NETWORK SELECTION MECHANISM FOR TELECARDIOLOGY APPLICATION IN HIGH SPEED ENVIRONMENT

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Specially dedicated to *my beloved parents and family*.

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ABSTRACT

The existing network selection schemes biased either to cost or Quality of Service (QoS) are not efficient enough for telecardiology application in high traveling speed environment. Selection of the candidate network that is fulfilling the telecardiology service requirements as well as user preference is a challenging issue. This is because the preference of telecardiology user might change based on the patient health condition. This research proposed a novel Telecardiology-based Handover Decision Making (THODM) mechanism that consists of three closely integrated algorithms: Adaptive Service Adjustment (ASA), Dwelling Time Prediction (DTP) and Patient Health Condition-based Network Evaluation (PHCNE). The ASA algorithm guarantees the quality of telecardiology service when none of the available networks fulfils the service requirements. The DTP algorithm minimizes the probability of handover failure and unnecessary handover to Wireless Local Area Network (WLAN), while optimizing the connection time with WLAN in high traveling speed environment. The PHCNE algorithm evaluates the quality of available networks and selects the best network based on the telecardiology services requirement and the patient health condition. Simulation results show that the proposed THODM mechanism reduced the number of handover failures and unnecessary handovers up to 80.0% and 97.7%, respectively, compared with existing works. The cost of THODM mechanism is 20% and 85.3% lower than the Speed Threshold-based Handover (STHO) and Bandwidth-based Handover (BWHO) schemes, respectively. In terms of throughput, the proposed scheme is up to 75% higher than the STHO scheme and 370% greater than the BWHO scheme. For telecardiology application in high traveling speed environment, the proposed THODM mechanism has better performance than the existing network selection schemes.

ABSTRAK

Skim pemilihan rankaian yang sedia ada mementingkan kos atau Kualiti Perkhidmatan (QoS) didapati tidak cukup berkesan untuk aplikasi telekardiologi dalam persekitaran kelajuan yang tinggi. Pemilihan rangkaian yang memenuhi keperluan perkhidmatan telekardiologi serta keutamaan pengguna adalah satu isu yang mencabar kerana keutamaan pengguna telekardiologi akan berubah berdasarkan keadaan kesihatan pesakit. Kajian ini mencadangkan mekanisme *Telecardiology-based Handover Decision Making* (THODM) yang terdiri daripada tiga algoritma*:* *Adaptive Service Adjustment* (ASA), *Dwelling Time Prediction* (DTP) and *Patient Health Condition-based Network Evaluation* (PHCNE). Algoritma ASA menjamin kualiti perkhidmatan telekardiologi apabila tiada rangkaian yang dapat memenuhi keperluan perkhidmatan telekardiologi. Algoritma DTP meminimumkan kebarangkalian kegagalan penyerahan dan penyerahan yang tidak perlu kepada Rangkaian Kawasan Tempatan Tanpa Wayar (WLAN) semasa mengoptimumkan masa sambungan dengan WLAN dalam persekitaran kelajuan yang tinggi. Algoritma PHCNE menilai kualiti rangkaian yang tersedia dan memilih rangkaian yang terbaik berdasarkan keperluan perkhidmatan telekardiologi dan keadaan kesihatan pesakit. Keputusan simulasi menunjukkan bahawa mekanisme THODM mengurangkan bilangan kegagalan penyerahan dan penyerahan yang tidak perlu sebanyak 80.0% dan 97.7% berbanding dengan kerja-kerja yang sedia ada. Kos bagi mekanisme THODM adalah 20% dan 85.3% lebih rendah daripada skim *Speed Threshold-based Handover* (STHO) dan *Bandwidth-based Handover* (BWHO). Dari segi pemprosesan, THODM adalah 75% dan 370% lebih tinggi daripada skim STHO dan BWHO. Aplikasi telekardiologi dalam persekitaran kelajuan yang tinggi, mekanisme THODM mempunyai prestasi yang lebih baik daripada skim pemilihan rangkaian yang sedia ada.

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LIST OF ABBREVIATIONS

2G	-	Second Generation Wireless Telephone Technology
3G	-	Third Generation Wireless Telephone Technology
4G	-	Fourth Generation Wireless Telephone Technology
AHP	-	Analytic Hierarchy Process
ANN	-	Artificial Neural Networks
AP	-	Access Point
ASA	-	Adaptive Service Adjustment
BS	-	Base Station
C	-	Cost per Mb
CI	-	Consistency Ratio
CNN	-	Current Connect Network
CNs	-	Corresponding Nodes
CR	-	Consistency Ratio
CVD	-	Cardiovascular Disease
DR	-	Data Rate
DTP	-	Dwelling Time Prediction
e-health	-	Electronic health
ECG	-	Electrocardiogram
EP	-	Ending Point
IEEE	-	Institute of Electrical and Electronics Engineers
FAHP	-	Fuzzy Analytic Hierarchy Process
FIS	-	Fuzzy Inference System
GPRS	-	General Packet Radio Service
GSM	-	Global System for Mobile Communications
HA	-	Home Agent
HMIPv6	-	Hierarchical Mobile IP version 6

LTE	-	Long Term Evolution
m-health	-	Mobile health
MAC	-	Medium Access Control
MADM	-	Multiple Attributes Decision Making
Mb	-	Megabit
MICS	-	Media Independent Command Service
MIES	-	Media Independent Event Service
MIH	-	Media Independent Handover
MIHF	-	Media Independent Handover Function
MIIS	-	Media Independent Information Service
MoH	-	Ministry of Health
MT	-	Mobile Terminal
NHO	-	Number of handover
NUHO	-	Number of unnecessary handover
PCI	-	Percutaneous Coronary Intervention
PD	-	Packet Delay
PHC	-	Patient Health Condition
PHCNE	-	Patient Health Condition based Network Evaluation
QNL	-	Qualify Network List
QoS	-	Quality of Service
RI	-	Random Consistency Index
RMSE	-	Root Mean Square Error
RSS	-	Received Signal Strength
SAW	-	Simple Additive Weighting
SINR	-	Signal to Interference Plus Noise Ratio
SNR	-	Signal to Noise Ratio
SP	-	Starting Point
STHO	-	Speed Threshold Based Handover Scheme
THODM	-	Telecardiology based Handover Decision Making
TOPSIS	-	Technique of Order Preference by Similarity to Ideal Solution
T_{WLAN_1}	-	Traveling time within the WLAN_1 coverage
T_{WLAN_2}	-	Traveling time within the WLAN_2 coverage
T_{WLAN_3}	-	Traveling time within the WLAN_3 coverage

T_{WLAN_4}	-	Traveling time within the WLAN_4 coverage
UMTS	-	Universal Mobile Telecommunications System
VHOM	-	Vertical Handover Manager
WBAN	-	Wireless Body Area Network
WiMAX	-	Worldwide Interoperability for Microwave Access
WLAN	-	Wireless Local Area Network
WMAN	-	Wireless Metropolitan Area Network
WPAN	-	Wireless Persona Area Network
WWAN	-	Wide Wireless Area Network

LIST OF SYMBOLS

Δ - Minimum value of *d*

Δt_p - Time needed by the MT to cover the two RSS sample points

ε - Zero-mean Gaussian random variable caused by shadow fading

Γ_{BS} - Channel coding loss factor

$\mathscr{B}$ - Best network candidate

ρ - RSS sampling time interval

Γ_{BS} - Channel coding loss factor

λ_{max} - The largest eigenvector

c - Acceleration

C - Cost per bit

$C_{cellular}$ - Average cost per Mb offered by cellular network

C_k - Cost per Mb of network candidate *k*

C_{HO} - Handover cost

C_{wlan} - Average cost per Mb offered by WLAN

C_{SINR} - cost per SINR

d - Traveling distance from WLAN boundary (P_{entry}) to predefined RSS threshold (P_{In_RSSth})

d_0 - Distance between the AP and a reference point

d_m - Maximum *d* value

d_{th} - Threshold of *d* value

d_{thf} - Handover failure threshold of *d* value

d_{thu} - Unnecessary handover threshold of *d* value

D - Actual traveling distance within the WLAN coverage

D_S - Sampling distance

DR_{REQ} - data rate requirement

E	-	Path loss exponent
E_SNR_{UMTS}	-	An equivalent SNR value in WLAN
G	-	Percentage of throughput gain
h	-	|AP y coordinate – MT y coordinate|
H	-	hysteresis value
$H_{default}$	-	predefined default hysteresis values
$H_{maximum}$	-	predefined maximum hysteresis values
$H_{minimum}$	-	predefined minimum hysteresis values
k	-	Network candidate
l	-	Estimate traveling distance within WLAN coverage
l_{th}	-	Estimate traveling distance threshold
l_{thf}	-	l_{th} for handover failure
l_{thu}	-	l_{th} for unnecessary handover
L_{th}	-	Distance threshold by Hussain *et al.* 2013
L_{thfH}	-	L_{th} of handover failure presented by Hussain *et al.* 2013
L_{thfY}	-	L_{th} of handover failure presented by Yan *et al.* 2008
L_{thuH}	-	L_{th} of unnecessary handovers presented by Hussain *et al.* 2013
L_{thuY}	-	L_{th} of unnecessary handovers presented by Yan *et al.* 2008
n	-	Number of available network
N	-	Number of samples
N_l	-	Normalized network load value
N_v	-	Normalized velocity value
$NUHO$	-	Number of unnecessary handover
NHO_{ideal}	-	Number of handovers achieved by ideal solution
P_{entry}	-	Entry point of the micro cell coverage boundary
P_f	-	Probability of failure
P_{In_RSSth}	-	Entry point of the micro cell coverage at RSS_{th}
P_{Out_RSSth}	-	Exit point of the micro cell coverage at RSS_{th}
P_s	-	Point MT collects the second RSS sample
P_{TX}	-	AP transmit power
P_u	-	Probability of unnecessary handover
P_{exit}	-	Exit point of the micro cell coverage boundary
PL_0	-	Power loss at the reference point

Q_{CCN}	-	Quality of current connected network
Q_k	-	Quality of network candidate k
r	-	Radius of WLAN from AP to RSS_{th}
R	-	Radius of WLAN from AP to coverage boundary
$R_{cellular}$	-	Average data rate of UMTS
R_{wlan}	-	Average data rate of WLAN
RSS_{CCN}	-	RSS of current connected network
RSS_{new}	-	RSS of target network
RSS_{old}	-	RSS of target network and current connected network
$RSS_{P_{In\_RSSth}}$	-	RSS value measured at points P_{In_RSSth}
$RSS_{P_{entry}}$	-	RSS value measured at points P_{entry}
RSS_{th}	-	Predefined RSS threshold
RSS_{thCCN}	-	Predefined RSS threshold of current connect network
SNR_{CCN}	-	SNR of current connected network
SNR_{REQ}	-	Dynamic SNR threshold defined based on the sum of the data rate required by the telecardiology services applied by the user
SNR_{REQ_WLAN}	-	SNR_{REQ} of WLAN
SNR_{REQ_CCN}	-	SNR_{REQ} of current connect network
SNR_{REQ_UMTS}	-	SNR_{REQ} of UMTS
SNR_{UMTS}	-	UMTS SNR value
$t_{cellular}$	-	total time connected to UMTS
t_d	-	time taken by the MT to travel from P_{entry} to P_{In_RSSth}
t_e	-	Time of the MT passes through P_{entry}
$t_{P_{In\_RSSth}}$	-	Time MT pass through point P_{In_RSSth}
t_{P_s}	-	Time MT pass through point P_s
t_R	-	Time of the MT passes through P_{In_RSSth}
t_{wlan}	-	Total time connected to WLAN
T_i	-	handover latency from macro cell to micro cell
T_m	-	RSS monitoring time interval
T_o	-	handover latency from micro cell to macro cell
$T_{Throughput}$	-	Total throughput
T_{UHO}	-	Time consumed by each unnecessary handover
T_{WLAN}	-	Traveling time within WLAN

T_{WLAN_th}	-	Threshold of traveling time within WLAN
T_s	-	RSS sampling time
TP_{THODM}	-	Total throughput achieved by THODM
TP_x	-	Total throughput of RSS or Cellular based scheme
U_{QNL}	-	Number network candidate in QNL
v	-	MT velocity
v_e	-	MT velocity at P_{entry}
v_R	-	MT velocity at P_{In_RSSth}
w	-	Weight of the parameter
W_{BS}	-	Network carrier bandwidth
W_{CCN}	-	Channel bandwidth (Hz) of current connected network
W_{UMTS}	-	Channel bandwidth (Hz) of UMTS network
W_{WLAN}	-	Channel bandwidth (Hz) of WLAN network
z	-	Distance between two RSS sample point by using Yan *et al.* and Hussain *et al.* methods

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CHAPTER 1

INTRODUCTION

1.1 Research Motivation

Cardiovascular disease (CVDs) is one of the world leading causes of non-communicable disease resulting in death. According to World Health Organization (WHO), it is estimated that 17.5 million people died from CVDs each year and over 80% of people died from CVDs occurred in low and medium income countries [1]. CVD also the main cause of death in Malaysia [2].

The scarcity of cardiologist is a common issue to both underdeveloped and developing countries including Malaysia. The density of cardiologist in Malaysia is 1 per 120,481 people [3]. This is significantly inadequate, as Royal College of Physicians and British Cardiac Society have recommended one cardiologist per 50,000 people [4].

The issue of lack of specialists has been highlighted by Minister of Health and the President of Malaysia Medical Association [5]. Although large number of doctor are graduating annually, the rural areas in Sabah and Sarawak still suffer from shortage of doctors and specialists [6, 7]. The lack of specialist care for the rural people is a major concern, and has been a major concern for a long time.

In order to overcome the barrier of healthcare services such as distance, time, cost, and effectiveness of health care services, deployment of mobile telecardiology system is necessary. Research has proven that telecardiology is useful in the management of acute coronary syndrome, atrial fibrillation, syncope and even in implementing strategies of cardiovascular primary care [8]. Paus *et al.* [9] proved that telecardiology is feasible for cardiovascular patients living in remote region and led to improve follow up rates. Other benefits of telecardiology are improvement in patient compliance with medication, reduced mortality and morbidity, better utilization of resources such as ambulance, tertiary beds, less travel, reduced treatment delay, improvement in hospitals and clinical administration workflow, and is more cost-effective [10-19]. By employing telecardiology, areas with less developed healthcare facilities, for example, rural areas in East Malaysia, can capitalize on the expertise available in the West Coast Peninsular by centrally managing patients across the nation through telecardiology. This would help to improve the overall healthcare quality across the whole country.

1.2 Problem Background

Telecardiology deals with the transmission of electrocardiogram (ECG) signal, vital signs, still image and video over different communication technologies from home or clinics to cardiology specialty centres [20]. It can be operated in two transmission modes, store-and-forward and real-time. In store-and-forward mode the user sends the pre-recorded health information (e.g. ECG data, vital signs) to hospital information system and the healthcare professionals check the patients' electronic health record some time later. In this application, the sender and the receiver do not have to be present simultaneously. On the other hand, real-time telecardiology requires both parties (patient and healthcare professionals) to be present at the same time. The example of real-time telecardiology application is the transmission of ECG data from ambulance to the hospital emergency department. Store-and-forward has been widely used to monitor or follow-up the patients that have chronic cardiac disease due to its expediency. However, real-time telecardiology service is crucial for the patient in critical condition. It could help patients to get treatment promptly. It also be a strong educational component for the remote practitioners [21].

Most of the existing telecardiology systems are relying on a single wireless technology. These systems are unable to guarantee that users remain continuously connected to the telecardiology service provider due to the imperfection of network coverage and poor network quality. A disconnection of a link will disrupt the telecardiology services and lead to misdiagnosis from healthcare professional. The study of Bergrath *et al*. [22] presented that only 73% of the still images had good signal quality that was helpful for teleconsultation. The reasons of failed transmission or transmission problems were attributed to connection breakdown and poor network condition [23].

In this research, a wireless telecardiology system integrated with heterogeneous wireless technologies is proposed. The proposed system is able to access to different wireless technologies based on the telecardiology services' requirement to maintain the quality of telecardiology service at the highest level. Moreover, the heterogeneous networks based telecardiology system will have larger service coverage compared to the system that relies on single wireless technology.

In terms of wireless technologies for telecardiology applications, high bandwidth wireless technologies are more desirable to guarantee the quality of telecardiology services. Wireless Local Area Network (WLAN) is the most preferable due to the high transmission capacity and low network access cost. However, WLAN based telecardiology system is typically for indoor application (home, clinic and hospital) due to its small network coverage [24-27]. For overcoming the network coverage issue, Worldwide Interoperability for Microwave Access (WiMAX) has been proposed for telecardiology application due to its large bandwidth and ability to support high mobility [28, 29]. The work in [28] was then further extended by providing telecardiology services over an integration of WLAN and WiMAX networks to minimize the cost of service [30]. Moreover, similar work about integration of WLAN and WiMAX networks for telecardiology application is presented in [31]. Generally, both Niyato *et al*. [30] and Yan and Tsunoda [31] proposed WLAN for short range communication within building such as mall, clinic, hospital and home. On the other hand, WiMAX is used to support the patient at outdoor environment. However, the detail of handover decision between WLAN and WiMAX is not discussed by authors. In addition, the use of WiMAX in telecardiology is limited as major network service providers are ceasing development of WiMAX [32].

Meanwhile, the rapid growth of mobile cellular network and smartphone technologies has boosted the research on mobile health (m-health). Cellular network based telecardiology system is presented in [33-37]. The advantages of cellular based telecardiology system are that it supports high mobility and offers large service coverage. The main drawback of using cellular network is insufficient network capacity to support real-time high quality diagnosis video transmission which requires at least 4 Mbps data transmission rate [38]. The high bandwidth Fourth Generation Long Term Evolution (4G-LTE) system is still under deployment and the coverage of 4G-LTE is imperfect especially in the rural area of underdeveloped and developing countries. Thus, the use of 4G-LTE in telecardiology application for the rural people in the underdeveloped and developing countries is limited.

The seamless handover management is a challenging issue in heterogeneous wireless networks. To provide seamless handover in heterogeneous networks, IEEE organization had approved a new standard in 2008 named IEEE802.21, Media Independent Handover (MIH) which enables handover in heterogeneous network with no perceivable interruption to an on-going voice or video conversation [39]. MIH provides link configuration, radio measurement reporting, new link discovery, and resource availability check. However, it does not include handover decision making which is the heart of the handover process [39, 40]. Handover decision is crucial for selecting the correct target and triggering handover at the right time so that the quality of the telecardiology services can be maintained at the acceptable level.

The existing vertical handover decision making across heterogeneous networks can be categorized into four groups, received signal strength (RSS), function, multi attributes and intelligent. RSS-Threshold based handover scheme is the oldest method which selects the best network station based on single RSS criterion. It is typically applied in intra-network because RSS of different wireless technologies cannot be compared directly. In vertical handover, the RSS-based handover scheme uses RSS criterion for predicting the distance between Mobile Terminal (MT) and Base Station (BS) or Access Point (AP). It also can be used to determine the MT moving direction either closer to or farther from BS.

The function based handover decision making algorithm combines few parameters such as bandwidth and cost in a function. In this function, different weights are assigned to each parameter depending on the user preference [39]. The candidate network that has the highest weight sum is considered as the best network. The most common function-based handover methods are Quality-of-Service (QoS) based and cost-based. The QoS-based method always chooses the network with the higher throughput in order to keep the service quality at the highest level. This scheme has high handover rate because it always triggers handover to higher bandwidth network whenever available. The cost-based algorithm selects the handover target based on the cost of the available networks. Typically, the wireless network with the lowest cost is the most preferred. The advantage of cost based scheme is that it improves the user satisfaction level by reducing the users' financial expenses, but the quality of service (QoS) or user mobility will be sacrificed.

Multiple Attributes Decision Making (MADM) scheme is mainly for selecting the best target based on the contribution of various handover criteria such as bandwidth, speed, power, security and cost. MADM strategy is a weighting system where different weights are assigned depending on the priority level of each criterion. The network candidate which has the highest weight sum will be considered as a target network. The main disadvantage of this strategy is that the algorithm complexity will be increased when more parameters are taken into account [39]. Consequently, the handover latency of MADM is higher compared to the RSS based as well as the function-based schemes that require less handover criteria. In addition, the weight assignment on input parameters of the existing MADM schemes is mostly done manually based on certain scenarios. This could lead to a degradation of service quality when different services are applied by the user or with the occurrence of unusual situations.

The fluctuation of network parameters such as RSS will lead to unnecessary handover and ping-pong effect [39, 40]. Ping-pong effect is a scenario of repeated handovers between two networks in a short period of time [41]. It usually occurs when the mobile terminal is within the overlap region of two different networks. Ping-pong effect is undesired because it wastes the network resources, consumes power, and leads to signal transmission degradation [42]. To prevent ping-pong effect, intelligent-based handover decision making schemes such as Fuzzy Logic and Artificial Neural Networks (ANN) have been applied in vertical handover process. Intelligent-based schemes are more reliable compared to other approaches. It has high success rate in connecting to the best network and in minimizing the ping-pong effect. However, this scheme has high handover latency caused by ANN learning/training computation, and/or Fuzzy Logic fuzzification or defuzzification processes [40].

1.3 Problem Statement

The main problems of the existing vertical handover decision making algorithms for telecardiology application in heterogeneous wireless networks are:

i. The existing handover algorithms connect to the preferred or the best candidate network even though this network has insufficient capacity to fulfil the telecardiology service requirements such as real-time video, audio, ECG and vital sign transmission. For example, the speed threshold based handover algorithm [43] selects the macro cell when the mobile terminal traveling speed is above the predefined speed threshold, even though the capacity of the macro cell is insufficient for telecardiology service requirement. An insufficient network capacity may cause loss of audio fidelity, choppy video and packet loss which can lead to misdiagnosis from healthcare professional.

ii. The existing algorithms do not optimize the utilization of WLAN when MT is traveling at high-speed. Most of the existing handover schemes define a traveling speed threshold for WLAN. MT triggers handover to WLAN if and only if the traveling speed is below the predefined threshold value to avoid the handover failure and unnecessary handover to WLAN. The application of WLAN is restricted to static or pedestrian navigation environment [44]. For example, researchers in [45-48] predefined the traveling speed threshold for WLAN at 10m/s and below. In addition, Fuzzy MADM based handover algorithm presented by Kaleem *et al.* [49] set the fuzzy if-else rule, "if MT velocity is low, then the probability of rejecting WLAN is low; otherwise, the probability of rejecting WLAN is high".

iii. Existing handover algorithm cannot fully satisfy the telecardiology user because most of them are biased either to QoS or cost. None of them are sensitive to patient health conditions. There is a trade-off between QoS and cost. In telecardiology application, the cost-based network selection scheme is suitable for stored-and-forward mode which is widely applied to the user in non-critical health monitoring because stored-and-forward mode does not require high service quality. However, cost based network selection scheme is inappropriate for real-time critical health monitoring application which desires a high service quality. For real-time critical health monitoring, QoS-based network selection scheme is more suitable. Therefore, it is important to have a handover algorithm that is responding to the patient health condition that dynamically selects the best QoS network and the lowest cost network for the case of store-and-forward non-critical health monitoring and real-time critical health monitoring, respectively.

1.4 Research Objectives

The aim of this research is to propose a novel handover scheme that is able to respond according to the patient health conditions and also optimize the quality of telecardiology service by minimizing unnecessary handover and handover failure rate while maximizing the connection time to the WLAN in high traveling speed scenario. The following research objectives are set to achieve the aim of this research work.

i. To design an Adaptive Service Adjustment (ASA) algorithm for guaranteeing telecardiology service quality when there is insufficient network capacity to fulfil the telecardiology service requirements.

ii. To design a novel Dwelling Time Prediction (DTP) algorithm for minimizing the probability of handover failures and unnecessary handovers while maximizing the connection time to WLAN at high traveling speed scenario.

iii. To design a Patient Health Condition based Network Evaluation (PHCNE) algorithm for improving the telecardiology user's satisfaction in terms of throughput and cost.

iv. To evaluate the performance of the proposed ASA, DTP and PHCNE algorithms and benchmark with existing relevant algorithms.

1.5 Research Contributions

This thesis presents a Telecardiology based Handover Decision Making (THODM) mechanism for telecardiology application in heterogeneous networks. In general, THODM mechanism resolves the problems such as limited coverage, insufficient network capacity and mobility issues faced by the existing telecardiology systems. The detail of research contributions are stated as below:

i. The Adaptive Service Adjustment (ASA) algorithm reduces the user bandwidth requirement by deactivating the telecardiology service at the lowest priority level while the best network has insufficient capacity to support the telecardiology service requirements. This priority deactivation technique allocates more bandwidth for supporting the telecardiology service at higher priority level. As a result, the quality of the telecardiology services at higher priority level is still maintained at the acceptable level. This algorithm guarantees the telecardiology service and prevents misdiagnosis from healthcare professional.

ii. The Dwelling Time Prediction (DTP) algorithm predicts the traveling time within the micro cell (WLAN Hotspot) coverage for the MT which is moving in dynamic speed. It overcomes the limitation of the existing prediction scheme [50] that assumes the MT is moving at a constant speed. The proposed DTP algorithm is more suitable for mobile telecardiology application such as transmitting health signal or data from high-mobility-ambulance to hospital, because the traveling speed of ambulance may not be constant at all time.

iii. The DTP algorithm minimizes the number of handover failures and unnecessary handovers while optimizing the utilization of micro cell in high speed scenario. With the proposed DTP algorithm, MT can benefit high bandwidth and low network access cost from the micro cell network with minimum interruption in high speed scenario. This can improve the quality of telecardiology service and the cost effectiveness.

iv. The Patient Health Condition based Network Evaluation (PHCNE) algorithm ensures the quality of the connected or targeted network fulfils the telecardiology service requirements. In critical health condition, the highest bandwidth network will be selected by this algorithm to optimize the quality of the telecardiology services. On the other hand, the lowest cost network that fulfils the telecardiology service requirement will be selected if the patient is in normal health condition. This is to minimize the financial expenses of telecardiology user.

1.6 Research Scopes

In this research, only wireless networks are considered because wireless technologies support mobility and have larger coverage compared to wired technologies. In addition, WiMAX technology is excluded from this research because the major network service providers are ceasing development of WiMAX and focusing on cellular network [32]. The scopes of this research are:

i. This research considers the high mobility scenario. The MT is an ambulance equipped with a telecardiology system.

ii. The mobile telecardiology is powered by an external power supply from vehicle. Therefore, power issue is not considered in this research.

iii. The MT is traveling at a speed in the range of 10 m/s to 40 m/s (36 km/h to 144 km/h) on the highway.

iv. It is assumed that the network services providers reserve certain number of network channels at each base station (BS) and access point (AP) for telecardiology purpose [30]. The AP is the WLAN Hotspot provided by network services providers and they have identical network characteristics. The reserved channels guarantee data transmission rate of 1 Mbps and 6 Mbps for cellular network and WLAN, respectively.

v. The research is focusing on the rural areas of underdeveloped and developing countries. The telecommunication infrastructure and healthcare facilities in these areas are still imperfect.

vi. The telecardiology user's satisfaction in this research is measured in terms of throughput and cost. The lower the cost per Megabit (Mb), the higher the user satisfaction.

vii. It is assumed that the Doppler shift problem caused by high mobility can be mitigated by using the Doppler diversity. In [51], Doppler domain multiplexing communication structure is proposed to achieve the maximum Doppler diversity in time varying fading. Furthermore, the Doppler frequency offset estimation and compensation algorithms presented in [52, 53] can be used to alleviate the Doppler effects in high-speed scenario.

1.7 Thesis Organization

This thesis comprises of six chapters. The remaining of the chapters are organized as follows:

Chapter 2 provides the extensive review of the existing wireless telecardiology systems, background of handover process and followed by a comprehensive survey of vertical handover decision making algorithms.

Chapter 3 describes research methodology, experiment design and verification of proposed Adaptive Service Adjustment (ASA) algorithm, Dwelling Time Prediction (DTP) algorithm and Patient Health Condition based Network Evaluation (PHCNE) algorithm.

Chapter 4 provides the framework of telecardiology system in heterogeneous wireless network. This chapter also explains the details of the proposed Adaptive Service Adjustment (ASA) algorithm, Dwelling Time Prediction (DTP) algorithm and Patient Health Condition based Network Evaluation (PHCNE) algorithm.

Chapter 5 shows the simulation results. The performance of the proposed algorithms evaluated against the performance of the existing relevant schemes.

Chapter 6 concludes the research work in this thesis and suggests possible future research directions.

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