

AUTONOMOUS NETWORK SELECTION STRATEGY FOR TELECARDIOLOGY APPLICATION IN HETEROGENEOUS WIRELESS NETWORKS

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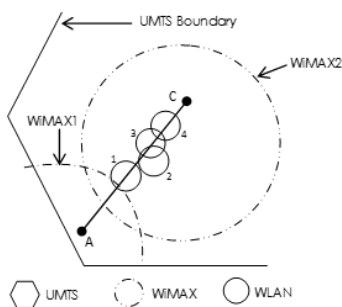
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Graphical abstract



Abstract

Existing telecardiology systems are mostly relying on a high bandwidth wireless technology. However, in developing countries, the coverage of high bandwidth wireless network is still imperfect. Thus, the existing telecardiology systems are unable to guarantee users are always connected to the healthcare service provider at anywhere. To overcome this issue, an autonomous network selection strategy for telecardiology application in heterogeneous wireless networks is proposed. This strategy is aware of user velocity, network quality, and telecardiology service setting (e.g. image, vital signs, ECG, etc.). It performs handover from one network to another without disruption to the link. The simulation results show that the proposed strategy outperforms conventional bandwidth-based strategy in term of handover rate, ping-pong effect and handover failure. It has successfully reduced the handover rate up to 97%, eliminated the ping-pong effect and handover failure in both high and low speed scenarios.

Keywords: Network selection, Telecardiology, Handover failure, Handover rate, Ping-pong effect

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1.0 INTRODUCTION

Telecardiology is a tool used by healthcare professionals to monitor cardiac patient's health condition distantly via information and communication technologies (ICT). It can be operated in either stored-and-forward or real-time modes. Stored-and-forward mode is patient stores the medical data (e.g. vital sign, electrocardiogram (ECG) etc.) and transmits to healthcare service provider at a later time. In contrast, real-time mode allows instantaneous interaction between healthcare professional and patient, for example, live video-conferencing. The advantages of using telecardiology include better management of hospital resources such as beds in tertiary hospital and ambulances, reduce the morbidity and

mortality, and bridging the gap between healthcare professional and patient [1-6]. Therefore, it has been used to solve the problem of healthcare professional shortage in sub-urban and rural areas of developing countries [7].

The quality of telecardiology service is highly dependent on telecommunication technologies. The main factor that may affect the performance of telecardiology service is insufficient network bandwidth. It may cause high latency and packet loss in transmission. A disruption of medical data in transmission may lead to misdiagnosis. Thus, in telecardiology application, high bandwidth networks such as Wireless Local Area Network (WLAN), Worldwide Interoperability for Microwave Access (WiMAX) and 4G-LTE (Fourth Generation-Long Term Evolution) are highly desirable to guarantee the quality of telecardiology service.

However, these high bandwidth networks are still under deployment and their coverage are imperfect even in urban of developing countries. Users (ambulances or patients) may experience connection breakdown whilst passing through the coverage holes or travels out of the network coverage. Thus, telecardiology system that relies on a high bandwidth network could not guarantee the users are always connected to the healthcare professional.

In this paper, an autonomous network selection strategy for telecardiology application in heterogeneous wireless networks is proposed to ensure users are able to connect to their healthcare professional at anywhere and maintain the quality of telecardiology service at the highest level.

The rest of the paper is organized as follows. Section 2 presents the related works on wireless telecardiology system and network selection strategies. The design of proposed algorithm and experiment design are discussed in Section 3 and 4, respectively. The result and discussion are presented in Section 5 and conclusion in the last section.

2.0 RELATED WORKS

This section discusses the related works on existing wireless telecardiology system and also the network selection strategies in heterogeneous wireless networks.

2.1 Existing Wireless Telecardiology System

Previous studies have proposed telecardiology systems with different type of wireless technologies, such as WLAN, WiMAX, satellite, and cellular network. A WLAN-based monitoring system that monitors the inpatients ECG signal within the hospital has been presented in [8]. The limitation of this system is the patient's monitoring area is restricted due to the small WLAN cell coverage. To overcome the coverage problem, research works in mobile health [9-13] has been rapidly raised in recent years with the help of evolution in mobile phone technologies and cellular network, as shown in Table 1.

Cellular wireless network such as 1G, 2G and 3G offer large coverage, hence could extend the telecardiology services to the population in sub-urban and rural areas. However, its bandwidth is still insufficient to support the services that require high bandwidth such as transmission of high quality medical images or conducting real-time consultation through video-conference.

Table 1 Evolution of Cellular Network [7]

Cellular network generation	Service type
1G	Analogue voice.
2G & 2.5G (GSM, GPRS)	Digital voice, higher capacity, packetized data.
3G (UMTS)	Higher capacity, broadband data up to 384kbps.
4G (LTE)	Complete IP based with speed > 100 Mbps (still under deployment).

bps: bit per second
 GSM: Global System for Mobile
 GPRS: General Packet Radio Service
 IP: Internet Protocol
 LTE: Long-term Evolution
 UMTS: Universal Mobile Telecommunication System
 #G: # Generation

In order to guarantee the quality of telecardiology services, WiMAX based telecardiology systems are proposed in [14, 15]. The advantages of WiMAX technology are large coverage and high throughput. It could compensate the limitation of WLAN (small cell coverage) and cellular networks (low bandwidth). However, in developing countries, WiMAX coverage is still imperfect and has coverage hole even in urban. To solve this issue, authors in [14] extended their work by integrates WLAN and WiMAX networks in their proposed telecardiology system [16], where WLAN is mainly for indoor application and WiMAX is for outdoor environment.

For the areas that out of the all ground networks' coverage, satellite communication becomes an only solution. Satellite communication based telecardiology system is suitable for offshore oil platform and military application [17, 18]. However, it is not widely used due to the high delay, poor quality during poor weather and extremely cost expensive in terms of satellite installation, maintenance and management.

Based on the discussed telecardiology systems, the existing systems are mostly relying on a single wireless technology. Two main problems facing by these systems are limitation of network coverage and bandwidth. To overcome these problems, existing telecardiology systems require a network selection strategy to assist them to select the most appropriate wireless network based on the user requirements and perform seamless handover in heterogeneous wireless networks to ensure the users are always connected to the healthcare professional with guarantee of services quality.

2.2 Network Selection Strategies

Network selection strategy is a scheme of keeping user connection remains active when the mobile device migrates from one network access point to another. The network selection strategies can be categorized into RSS-based, cost-based, bandwidth-based and multi attribute based strategies. RSS-based strategy is the traditional method which usually applies in intra-network. For inter-networks

handover, RSS-based strategy is inappropriate due to RSS of different wireless technologies cannot be compared directly [19]. The cost-based strategy chooses the handover target based on the cost of the available networks. Typically, the wireless network with lower cost is the most preferable. On the other hand, bandwidth-based strategy usually selects the network with the highest bandwidth or throughput to maintain the quality of service at the highest level.

In order to find a balancing point between the bandwidth and cost, multiple attributes decision making (MADM) strategy has been proposed by many researchers in network selection process. MADM strategy is a weighting system that considers various network parameters (e.g. RSS, cost, velocity, bandwidth, etc.) as metrics of the network selection function. The network with the highest weight sum will be considered as a targeted network to handover. The main disadvantage of this strategy is that the algorithm complexity will be increased when more parameters are taking into account, hence increasing the handover latency.

To improve the handover performance, fuzzy logic and Artificial Neural Networks (ANN) are applied in network selection process. These intelligent based strategies are more reliable and has high successful rate in connecting to the best network. However, they suffer from high handover latency which caused by ANN learning or training process, and fuzzy logic fuzzification or defuzzification processes.

In our proposed strategy, MADM method is used to select the best network based on the user requirement and contextual information (velocity). However, weighting system is not used in our proposed strategy because the weight assignment on input parameters of the existing MADM schemes is mostly done manually and fixed based on certain scenarios. This could lead to a degradation of service quality when different services are applied by user or unlike scenarios are happened.

3.0 PROPOSED NETWORK SELECTION STRATEGY FOR TELECARDIOLOGY APPLICATION

The proposed network selection strategy as shown in Figure 1 is a low-complexity algorithm to minimize the handover latency. It consists of two major phases: self-inspection and quick evaluation. The input parameters for the proposed strategy are received signal strength (RSS), user's velocity (V_{user}), signal-to-noise ratio (SNR), network channel bandwidth (B) and minimum data transmission rate required by user (DR_{req}).

The first parameter, RSS, is used to discover the present of neighboring networks. Second parameter, V_{user} , is required to avoid handover failure by comparing the user traveling time in specific network cell coverage with handover execute time (HET). Handover failure occurs when the travelling time in network cell is less than HET. Hence, the small

coverage network such as WLAN should be avoided in high speed scenario as user may move out from cell coverage before the completion of handover process.

Parameter SNR represents network quality or capability of data transmission rate. The higher SNR value means the better network quality and provide higher data transmission rate. Thus, SNR is needed to guarantee that the selected network has capability of supporting the telecardiology services. In this strategy, the SNR of a network candidate is required to determine capability of data transmission rate (DR_k). On the other hand, the total data transmission rate required by user (DR_{req}) is according to the telecardiology services that have been preset by user. DR_{req} for each type of telecardiology service is shown in Table 2. The relationship between SNR_k , B_k and DR_k is given by:

$$DR_k = B_k \log_2(1 + SNR_k) \quad (1)$$

Where, B_k is channel bandwidth of network k in Hertz (Hz). The network k can be any wireless network (e.g. WLAN, WiMAX or cellular network).

Table 2 Telecardiology service requirement [22]

Telecardiology service	Data rate (DR_{req})
Voice	4 kbps
Diagnostic sound	32 kbps
High quality diagnostic video	640 kbps
ECG (12 channels)	24 kbps
Vital sign	5 kbps

Proposed Network Selection Strategy

Input parameters: $RSS_k, SNR_k, V_{user}, DR_{req}, B_k$	
Predefined threshold: RSS_{kt}, V_{kt}	
1	DO
2	$DR_{req} \leftarrow$ User telecardiology service setting
3	$F(V) = F(V_{CCNT} - V_{user})$
4	$F(RSS) = F(RSS_{CCN} - RSS_{CCNT})$
5	$DR_{CCN} = B_{CCN} \log_2(1 + SNR_{CCN})$
6	$Q_{CCN} = F(V) * F(RSS) * (DR_{CCN} - DR_{req})$
7	WHILE ($Q_{CCN} > 0$)
8	$k = 0$
9	$N = 0$
10	Scan for neighboring networks based on RSS
11	Count = Total number of detected network candidates
12	IF (Count == 0)
13	Maintain at CCN
14	Back to step 1
15	ELSE
16	WHILE ($k < \text{Count}$)
17	Obtain network parameters $RSS_k, V_{user}, SNR_k, B_k$
18	$DR_{req} \leftarrow$ User telecardiology service setting
19	$F(V) = F(V_{kt} - V_{user})$
20	$F(RSS) = F(RSS_k - RSS_{kt})$
21	$DR_k = B_k \log_2(1 + SNR_k)$
22	$Q_k = F(V) * F(RSS) * (DR_k - DR_{req})$
23	IF ($Q_k > 0$)
24	Network k is a qualified network
25	$N = N + 1$
26	ELSE

27	Reject network k
28	ENDIF
29	k = k + 1
30	ENDWHILE
31	ENDIF
32	N = Total number of qualified network
33	IF (N == 0)
34	Maintain at CCN
35	ELSE
36	Targeted network = Max (Q _k)
37	Trigger handover to targeted network
38	CCN = New targeted network
39	ENDIF
40	Back to Step 1

CCN: Current connected network
 DR_k: Capability of network k transmission data rate
 DR_{req}: Transmission data rate required by user
 F(V): Velocity function (as equation 3)
 F(RSS): RSS function (as equation 4)
 Q_k: Quality of network k
 Q_{CCN}: Quality of CCN
 RSS_k: RSS of network k
 RSS_{IT}: Predefined threshold value for RSS network k
 RSS_{CCN}: RSS of current connected network
 RSS_{CCNT}: Predefined threshold for RSS of current connected network
 SNR_{CCN}: SNR of current connected network
 SNR_k: SNR value of network k
 V_{CCN}: Maximum velocity support by current connect network
 V_{IT}: Predefined maximum velocity supported by network k
 V_{user}: User velocity

Figure 1 Proposed Network Selection Strategy

The parameters B_k, RSS_k and SNR_k values can be obtained via Media-Independent Handover standard (MIH). MIH is IEEE802.21 standard which enable seamless handover and interoperability between two different wireless technologies. It also provides information such as neighboring network, network configuration, and network quality [20, 21]. In this proposed algorithm, the authors assume each portable telecardiology monitoring device is integrated with an accelerometer to measure the user velocity.

In self-inspection process (step 1 to 7 in Figure 1), it monitors the RSS_{CCN}, SNR_{CCN}, V_{user} and existing user's telecardiology service setting (e.g. ECG, image, video, etc.) in every 0.5 second to ensure that the current connected network (CCN) is achieving the user's requirements. The objective of this self-inspection process is to avoid ping-pong effect and reduce the number of unnecessary handover. Ping-pong effect is a scenario that user performs handover forth and back repeatedly between two different wireless network in a short period of time. It is waste of energy and network resources. The proposed strategy only scans for other networks whilst the CCN failed to fulfill the user requirements (Q_{CCN} ≤ 0).

In quick evaluation process (step 8 to 40 in Figure 1), the quality of each detected network candidates (Q_k) will be evaluated based on the input parameters. Q_k can be determined by:

$$Q_k = F(V) * F(RSS) * (DR_k - DR_{req}) \quad (2)$$

Where,

$$F(V) = F(V_{kT} - V_{user}) = \begin{cases} 0, & V_{kT} \leq V_{user} \\ 1, & V_{kT} > V_{user} \end{cases} \quad (3)$$

$$F(RSS) = F(RSS_k - RSS_{kT}) = \begin{cases} 0, & RSS_k \leq RSS_{kT} \\ 1, & RSS_k > RSS_{kT} \end{cases} \quad (4)$$

The network candidate with Q_k > 0 is the qualified network and will be added to the qualified network list, N, otherwise reject. The best network among the qualified network candidates can be determined by:

$$Max(Q_k) \quad (5)$$

4.0 EXPERIMENT DESIGN

Figure 2 shows the experiment design to evaluate the performance of proposed strategy. It is assumed that the user travels from point A to point C with a constant velocity. The performance of the proposed network selection strategy is compared with the conventional bandwidth-based network selection strategy under two different scenarios. The first scenario is user travels at high speed (30m/s) and second scenario is at low speed (2m/s). The traveling path is covered by three different wireless networks, WLAN, WiMAX and UMTS. The RSS of all these networks from point A to point C are shown in Figure 3, whereas, the experiment parameter settings are as shown in Table 3. The experiment is aim to transmit high quality diagnostic video which requires minimum 640kbps data transmission rate, according to Table 2.

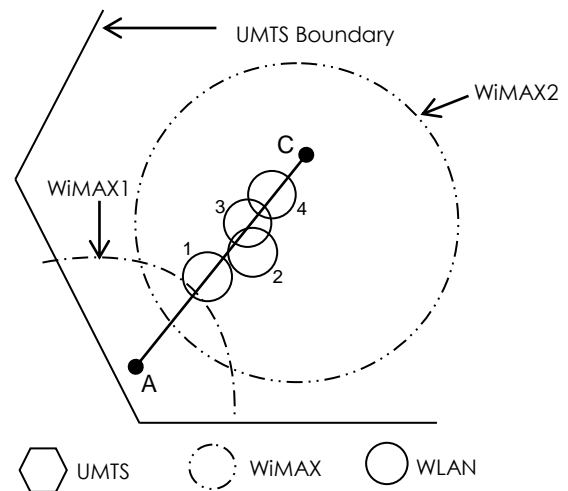


Figure 2 Scenario in heterogeneous wireless network

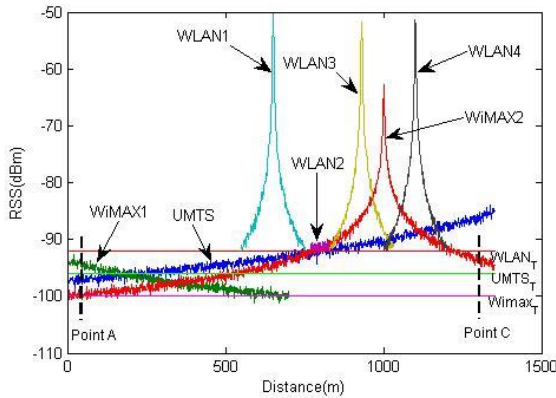


Figure 3 RSS of various wireless networks coverage along the travelling path from point A to point C

Table 3 Parameters' Setting

Parameter	WLAN	WiMAX	UMTS
RSS _{kt} (dBm)	-92	-100	-96
V _{kt} (m/s)	5	40	95
Cell Radius (m)	100	1000	3000
B (MHz)	20	10	5
User setting (DR _{req})	High quality diagnostic video (640kbps)		
User velocity (V _{user})	Scenario 1: 30m/s or 108km/h Scenario 2: 2m/s or 7.2km/h		
Time Interval (Monitoring)	0.5 second		
HET	Intra-network	1 second	
	Inter-network	2 seconds	

5.0 RESULTS AND DISCUSSION

The performance of the proposed strategy is evaluated based on number of handover failures, unnecessary handover and ping-pong effect according to two aforementioned scenarios. The handover failure occurs when the traveling time (TT) in specific network is less than HET. The HET for intra-network and inter-network handovers are set to 1 second and 2 seconds, respectively, according to the value recommended by [23, 24]. The TT in specific network is equal to time interval between two handovers, as shown in equation (6).

$$TT = Handover\ Time_{i+1} - Handover\ Time_i \quad (6)$$

In term of percentage of unnecessary handover (%UH), it is computed as,

$$\%UH = \frac{HR_{BW_based} - HR_{proposed}}{HR_{BW_based}} \times 100 \quad (7)$$

Where, HR_{BW_based} and $HR_{proposed}$ denote the handover rate of conventional bandwidth-based and proposed network selection strategies, respectively. Ping-pong effect is also considered as a part of unnecessary handover. It happens when numerous unnecessary handover between two networks occur in a short period of time.

5.1 Scenario 1: High Speed (30m/s)

In high speed scenario, WLAN is rejected by proposed strategy because user velocity is above the predefined maximum velocity supported by WLAN ($V_{user} > V_{kt}$). Note, this predefined velocity threshold is not applicable to conventional bandwidth-based strategy. Typically, conventional bandwidth-based strategy selected the highest bandwidth network based on the RSS and bandwidth of network candidates without restriction of user velocity.

Figure 4 and Table 4 show the handover performance of the conventional bandwidth-based network selection strategy, whereas, Figure 5 shows the handover performance of the proposed strategy. It can be observed that total of 9 handovers occurred while user travels from point A to C, whereas, only one handover is performed by the proposed network selection strategy. Referring to Figure 4 in more detail, ping-pong effect is occurred at overlap region of WiMAX1 and WiMAX2 where there is total of 3 handovers occur consecutively within 1.5 seconds (H_1 to H_3 in Table 4). Furthermore, two handover failures occurred at H_1 to H_2 and H_5 to H_6 (Table 4). Conversely, the proposed network selection strategy has no ping-pong effect and handover failure along the journey from A to C.

Table 5 summarizes the performance comparison between bandwidth-based strategy and proposed strategy at high speed scenario which the user traveling speed is 30m/s. It can be observed that the proposed strategy has successfully reduced the unnecessary handover up to 89% (equation 7). The proposed strategy connects to WiMAX2 instead of UMTS networks because WiMAX2 has higher data transmission rate.

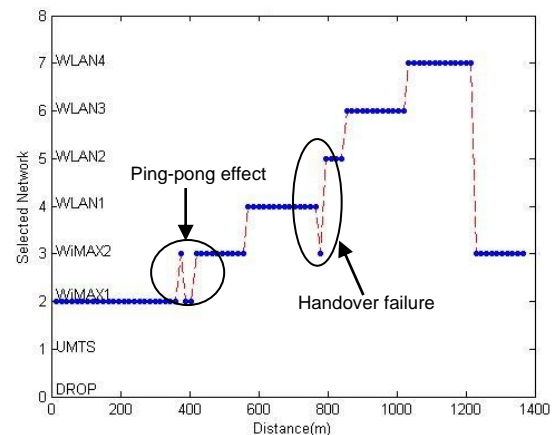


Figure 4 Handovers performed by conventional bandwidth-based network selection strategy from point A to point C at speed of 30m/s

Table 4 Detail of handovers performed by conventional bandwidth-based network selection strategy at high speed

Handover (Hi)	At time (Sec)	Distance from point A (m)	Handover to	Remark
1	12.5	375	WiMAX2	Ping-pong effect
2	13.0	390	WiMAX1	
3	14.0	420	WiMAX2	
4	19.0	570	WLAN1	Handover failure
5	26.0	780	WiMAX2	
6	26.5	795	WLAN2	
7	28.5	855	WLAN3	
8	34.5	1035	WLAN4	
9	41.0	1230	WiMAX2	

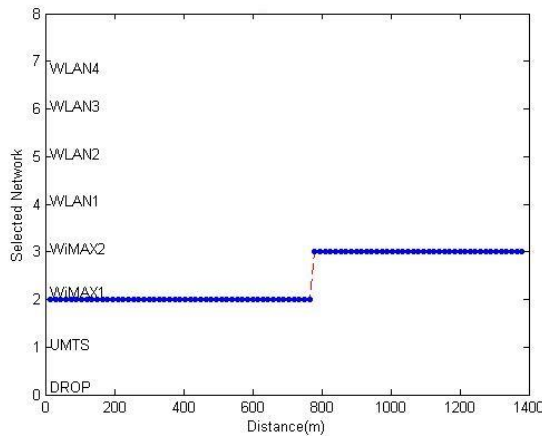


Figure 5 Handover performed by proposed network strategy at speed of 30m/s

Table 5 Performance comparison between conventional bandwidth-based and proposed strategy at speed of 30m/s

Network Selection Strategy	Number of Handovers (HR)	Number of Handover Failures	Ping-pong Effect	Number of unnecessary handover
Proposed	1	0	No	0
Bandwidth-based	9	2	Yes	8

5.2 Scenario 2: Low Speed (2m/s)

Figure 6 shows the handover performance of the conventional bandwidth-based network selection strategy, whereas, Figure 7 shows the handover performance of the proposed strategy, with both of them apply to low speed scenario at pedestrian speed of 2m/s. It can be observed that bandwidth-based strategy suffers from 32 handover failures out of 67 total handovers. On the other hand, the proposed strategy only requires 2 handovers with no handover failure or ping-pong effect.

Table 6 shows the summary of performance comparison between two strategies. It is proven that the proposed strategy can reduce unnecessary handover percentage up to 97% at low speed scenario.

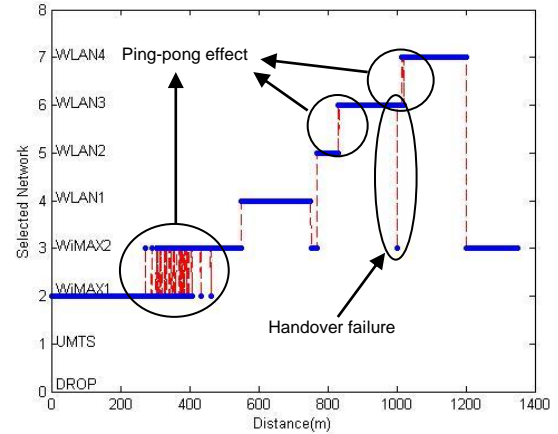


Figure 6 Handovers performed by conventional bandwidth-based strategy at low speed scenario (2m/s)

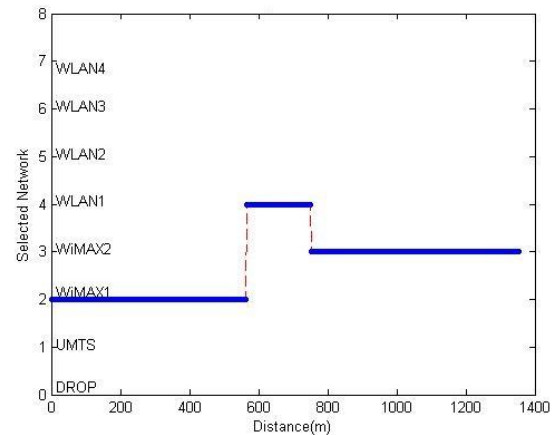


Figure 7 Handovers performed by proposed strategy at low speed scenario(2m/s)

Table 6 Performance comparison between conventional bandwidth-based and proposed strategy at speed of 2m/s

Network Selection Strategy	Number of Handovers (HR)	Number of Handover Failure	Ping-pong Effect	Number of unnecessary handover
Proposed	2	0	No	0
Bandwidth-based	67	32	Yes	65

6.0 CONCLUSION

In this paper, a low complexity autonomous network selection strategy is proposed for telecardiology application in heterogeneous wireless networks. It has successfully eliminated the ping-pong effect and handover failure. It also reduced up to 97% and 89% of unnecessary handover at low speed and high speed scenarios, respectively, as compared to conventional bandwidth-based network selection strategy whilst satisfying the user requirement.

In future, the parameters such as cost and power consumption can be added to the proposed strategy to improve the user's satisfaction. Typically,

user prefers the high bandwidth with low cost network such as WLAN. WLAN also has less power consuming compared to the other networks (e.g. WiMAX, UMTS) due to its short transmission distance. However, the small WLAN cell coverage has put some limitation on user mobility. Thus, utilization of WLAN at outdoor environment and high velocity scenario is still an open issue and future direction of research.

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