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TELECARDIOLOGY SYSTEM FOR FOURTH GENERATION HETEROGENEOUS WIRELESS NETWORKS

Hoe Tung Yew[1, 2], Yudha Aditya[1], Haikal Satrial[1], Eko Supriyanto[1] and Yuan Wen Hau[1]
[1]IJN-UTM Cardiovascular Engineering Centre, Faculty of Biosciences and Medical Engineering, Universiti Teknologi Malaysia (UTM), Skudai, Johor, Malaysia
[2]Faculty of Engineering, Universiti Malaysia Sabah, Kota Kinabalu, Sabah, Malaysia
E-Mail: htyew@ums.edu.my

ABSTRACT

Telecardiology allows healthcare professionals to monitor and interpret their patients' electrocardiography (ECG) via information and communication technologies (ICT). It improves the cardiac patient's life quality by bridging the gap between healthcare professionals and patients. With the rapid development of ICT, telecardiology systems now can support high quality medical image and video. However, the existing telecardiology systems are relying on a single wireless network. These systems are unable to guarantee that the users will be always connected to the wireless network. Furthermore, these systems are less reliable due to poor network quality will results an interruption on telecardiology application. Thus, a telecardiology system integrated with vertical handover algorithm for Fourth Generation (4G) heterogeneous wireless networks is proposed to compensate the imperfection of existing telecardiology systems. The proposed system allows users always connected to the best quality network at anytime and anywhere in seamless manner. The simulation result shows that the proposed system outperforms the existing telecardiology systems which rely on single network in term of network quality.

Keywords: telecardiology, fourth generation heterogeneous wireless networks, handover, network quality.

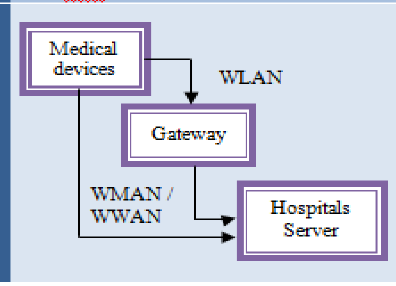
INTRODUCTION

Cardiovascular diseases are leading cause of death in worldwide. According to World Health Organization (WHO), 17.5 million people died from cardiovascular diseases globally in year 2012. By year 2030, it has been estimated that there will be more than 23 million people die from cardiovascular diseases (WHO, 2012). To improve the cardiac patients' life quality and reduce the mortality, telecardiology system has been implemented. Telecardiology is a mechanism of delivering cardiovascular health care services by using ICT at distance (Yew *et al.*, 2014). Numerous studies have presented that telecardiology could reduce morbidity and mortality (Brunetti *et al.*, 2013), (Brunetti *et al.*, 2010), (Brown *et al.*, 2008) improve patients follow up rate (PausJessen *et al.*, 2008), and better utilization of hospital resources (Maarop and Khin, 2012).

The existing telecardiology systems are able to support different type of wireless networks such as Wireless Local Area Network (WLAN) (Ken and Liang, 2010), Wireless Metropolitan Area Network (WMAN) (Chorbev *et al.*, 2008), satellite (Clarke *et al.*, 2000), (Mair, *et al.*, 2010), (Alberto, 2011), (Aziz *et al.*, 2009) and Wireless Wide Area Network (WWAN) (Abo-Zahhad *et al*. 2014), (Huang *et al*. 2014), (Lin *et al*., 2010), (Mitra *et al.*, 2008), (Sufi *et al.*, 2010), (Sufi *et al.*, 2009), (Warren *et al*., 2011). However, these systems are relying on a single wireless network during transmission of medical data. They are unable to guarantee that the users will be always connected to the wireless network at anywhere and anytime. Moreover, coverage area of these systems is also limited. For example, the users outside of WiMAX wireless network coverage cannot use the telecardiology system which is using WiMAX wireless technology. Furthermore, the systems rely on single network are less reliable because poor network quality or disconnections of wireless network will results an interruption on telecardiology application.

In addition, the different characteristic for each type of wireless networks (as shown in Table-1) may cause users face a difficulty to choose the right telecardiology system for their circumstance. For example, WLAN has higher bandwidth than cellular network but the network coverage is very limited and it does not support high mobility. Conversely, cellular network has large coverage and support high mobility but the bandwidth is lower than WLAN.

Table-1. Characteristic of wireless technologies.

	WLAN	WMAN	WWAN
Maximum Bandwidth (bps)	Up to 54Mbps	Up to 54Mbps	Up to 5 Mbps
Distance (km)	Depend on frequency and transmission power: 0.1	35	50
Cost	Low	Medium	High
Mobility (speed)	Low	Medium	High
Standard	IEEE 802.11	IEEE 802.16	3GPP
Example	WiFi	WiMAX	UMTS
Application in Telecardiology			

4G HETEROGENEOUS WIRELESS NETWORKS

Wireless communication technologies play an important role in telecardiology system. The evolution of Wireless Wide Area Network (WWAN) from First Generation (1G) to Fourth Generation (4G) is shown in Table-2. Referring to Hui and Yueng (2003), 4G wireless technology is merged of multiple wireless network technologies. It integrates both IP (Internet Protocol) and non-IP based systems. It has a structure based on unified IP. With unified IP based, mobile terminal or user can access to different wireless network technologies at anytime and anywhere via seamless handover mechanisms (Yan, 2010), (Ahmed *et al*., 2014).

By using 4G wireless technology, telecardiology system is able to connect to different type of high bandwidth with better quality-of-service (QoS) wireless networks in seamless manner (Niyato and Hossain, 2008), (Varshney, 2012). The coverage and reliability of telecardiology system are also increased (Vaeshney and Radhika, 2001). Even one or more networks are failed; the system is still able to connect to the most appropriate network among the available alternatives.

Table-2. Evolution of wireless network.

Cellular network generation	Year	Service	Standard	Bandwidth (bps)
1G	1980	Analogue voice	AMPS	2.4K ~ 30K
2G	1991	Digital voice, Short Message Service (SMS)	GSM	9.6K ~ 14.4K
2.5G	1999	Higher capacity, packetized data	GPRS, TDMA, EDGE	171K ~384K
3G	2003	Broadband data up to 2Mbps	UMTS, CDMA, CDMA 2000, HSPDA	2M ~5M
4G	2010	Unified IP based with speed > 100 Mbps	Single standard	>100M

RELATED WORKS

Seamless handover is one of the main issues in 4G wireless technology. The problems such as when to initiate handover and how to select the most appropriate network need to be solved. Authors in (Yang et al., 2007) (Yang and Qiu, 2007) presented a QoS based vertical handover algorithm between WLAN and WWAN using signal-to-interference-plus-noise ratio (SINR) to consistently offer mobile terminal (MT) with maximum available bandwidth. But, variation of SINR will cause high handover rate and unnecessary handover.

Hong et al., (2009), proposed a cost function based vertical handover decision algorithm that operates based on network cost. The output result shows that WLANs are always preferred whenever the WLAN access is available. It is because WLAN cost is lower than WWAN. Approach in (Hong *et al*., 2009) is power consuming and high number of handover.

Tawil *et al*., (2008) proposed a Multiple Attribute Decision Making (MADM) based vertical handoff for WLAN and cellular networks. The input parameters for this scheme included bandwidth, cost and dropping probability. In this scheme, cellular network is defined as Home Network. If MT detects few available WLAN networks simultaneously, it will measure every network quality and dropping probability. The MT will avoid making connection to the WLAN network with high dropping probability. This scheme is able to reduce the handover blocking and increase throughput. However, handover latency will increase when network load is increased because MADM calculation is processed by network.

To improve the handover performance, Fuzzy Logic and Artificial Neural Network (ANN) are combined with MADM in handover decision making. For example, Chamodrakas and Martakos (2011) used Fuzzy TOPSIS (Technique for Order Preference by Similarity to the Ideal Solution) approach to select the optimal network which achieves the best network balance between performance and energy consumption. Furthermore, Radhika, K. and Reddy, A.V. (2011), presented a network selection algorithm based on Fuzzy Multiple Criteria Decision Making (MCDM) that calculates the quantitative value of each normalized parameter and finds the weight of each quantitative value. This weight vector together with normalized parameter values are used to evaluate the available networks. The network with highest score is selected as the target network. The combination algorithms provide high successful rate in selecting the best network but these algorithms have high handover delay due to multiple networks parameters take in account and complex algorithm. The high handover delay may increase packet loss.

In this paper, a telecardiology system integrated with robust and fast vertical handover (RFVHO) algorithm for 4G heterogeneous wireless networks is proposed to improve the reliability, increase the coverage area and guarantee the network quality of telecardiology system.

TELECARDIOLOGY FOR 4G HETEROGENEOUS WIRELESS NETWORKS

The next generation telecardiology system is expected to allow patients always connected to wireless network at anytime and anywhere with guaranteed network quality. The proposed telecardiology system for 4G heterogeneous wireless networks framework is shown in Figure-1. The main different between the proposed system and existing system is that the proposed system is integrated with vertical handover mechanism which able to search for the available networks, always connecting to the best quality network; whereas, the existing system can only connect to a single wireless network. The wireless networks supported by the proposed system include WLAN, WiMAX, Universal Mobile Telecommunication System (UMTS) and satellite network. Satellite

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communication is as a backup network. The system connects to satellite network only when MT is out of the coverage of all networks. This is because satellite network is costly and high power consumption.

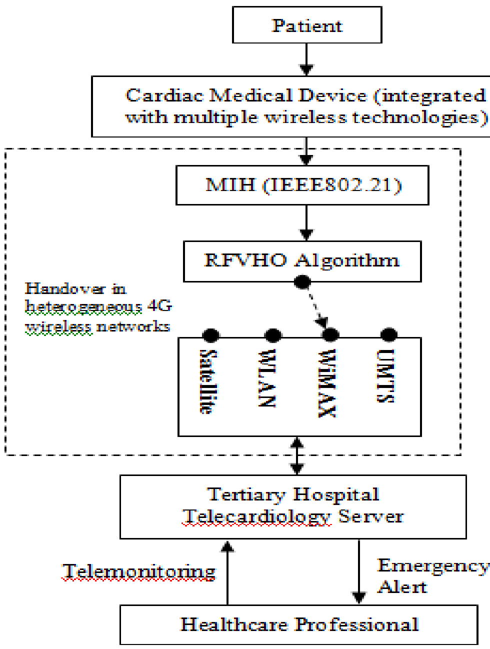

Figure-1. Proposed telecardiology system.

The existing telecardiology systems with single wireless technology have common signaling protocol and similar technology standard. However, in 4G heterogeneous wireless networks, the inter-network handover requires interface between different networks' link layer technologies. The proposed system needs to be always connected to the best network candidate in 4G heterogeneous wireless networks. To achieve this goal, Media Independent Handover (MIH) is used to handover and interoperability between heterogeneous networks (as shown in Figure-1). MIH enables handover in heterogeneous networks with no perceivable interruption to an ongoing voice or video conversation (Oliva et al., 2011), (Ghahfarokhi and Movahhedinia, 2013). In MIH architecture, MIH Function (MIHF) acts as an intermediate layer between upper and lower network layers.

MIH provides interface between network link layers, radio measurement report, new link discovery, and resource availability check, but, it does not include handover decision making (Yan et al, 2010) (Oliva et al., 2011). Hence, RFVHO algorithm (as shown in Figure-2) is designed to decide when and where do handover occur.

In real-time telecardiology application, the priority is given to the network with higher bandwidth. The high bandwidth is desirable because it provides better cardiac medical image quality and smoother video streaming. In addition, the number of handover should be minimized. It is to prevent unnecessary handovers since it will cause packet loss and wastage of network resources.
The RFVHO algorithm for the proposed telecardiology system is shown in Figure-2. The traditional handover method is mostly based on Received Signal Strength (RSS), where MT searches for all available networks when RSS of old network falls below the predefined threshold value. This method is suitable for horizontal handover but not for vertical handover because RSS of different network technologies cannot be compared directly. For example, WiMAX network with lower RSS may have higher data rate than UMTS network with excellent RSS, due to WiMAX has higher network bandwidth than UMTS. The handover initial based on RSS may cause unnecessary handover requests and high number of handover. Thus in RFVHO algorithm, MT monitors the RSS, velocity and user bandwidth requirement

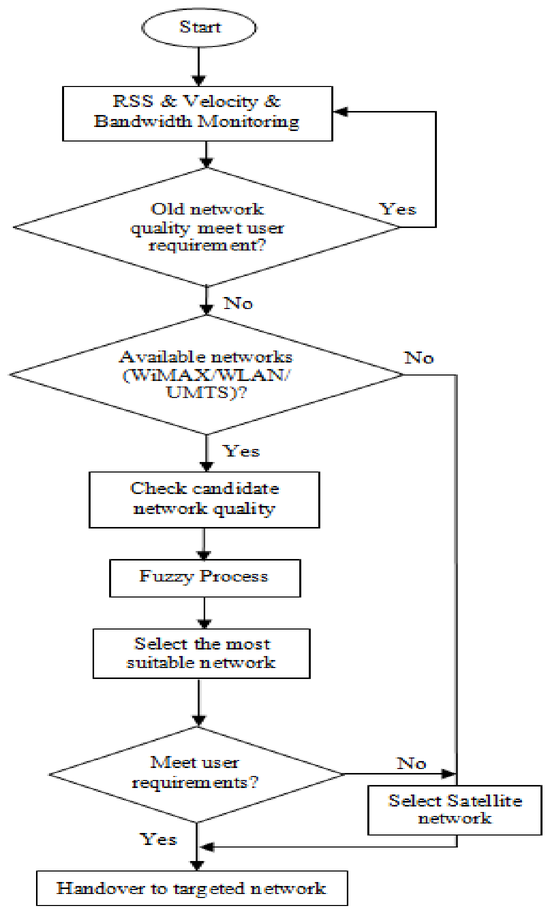

Figure-2. RFVHO algorithm.

periodically. This is to make sure that no handover initial while the old network is still appropriate to the user requirements (i.e. Video, biosignal, etc.). The user bandwidth requirement is based on the type of services (as shown in Table-3) applied by user. Equation (1) is used to indicate whether or not the network quality, Q_k, fulfills MT requirements.

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$$Q_k = F(RSS_k - RSS_{Tk}) \times F(B_k - B_{req}) \times F(V_k - V_{MT}) \quad (1)$$

Where RSS_k is RSS of network k, RSS_{Tk} is RSS threshold for network k, B_k is bandwidth of network k, B_{req} is user bandwidth requirement, V_{MT} is MT velocity and V_k is the maximum velocity support by network k. Network k can be WLAN, WiMAX or UMTS. The functions, F(x), in equation (1) are unit step functions. If x>0, then F(x) =1 and if x<0, then F(x)=0. If Q_k =0, it represents network quality does not meet the user requirements. Only network candidates with Q_k =1 will be considered. This approach is simple and fast. It can reduce handover process time and avoid the unnecessary handover.

For network bandwidth, it is assumed that (B_{WL}>B_{WI}>B_{UM}) WLAN bandwidth, $B_{WL,}$ (7.2Mbps), is larger than WiMAX bandwidth, B_{WI} (5 Mbps), and UMTS bandwidth, B_{UM} (384kbps), is the smallest. Apart of this, maximum velocity supported by each network is also set as 10km/h (WLAN), 100km/h (WiMAX) and 350km/h (UMTS). The networks' bandwidth and MT velocity are mapped to telecardiology services and created Table-4. Table-4 presents that WLAN is applicable only at low velocity; WiMAX is invalid if MT is at high velocity and UMTS is unable to support video service.

Table-3. Bandwidth requirements for telecardiology system (Gállego *et al*., 2005).

Services	Bandwidth
Video	640 – 5000 kbps
Audio	32 -256 kbps
ECG	24 kbps / 12 leads
Vital Signs	2 - 5 kbps

Table-4. Network for telecardiology service.

Velocity (km/h)	Network	Real-time Telecardiology services			
		Video	Audio	ECG	Vital Signs
Low (<10)	**WLAN**	√	√	√	√
	WiMAX	√	√	√	√
	UMTS	X	√	√	√
Medium (20~100)	**WLAN**	X	X	X	X
	WiMAX	√	√	√	√
	UMTS	X	√	√	√
High (>100)	**WLAN**	X	X	X	X
	WiMAX	X	X	X	X
	UMTS	X	√	√	√

√ = support, X = not support

Fuzzy process is used to select the most appropriate network among the available network candidates. For example, the Fuzzy rule set for velocity is shown in Figure-3 and Table-5. It has one input variable (MT velocity) and three output variables. These input and output variables have three membership functions (Low, Medium, and High). The output variables reflect a probability of specific network selection based on a given input velocity.

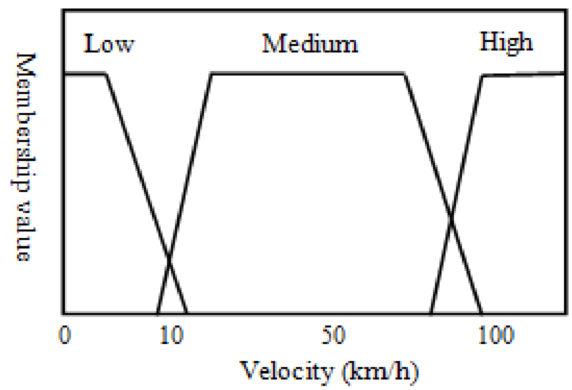


Figure-3. Fuzzy membership function for velocity.

Table-5. Fuzzy rule set for velocity.

Velocity	Probability of selection		
	WLAN	WiMAX	UMTS
Low	High	Medium	Low
Medium	Low	High	Medium
High	Low	Low	High

In low velocity, WLAN is the most preferred network since B_{WL}>B_{WI}>B_{UM}. If WLAN is not available, WiMAX will be selected instead of UMTS since B_{WI}>B_{UM}. If MT is in medium velocity, WLAN will be rejected because WLAN coverage area is limited. It is not capable to support MT in medium or high velocity. By rejecting the WLAN, MT in medium or high velocity only has to collect parameters from the qualified network candidates (WiMAX and UMTS). This could reduce the handover process time. The summative of Fuzzy process is shown in Table-6.

Table-6. Rules for fuzzy process.

Velocity (km/h)	Network	Probability of selection			
		Video	Audio	ECG	Vital signs
Low	WLAN	H	H	H	H
	WiMAX	M	M	M	M
	UMTS	L	L	L	L
Medium	WLAN	L	L	L	L
	WiMAX	H	H	H	H
	UMTS	L	M	M	M
High	WLAN	L	L	L	L
	WiMAX	L	L	L	L
	UMTS	L	H	H	H

L = Low, M = Medium, H = High

Assume there is a user willing to have video conference with healthcare professional from home. Where,

Velocity = 0 km/h.
User bandwidth requirement > 640kbps.
Available network = WLAN, WiMAX, UMTS.
All networks RSS > RSS threshold.

In this scenario, RFVHO algorithm first uses equation (1) to measure the quality of available networks. The result will be Q_{WL}=1, Q_{WI}=1, and Q_{UM}=0, where Q_{WL} is WLAN network quality, Q_{WI} is WiMAX network quality, and Q_{UM} is UMTS network quality. UMTS is rejected because B_{UM} < 640kbps. The qualified network candidates are WiMAX and WLAN. Fuzzy process will select the best network out of this two network candidates. WLAN will be selected as the best network for user because B_{WL}>B_{WI}. By referring to Table-6, conducting video conference at low velocity, WLAN has higher selection probability than WiMAX. The telecardiology system is then connected WLAN.

PERFORMANCE SIMULATION AND EVALUATION

For real-time telecardiology application, it is important to ensure that the network quality is always fulfills the user requirements in order to maintain the integrity of real-time medical data. Thus, selecting the most appropriate network based on user requirements is crucial. A scenario as shown by Figure-4 is created. The simulation parameters are listed in Table-7. The MT is moving from point A to point B which is within the WLAN, UMTS and WiMAX overlapping region. The services requested by MT are real-time transmission of ECG signal plus vital signs. MT is moving at 72km/h and total bandwidth required is not less than 26 kbps (ECG 24 kbps + Vital signs 2 kbps, as referred to Table-3). In this scenario, WLAN is rejected because WLAN cannot support MT velocity. This can be proved by using equation (1), that WLAN network quality, Q_{WL}, is equal to zero. If WLAN is selected as one of the available network candidate at the very beginning state of departure time, it will be rejected in Fuzzy process. Thus, the qualified network candidates in this scenario are UMTS and WiMAX. To select the most appropriate network between WiMAX and UMTS, Fuzzy process is used. By referring Table-6, WiMAX network is preferred compared to UMTS at medium velocity (72km/h). Thus, MT is connected to WiMAX at departure point A.

The RSS of UMTS and WiMAX changing over distance is shown by Figure-5. $UMTS_T$ and $Wimax_T$ denote the RSS threshold for both UMTS and WiMAX network, respectively.

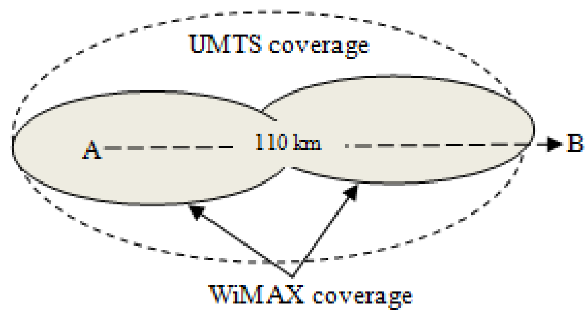


Figure-4. Simulation scenario.

Table-7. Simulation parameters.

Service	ECG signal and vital signs
Velocity	72 km/h (20m/s)
Mode	Real-time
Available networks	WLAN, WiMAX, UMTS
WLAN coverage radius	50m
WiMAX coverage radius	30km
UMTS coverage radius	50km
WLAN RSS Threshold	-115dBm
WiMAX RSS Threshold	-110dBm
UMTS RSS Threshold	-95dBm

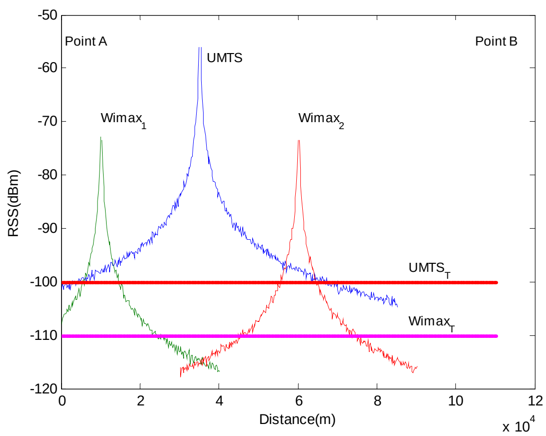


Figure-5. RSS of UMTS and Wimax change over distance.

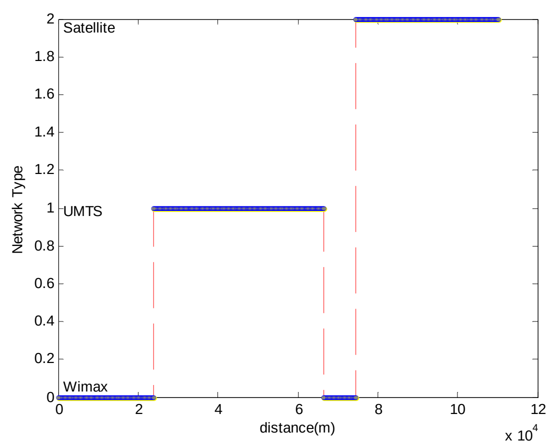


Figure-6. Handover in heterogeneous wireless networks by using a RFVHO algorithm.

The performance of RFVHO algorithm is shown in Figure-6. RFVHO algorithm has low handover rate, no ping-pong effect and no unnecessary handover. Total three handovers are occurred while MT was moving from point A to point B. The first handover from WiMAX to UMTS is occurred while WiMAX RSS fall below $Wimax_T$.

Q_{WL}=0, Q_{WI}=0, and Q_{UM}=1

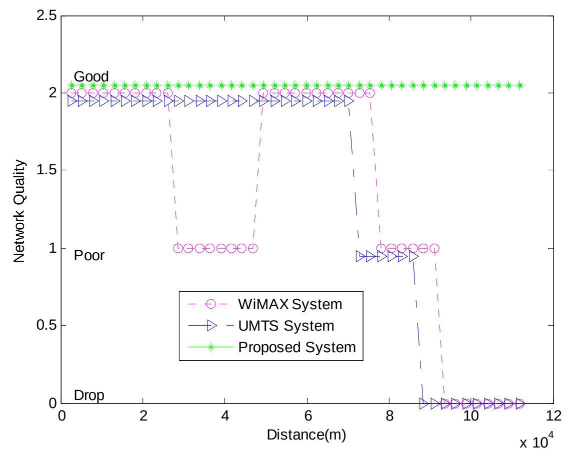
Second handover occurred when UMTS RSS reached at $UMTS_T$.

Q_{WL}=0, Q_{WI}=1, and Q_{UM}=0

The final handover is from WiMAX to satellite network because both UMTS and WiMAX networks quality do not achieve the user requirements.

Q_{WL}=0, Q_{WI}=0, and Q_{UM}=0

Furthermore, MT is moving outside the UMTS and WiMAX networks coverage after 90km from point A. Thus, MT is maintaining in satellite network until it reached destination point B.



Good: Network quality fulfills user requirements.
Poor: Network quality does not fulfills user requirements.
Drop: Network disconnected.
WiMAX System: Telecardiology system that rely on WiMAX only.
UMTS System: Telecardiology system that rely on UMTS only.

Figure-7. Performance evaluation on proposed and existing telecardiology systems.

Figure-7 shows the network quality obtained by three different telecardiology systems while moving from point A to point B. One of them is the proposed telecardiology system which is integrated with RFVHO algorithm, enabling vertical handover in heterogeneous wireless network. The other two systems are relying on UMTS and WiMAX wireless technology, respectively. Proposed telecardiology system is always connected and maintains good network quality along the journey from point A to point B at velocity of 72km/h. It outperforms the existing telecardiology systems which rely on single network (WiMAX or UMTS) (as shown in Figure-7). Even when it moves outside the WiMAX and UMTS network coverage, the proposed system is still able to maintain a good network connection via satellite network.

CONCLUSIONS

Telecardiology system for 4G heterogeneous wireless networks is presented in this paper. The proposed system guarantees that users can always be connected to the most appropriate network based on user requirements at anytime and anyplace. Furthermore, the method to achieve seamless vertical handover in 4G heterogeneous wireless networks for telecardiology application is also discussed. The proposed RFVHO algorithm is able to select the most appropriate network in a fast and robust manner. It has low handover rate and no unnecessary handover. The evaluation result also shows that the proposed system has larger coverage and it is more reliable than telecardiology systems with single wireless network. With the proposed telecardiology system, patients can move freely without network coverage restriction.

In the future, some network parameters, such as security and cost can take into account to increase the user satisfaction on telecardiology application. However, the more network parameters used, the more complicated the handover algorithm will be. Thus, it may increase the handover latency.

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