2,000 kbps
Stethoscope	40 kbps	160 kbps
Microphone	40 kbps	160 kbps
Total	323 kbps	2,893 kbps

The minimum data rate for acceptable service in telemedicine system is 323 kbps, whereas for excellence quality minimum data rate 2,893 kbps is required.

Up to now, there is no specific rule defining QoS provisions of telemedicine application. In addition, parameterized QoS is a clear QoS bound which are stated in terms of quantitative values such as throughputs, end delay, jitter and packet loss. These QoS bounds are explained in Table 3.

3. WIRELESS MESH NETWORK FOR TELEMEDICINE SYSTEM

Hardware configuration for low cost telemedicine communication infrastructure is shown in Fig. 2. This infrastructure is divided into three areas of implementation; client and indoor network, backhaul outdoor network and medical central service.

Table 3 QoS for low cost telemedicine system

parameter	definition	requirement
throughput	packet arrival rate	min 323 kbps
delay	the time taken by a packet to reach its destination	max 100 ms
jitter	time of arrival deviation between packets	max 50 ms
packet loss	percentage of non-received data packets	max 5 %

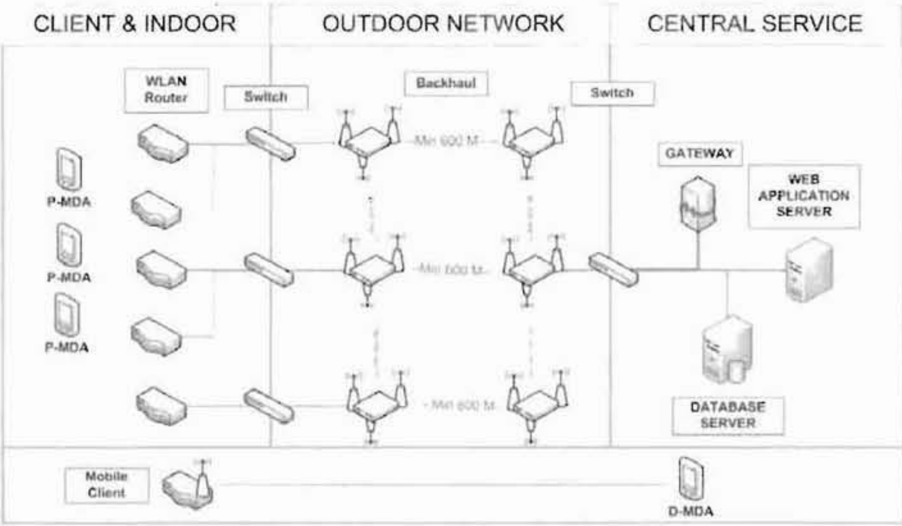

Fig. 2 Hardware configuration for low cost telemedicine communication infrastructure

In indoor network, a wireless router is connected to medical devices through MDI and connected to outdoor network via switch. Outdoor network is main structure of wireless mesh network. This configuration enables a communication between client and central service or medical doctor via Doctor-Medical Data Assistant (D-MDA). This enables also mobile communication between patient and medical doctor.

Characteristic of WMN outdoor backhaul are described in Table 4. The operational frequency of 5.750 GHz has been used to overcome distance and obstacles between backhaul connections. Parameters for the WMN indoor router are described in Table 5. The operational frequency of WMN indoor router is 2.470 GHz.

Table 4 WMN outdoor backhaul characteristic

Parameter	value
antenna	
Type	directional antenna
gain transmitter	10 dBi
gain receiver	10 dBi
receiver sensitivity	-100 dBm
line of sight range	20 km
network interface	
input power (max)	1 W
channel frequency	5.750 GHz
data rate	54 Mbps

Table 5 WMN indoor router characteristic

Parameter	value
antenna	
Type	omni directional
gain transmitter	1 dBi
gain receiver	1 dBi
receiver sensitivity	-104 dBm
network interface	
input power (max)	10 mW
data rate	11 Mbps
channel frequency	2.470 GHz

NS2 version 2.33 network simulator has been used to simulate the QoS parameter including delay, throughput, jitter and packet loss. Three protocols have been implemented in the simulation. The simulation method and results are reported by Supriyanto et al. (2008). Fig. 3 shows throughput as function of hop number. Simulation result shows variations of throughput for each routing protocol. The bigger hop number, the smaller throughput. It is due to delay and waiting time in routing mechanism. DSDV routing protocol inferred its throughput better than the other protocols. Simulation result shows that the network able to transfer the medical data up to 2 Mbps, even still more than 200 kbps for 6 hops. This result shown the ability of network to fulfill the qood quality medical data transfer requirement.

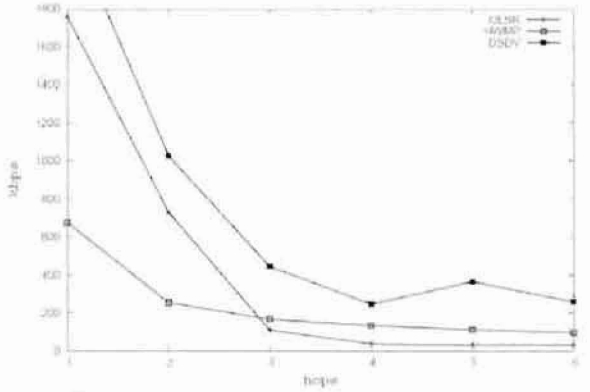

Fig. 3 Throughput comparison of each routing protocol in EPT system.

4. WIRELESS MEDICAL INTERFACE

In order to enable the connection between common medical devices and network infrastructure, a wireless medical interface has been developed. The wireless medical interface is implemented using Zigbee and Bluetooth technology.

Two kinds of wireless medical interface has been developed; MDIz and MDIzb. MDIz is a device which acquires data from medical device and transmits it out through Zigbee network, while MDIzb coordinates the Zigbee network as well as communicates with Medical Data Assistant through Bluetooth network.

Medical data is acquired by MDIz and then added with a frame as shown in Fig. 4. The data is then transmitted to MDIzb through Zigbee network. MDIz is able to send data up to 115200 bps. The bandwidth is more than enough for vital sign data. The network has a PAN ID to differ with the other Zigbee networks.

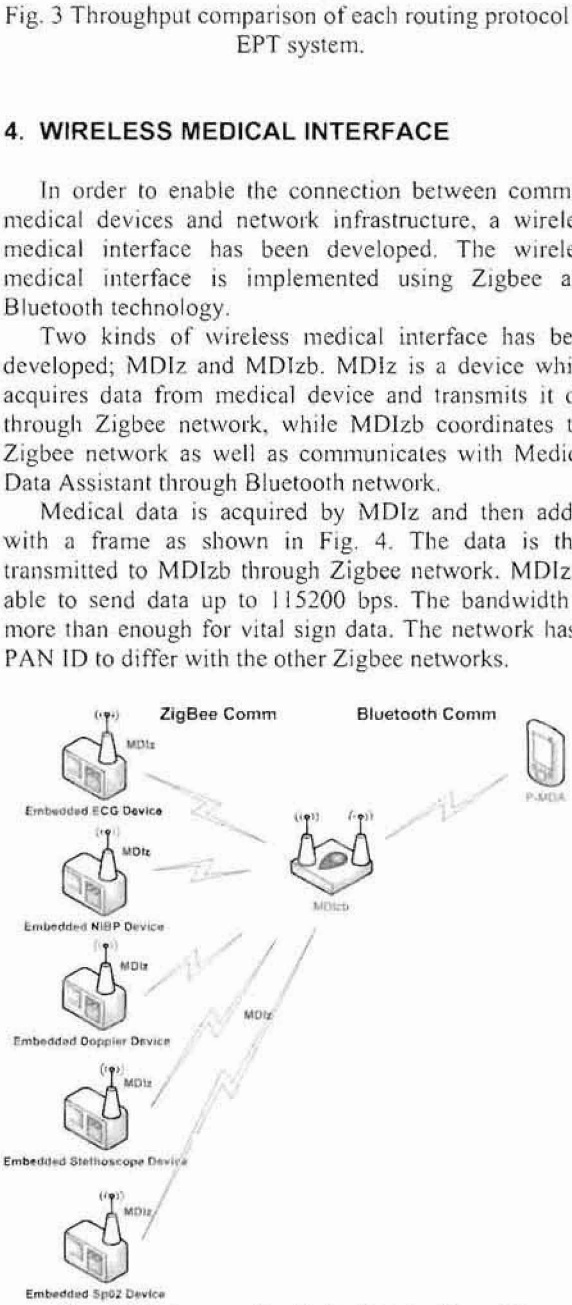

Fig. 4 Wireless medical interface configuration

The MDIz was designed for short range communication, between the embedded device attached to the patient and MDIzb. Table 6 shows MDIz characteristics. MDIzb has the same operational frequency as MDIz, but the modulation is slightly different. Table 7 shows MDIzb characteristics.

Table 6 MDIz characteristic

parameter	Value
Antenna	
type	omni antenna
gain transmitter	1 dBi
gain receiver	1 dBi
receiver sensitivity	-92 dBm
indoor coverage range	30 m
line of sight range	100 m
Zigbee module	
channel frequency	2.411 GHz
bandwidth	1.359 MHz
data rate	115200 bps

Table 7 MDIzb characteristic

parameter	Value
Antenna	
type	omni antenna
gain transmitter	1 dBi
gain receiver	1 dBi
average power	-89 dBm
line of sight range	100 m
Bluetooth module	
channel frequency	2.411 GHz
bandwidth	1.359 GHz
data rate	723300 bps

Fig. 5 shows block diagram of MDIz. Analog signal from medical sensor is conditioned, digitized and processed by a processor. The data from processor is converted to Zigbee and then transmitted out. The data is arranged in a frame as shown in Fig. 6. It consists of device ID, status, length of frame, data and checksum. The Zigbee module is bidirectional. MDIz can receive the command through Zigbee module.

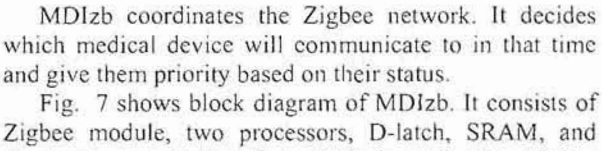

Fig. 5 MDIz Block Diagram

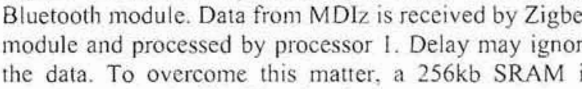

Fig. 6 Data Frame of MDIz

MDIzb coordinates the Zigbee network. It decides which medical device will communicate to in that time and give them priority based on their status.

Fig. 7 shows block diagram of MDIzb. It consists of Zigbee module, two processors, D-latch, SRAM, and Bluetooth module. Data from MDIz is received by Zigbee module and processed by processor 1. Delay may ignore the data. To overcome this matter, a 256kb SRAM is added as a data buffer. The data is then sent to processor

2 to add a frame as shown in Fig. 8 before transmitted out by Bluetooth module. Bluetooth data is acquired by mobile data assistant. The Bluetooth module is bidirectional. MDIzb can receive the command through Bluetooth module.

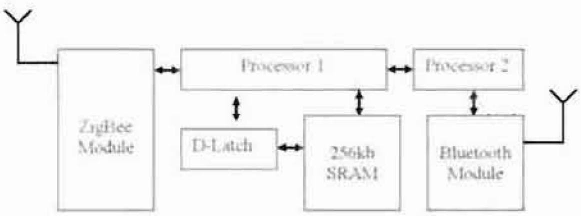

Fig. 7 MDIzb block diagram

Fig. 8 Data frame of MDIzb

5. TESTING AND ANALYSIS

The testing has been done to investigate the network performance and the reliability of system including wireless medical interface.

Fig. 9 shows the test result for MDIz signal strength. MDIz signal strength is the MDIz power to receive the data between receiver at medical interface and transmitter at medical equipment communication using Zigbee communication. It should be higher rather than its receiver sensitivity (Signal Strength ≥ Rx sensitivity) from the specification of MDIz. Test result shows that for the distance up to 10 meters, the MDIz Signal strength gives the result higher than its receiver sensitivity at -92 dBm.

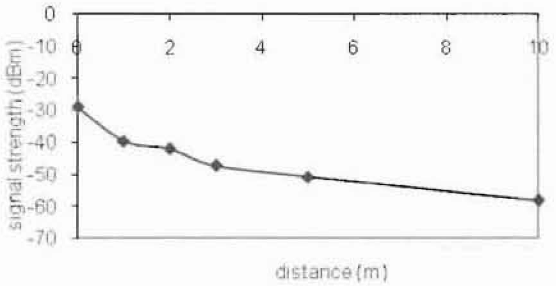

Fig. 9 MDIz signal strength

The measurement has also been done for the data transmission between wireless medical interface and P-MDA client. Fig. 10 shows the signal strength of communication between medical interfaces through the P-MDA client using Bluetooth communication.

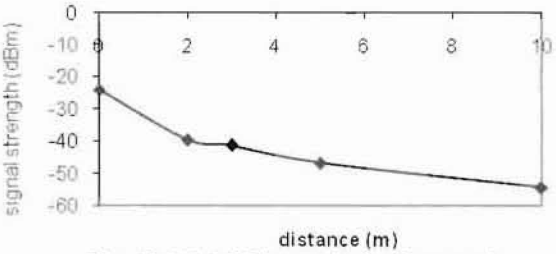

Fig. 10 MDIzb Bluetooth signal strength

Fig. 11 shows the signal strength of communication between P-MDA and WLAN router using WiFi communication. This result shows that the cover of 10 meters still give high Signal to Noise Ratio (SNR) from wireless router sensitivity.

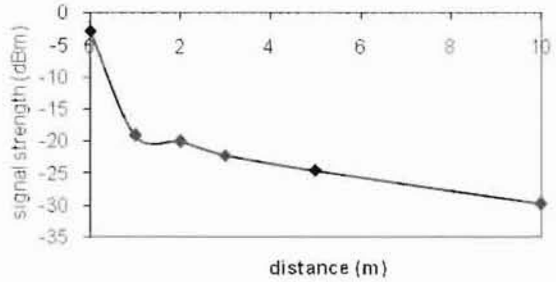

Fig. 11 Wireless router WiFi signal strength

The network performance test result is shown in Table 8. The measurement is done for backhauls 1 km distance. The result shows the noise rate varies from its receiver sensitivity. The average signals for each backhaul in open space area with clear weather are in range of -26 and -28 dBm. This gives the SNR values of 72 dB for low SNR and 82 dB for high SNR.

Table 8 Network performance testing of each backhaul at 1 km

Location	antenna	band (MHz)	noise high (dBm)	noise low (dBm)	signal strength (dBm)
Location	1	5180	-98	-106	-26
1	2	5180	-98	-107	-28
Location	3	5180	-98	-108	-26
2	4	5180	-97	-108	-28
Location	5	5180	-98	-106	-26
3	6	5180	-98	-106	-26

The testing has been done to transfer the medical data up to 2 Mbps. Test result shows the network is still able to fulfill the minimum requirement stated in Table 3 with excellent signal strength.

Table 9 Connection characteristic per hop between backhaul

hop	distance (km)	SNR (dB)	data rate (Mbps)
1	1.2	54	6.35
2	2.6	32.5	4.62
3	3.4	30	4.11

Table 9 shows the average values from connection measurement in each number of hops. Hop is counted from the user in location 1 to the destination in other location. The data rate was calculated from the average of data rate of each user. Testing results shows that the low cost telemedicine infrastructure within 3 hop count with distances more than 3 km fulfills the requirement of medical data rate of more than 2.8 Mbps for excellent quality of medical data. Moreover, the attenuation of weather and obstacles, such as building and tree has decreased the SNR value into low than 72 dB in distance of 1.2 km.

CONCLUSION

A novel low cost telemedicine system using WMN has been successfully developed and tested. The system consists of wireless medical interface and communication infrastructure.

The wireless medical interface using Zigbee and Bluetooth technology has been implemented to enable the connection some medical devices to communication infrastructure. The communication infrastructure has been implemented using low cost 5.8 GHz transceiver for backhauls and low cost 2.4 GHz transceiver for clients. Simulation and test results show that the system is able to transfer the required medical data up to 2 Mbps.

In order to enable the implementation of this system, a data encryption and safety monitoring units of medical devices should be integrated in the system.

REFERENCES

Al-Taei, M., Telemedicine needs for multimedia and integrated services digital network (ISDN), *Proc. ICSC Congress on Computational Intelligence Methods and Applications*, IEEE, Amman, Jordan. 2005.

Cabral, J.J. & Kim, Y,. Multimedia systems for telemedicine and their communications requirements. *IEEE Communications Magazine*, 1996.

Chorbev, I., et.all., WiMAX supported telemedicine as part of an integrated system for e-medicine. *Proc. 30th International Conference on Information Technology Interfaces*. IEEE, Dubrovnik, 2008.

Deng, L. & Poole, M.., Learning through telemedicine networks, *Proc. the 36th Annual Hawaii International Conference on System Sciences*. IEEE, 2003.

Gibson, O.J., Cobern, W.R., Hayton, P.M. & Tarassenko, L., A GPRS mobile phone telemedicine system for self-management of type 1 diabetes, Proc. *2nd IEEE EMBSS Conference on Biomedical Engineering and Medical Physics*, Birmingham, 2003.

Kugean, C. et al., Design of a mobile telemedicine system with WLAN, Proc. *Asia-Pacific Conference on Circuits and Systems*, IEEE, Singapore, 2002.

Ling, L. et al., A multimedia telemedicine system, Proc. *27th Annual International Conference of the Engineering in Medicine and Biology Society*, IEEE, 2005.

Nanda, P. & Fernandes, R., Quality of Service in Telemedicine, Proc. *First International Conference on the Digital Society*, IEEE, Guadeloupe 2007.

Pandian, P. et al., Internet Protocol Based Store and Forward Wireless Telemedicine System for VSAT and Wireless Local Area Network, Proc. *International Conference on Signal Processing, Communications and Networking*, IEEE, Chennai, *2007*.

Pavlopoulos, S. et al., A novel emergency telemedicine system based on wireless communication technology-Ambulance, *IEEE Transactions on Technology in Biomedicine*, vol.2, no.4, p.261 – 267, 1998.

Sudhamony, S., Nandakumar, K., Binu, P. & Niwas, S., Telemedicine and tele-health services for cancer-care delivery in India, *IET Communications*, vol.2, no.2, p. 231 – 236, 2008.

Supriyanto, E. et al., Simulation of Emergency Prenatal Telemonitoring System in Wireless Mesh Network, Proc. *Third international conference on modeling, simulation and applied optimization*, IEEE, Sharjah, 2008.

Xiaohui, X., Ruxu, D., Lining, S. & Zhijiang, D., Internet based telesurgery with a bone-setting system, Proc. *IEEE International Conference on Integration Technology*, Shenzhen, 2007.

Y. E. Tan, N.P. & Istepanian, R.S.H., Fragility Issues of Medical Video Streaming over 802.11e-WLAN m-health Environments, *Proc. the 28th IEEE EMBS Annual International Conference*, *2006*.

Yoo, S.K. et al., Prototype Design of Mobile Emergency Telemedicine System, Proc. *Computational Science and Its Applications*, Springer, Berlin, 2005.

Eko Supriyanto
received M.Eng in Biomedical Engineering from Institut Teknologi Bandung and Dr.-Ing (2003) from University of Federal Armed Forces Hamburg, Germany. He is currently a senior lecturer in Faculty of Biomedical Engineering and Health Science, Universiti Teknologi Malaysia.

Muhammad Haikal Satria
received the B.E. (2002) from Universitas Indonesia and M.Sc. (2006) from Universität Duisburg Essen, Germany. He is a PhD student in Faculty of Electrical Engineering, Universiti Teknologi Malaysia.

Indra Hardian Mulyadi
received the B.E. (2004) from Institut Teknologi Bandung. He is a Master student in Faculty of Electrical Engineering, Universiti Teknologi Malaysia.