INTEGRATION OF MULTIMETRIC PATH MANAGEMENT INTO 802.11S FOR TELEMEDICINE QUALITY OF SERVICE PROVISION

MUHAMMAD HAIKAL SATRIA

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Universiti Teknologi Malaysia

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ABSTRACT

The merits of 802.11s as the wireless mesh network standard provide a low cost and high independent scalability telemedicine infrastructure. However, challenges in degradation of performance as hops increase and the absence of Quality of Service (QoS) provision need to be resolved. Reliability and timely manner are important factors for successful telemedicine service. This research investigates the use of 802.11s for telemedicine services. A new model of 802.11s based on telemedicine infrastructure has been developed for this purpose. A non deterministic polynomial path selection is proposed to provide end-to-end QoS provisioning in 802.11s. A multi-metric called QoS Price metric is proposed as measurement of link quality. The QoS Price is derived from multi layers values that reflect telemedicine traffic requirement and resource availability of the network. The proposed solution has modified the path management of 802.11s and added resource allocation in distributed scheme. This modification and resource allocation improvement of 802.11s were given the designation medQoS-802.11s. MedQoS-802.11s could provide a link guarantee of telemedicine traffic transmission in the selected path. MedQoS-802.11s had been tested using ns3 simulation and real environment testbed. The result has shown that medQoS-802.11s could achieve the traffic guarantee for almost 95% telemedicine traffic with 58% for the resource intensive diagnostic video traffic. It has also shown that the cost of link path overhead is efficient with the transmission overhead having an increment of 6% compared to the original 802.11s. The concurrent connection results for single time transmission shows that medQoS-802.11s has a significant increase of up to 12% traffic than original 802.11s. The testbed results have verified the QoS guarantee of the intended telemedicine traffic per transmission time. In summary, the reliability and time guarantee of medQoS has highly improved 802.11s to transmit telemedicine traffic.

ABSTRAK

Faedah utama 802.11s adalah rangkaian jaring tanpa wayar yang menyediakan infrastruktur teleperubatan berkos rendah dan berskala bebas. Walau bagaimanapun, cabaran dalam kemerosotan prestasi disebabkan peningkatan lompatan dan ketiadaan penyediaan Kualiti Perkhidmatan (QoS) perlu diselesaikan. Kebolehpercayaan dan ketepatan masa adalah faktor penting untuk perkhidmatan teleperubatan yang berjaya. Kajian ini menyiasat penggunaan 802.11s untuk perkhidmatan teleperubatan. Sebuah 802.11s model baru yang berasaskan infrastruktur teleperubatan telah dibangunkan untuk tujuan ini. Selain itu, pemilihan jalan polinomial tidak berketentuan dicadangkan untuk menyediakan penyediaan QoS bagi 802.11s. Pengukuran kualiti pautan ditentukan berdasarkan berbilang nilai metrik yang telah dicadangkan dan dikenali sebagai metrik “QoS Price.” QoS Price berasal dari pelbagai nilai-nilai lapisan yang mencerminkan keperluan trafik teleperubatan dan ketersediaan sumber rangkaian. Penyelesaian yang dicadangkan telah mengubah suai pengurusan laluan 802.11s dan menambah skim peruntukan sumber. MedQoS - 802.11s telah diuji dengan menggunakan simulasi ns3 dan persekitaran yang sebenar. Keputusan telah menunjukkan bahawa medQoS - 802.11s boleh mencapai jaminan trafik bagi hampir 95% trafik teleperubatan dengan 58% bagi sumber intensif trafik video diagnostik. Ia juga menunjukkan bahawa kos adalah cekap dengan kos penghantaran hanya meningkat sebanyak 6% dibandingkan dengan 802.11s yang asal. Keputusan beberapa penghantaran pada masa yang sama menunjukkan medQoS - 802.11s mempunyai peningkatan trafik yang ketara sehingga 12% daripada 802.11s asal. Keputusan *testbed* telah mengesahkan jaminan trafik teleperubatan direka per masa penghantaran. Secara keseluruhan, kebolehpercayaan dan masa jaminan medQoS telah sangat meningkatkan 802.11s untuk menghantar trafik bagi perkhidmatan teleperubatan.

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LIST OF SYMBOLS

mp	-	A wireless mesh point or node as in 802.11s
V	-	Overall mesh network
mpp	-	A wireless mesh point act as portal in 802.11s
mpn	-	A set of neighbor from mp
f_c	-	Fixed size time slot for control message
f_d	-	Fixed size time slot for data message
c_v	-	Maximum packet transmission capacity in one time slot for mode transmission v
λ	-	Transmission Rate of packet arrival (Poisson Distribution Rate)
μ	-	Job Service rate for the queue process
K	-	Slot size / queue size
π_{xy}^{k}	-	A k-th path from source x to destination y
$C(q)$	-	QoS Price Ratio as metric for a link q
D_q^a	-	An actual delay measured from a link q
T_q^a	-	An available throughput measured from a link q
E_q^a	-	A probability of error rate measured from a link q
D_q^r	-	An actual delay measured from a link q
T_q^r	-	An available throughput measured from a link q
E_q^r	-	A probability of error rate measured from a link q
α_m	-	interest cost for a QoS Price at metric m
I_m	-	Indicator for a QoS Price at metric m

LIST OF EQUATIONS

LIST OF ABBREVIATIONS

AC	-	Access Point
ACK	-	Acknowledgement Frame
AE	-	Address Extension in 802.11s frame
AODV	-	Ad hoc On-Demand Distance Vector
CATT	-	Contention-Aware Transmission Time
CCA	-	clear channel assignment
CSMA/CA	-	carrier sense multiple accesses with collision avoidance
DCF	-	Distributed Coordination Function
DICOM	-	Digital Imaging and Communications in Medicine
ECG	-	electrocardiography machine
EDCA	-	Enhanced Distributed Channel Access
ENT	-	Effective Number of Transmissions
ETT	-	Expected Transmission Time
ETX	-	Expected Transmission Count
HWMP	-	Hybrid Wireless Mesh Protocol
iAWARE	-	Interference aware
ICT	-	Information and Communication Technology
IETF	-	Internet Engineering Task Force
INX	-	Interferer Neighbors Count
ITU	-	International Telecommunication Union
LAN	-	Local Area Network
LBT	-	Listen before Talk
MAC	-	Medium Access Control
MAN	-	Metropolitan Area Network
MAP	-	Mesh Access Point
MBSS	-	Mesh Base Station Service
MCCA	-	Mesh Coordination Function Controlled Access

MCCAOP	-	Mesh Coordination Function Controlled Access - Transmission Opportunity
MCF	-	Mesh Coordination Function
MDA	-	medical data assistant
mETX	-	modified Expected Transmission Count
MIC	-	Metric for Interference and Channel Switching
ML	-	Minimum Lost
MP	-	Mesh Point
OSI	-	Open System Interconnection
PERR	-	Path Error Message
PREP	-	Path Reply Message
PREQ	-	Path Request Message
QoS	-	Quality of Service
RANN	-	Root Announcement Message
RARE	-	Resource Aware Routing for Mesh
RFC	-	Request for Comment
RSSI	-	Received Signal Strength Indicator
SNR	-	Signal to Noise Ratio
TDMA	-	Time Division Multiple Access
TTL	-	Time to Live
TXOP	-	Transmission Opportunity
WCETT	-	Weighted Cumulative Expected Transmission Time
WLAN	-	Wireless Local Area Network

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CHAPTER 1

INTRODUCTION

1.1. Problem Background

The implementation of information and communication technologies (ICT) to provide healthcare service at distance has been done for more than a century. This can be traced back to the work of *Telecardiogram* by William Einthoven on 22 March 1905 (Hjelm and Julius, 2005). He transmitted his electrocardiograph successfully through Leyden mile, a 1.5 km telephone cable in length from Polytechnic School in Delft to the hospital in Leiden. The booming of this field was started in early 1960s when National Aeronautics and Space Administration (NASA) implemented vital signs monitoring of astronauts during space mission and the first transmission of radiological images called Telognosis by Gershon and Cohen (1965). The telemedicine term was then introduced by Thomas Bird (1975) to recognize a delivery service where physicians examine distant patient through the use of telecommunication technologies.

Telemedicine then came to community services as researchers and government bodies realized the potential of telemedicine. Several telemedicine pilot and large projects had been launched for community services in early 1970s through mid-1980s. Most telemedicine projects at that time were short-lived and terminated without being able to achieve its real niche market potential. Many reasons had been argued for the cause of their failures, but the main technologies discrepancy at that time prevented the sustainability of telemedicine project in the long term and large scale implementation (Bashshur, 1995). The use of high cost communication to reach remote area and equipment reliability were the main constrains to provide the cost-effective telemedicine as a substitute of face-to-face contact in this first era.

In the mid-1990s, telemedicine came to age with the advancement in image digitization, data compression and communication technology. The cost problem had lowered by the vast distribution of new technologies and reduced computational cost. The question regarding feasibility and reliability has been relatively answered by demonstrations of specific healthcare services, such as *teleradiology*, *telecardiolog*y and *teledermatology*. Nowadays, it is difficult to find a country without an established policy or plans for implementing a telemedicine capability. The issues then arise for the large-scale implementation of telemedicine.

The most significant barriers for the recent telemedicine implementation can be described in three different perspectives. The first perspective is the healthcare management where the barriers are the user and healthcare personnel acceptance with the technology skill improvement among parties. Second barrier is the regulation and policies issues, involving the reimbursement method and licensure of parties in global connectivity of telemedicine services. The third barrier is the selection of technologies to fulfill the increasing requirements in medical data exchanges with the lowest or even elimination of the cost. In this research, we are focusing on the minimization of the third barrier.

Current technology advancements have increased the need of complex information in telemedicine. For example, the transmission of high and low signals has evolved into the high quality diagnostic images with three or four dimensional features. The conceptual definition of telemedicine also spans to provide ubiquitous health services for personal and also large process policies for health care organization. This new telemedicine paradigm triggers new domain concept where the exploitation of modern wireless technologies as the main key (Pattichis *et al.*, 2002). The expansion of emerging technology in telemedicine creates bigger challenges, where access availability, scalability and information reliability are the most dominant factors.

Wireless communication technology has seen the fastest growth in the history to provide telemedicine innovation, boosted by deployment of enabling technology and technological advancement in signal processing, access and coverage area. The well established and emerging wireless technologies have tackled the location boundary from wired based telemedicine, where the parties need at specific place with the cable connection. The parties involved can tap into vital information anywhere and at any time within the wireless network coverage. Various wireless telemedicine solutions have been proposed and developed by adopting recent wireless technologies.

Most proposed solutions were based on commercial off-the-shelf wireless technologies, with enhancements on flexibility and deliverability for heterogonous data. The use of commercial network services, such as cellular and long term evolution (LTE), creates integration problems between different global communication options and standards. Restricted scalability from network providers may limit the extent of telemedicine service, especially in the low market area. The reliability and the quality of medical data exchanges in this network are very much reliant on the service level from network provider. The use of independent wireless network is needed to provide an open integrity for telemedicine service enhancement.

The proliferation of low cost wireless mesh network (WMN) in a number of large scale implementation, e.g. MIT roofnet (Bicket *et al.*, 2005), has opened the door for independent telemedicine infrastructure. The Institute of Electrical and Electronics Engineers (IEEE) has initiated the standardization work of WMN technology, where the identification nomenclature is IEEE 802.11s standard for WMN semi-infrastructure. The IEEE 802.11s has a self-organization characteristic, scalability in coverage area and its carrier technology solely based on independent and free license-exempt frequency spectrum. The 802.11s gives less backhaul constructions to every wireless node in the network compared to the conventional wireless local area network (WLAN) deployment. It is a low cost network with the reduction of installation, commissioning and operational cost thereby achieving 70% saving compared to conventional approaches (Roch, 2005). These criteria offer promises for an open implementation of cost-effective telemedicine services. IEEE 802.11s is suitable candidate to leverage telemedicine service with the lower cost technology.

Even though there are feasible promises for WMN implementation as telemedicine infrastructure, study shows only one large scale telemedicine project had been done within past ten years. This project was launched in 2007, called

Emergency Room Link (ER-LINK). ER-LINK was worked on 365 square kilometer with 95% coverage area of the city of Tucson, Arizona, USA (Wang, 2008). Unfortunately, due to its lack of operational fund, this project had been shut down since 2011 by the local government albeit the mesh infrastructure still in use daily (Versel, 2011). This project involves the use of Open Link State Routing (OLSR) WMN type.

The other telemedicine infrastructure which involving non-802.11s standard WMN could be seen in Pirzada *et al.* (2009) for the incident area infrastructure, the concept of emergency application by Yarali *et al.* (2009) and triage infrastructure by Marti *et al.* (2009). However, most of implementation performances, especially in throughput and delay, degrade significantly when the source is located at an increasing number of hops away from the destination.

1.2. Problem Statement

The implementation of wireless mesh network, by means of 802.11s, could provide a low cost infrastructure for telemedicine services and improve grade of service performance. However, it is difficult to find current 802.11s WMN implementation for telemedicine infrastructure and its comparison analysis to other WMN architecture. There is a need to provide a performance evidence of 802.11s with other WMN architecture for telemedicine infrastructure.

Despite the effort of 802.11s standard to fully optimize path control in the physical layer, the multihop 802.11s still depends on the path process performance for a correct path selection. Unfortunately, this path selection mechanism is hard to recognize the end-to-end Quality of Service (QoS) requirement from the upper layer.

The reliability and timely manner of service in telemedicine could determine life and death situation (Philip and Istepanian, 2007). Thus, it makes QoS provision as the very important parameter in telemedicine infrastructure. The requirement on joint layer optimization in cross layering approach is one of the feasible solutions to provide the optimum path selection (Borges *et al.*, 2011; Mogre *et al.*, 2007). In this way, the deployment of 802.11s can be self-adaptive to physical network dynamics and meet end-to-end requirements of the applications (Gungor *et al.*, 2008).

Most cross-layering approach solutions for WMN relied on the network layer to provide routing mechanism. These works only considered a single performance parameter, which is taken from upper layer or lower layer. Most of the existing works also relied on the adaptation from mobile ad hoc networks with little support for Quality of Service (QoS) (Kone *et al.*, 2007). These solutions did not cover the core point that data link layer mechanism is the main distinctive part from 802.11s WMN. There is a consideration need to implement such solutions at data link layer.

1.3. Aim and Objective

The aim of this research is to provide 802.11s based telemedicine infrastructure with the end-to-end QoS provisioning of telemedicine service. The objectives below have been set out in order to achieve the aim of research;

- To develop a system model of telemedicine service by utilizing 802.11s wireless mesh network as the main wireless backhaul.
- To develop multi-metric model for the path selection mechanism in 802.11s by reflecting the required parameters from the telemedicine service and available resources in the network.
- To integrate the path management and resource allocation in 802.11s based on the new multi-metric in a distributed manner by considering the condition of link resources.
- To test and analyze 802.11s with the proposed modified 802.11s on the developed discrete time simulator and real environment test bed.

1.4. Scope and limitation

In this thesis, the network is considered as the abstraction layers of OSI model. Over this past three decades, the clear boundaries of OSI model has been used to produce modular and well defined architecture system (Kawadia and Kumar, 2005). These advantages could help this research to focus on the optimized solution design related in layer two of OSI perspectives.

This research is focused on the improvement of 802.11s - 2007 standards for telemedicine service infrastructures. 802.11s use 802.11a/b/g as physical layer and deliberately works in data link layer. The justification of the improvement needs for 802.11s should be done by comparing 802.11s performance with the other WMN protocols. The proposed improvement is the modified 802.11s mechanism by integrating end-to-end QoS provisioning to the selected path. The selected path should satisfy the required performance from telemedicine services by considering the condition of available link resources.

The general concept of telemedicine service is considered in this research. This means, the proposed solution should cover the data transmission from general medical devices for any scenario. There is no specific environmental scenario that should be determined, since any medical scenario is intended to use one or more medical devices.

A set of minimum performance requirement for each telemedicine service should be determined to evaluate the proposed solution. This requirement should support its unique medical interface and should support the integration of all services regardless of their location and application (Rashvand *et al.*, 2008) . There is no agreement on the perceived values and selected parameters from the study in literatures. Hence, all of parameters were based on the proposed telemedicine data model and its data traffic parameters. These traffic parameters should be quantifiable and feasible to be measured in 802.11s mechanism. It is wise to adopt several standards that are linked to the medical and networking for finding the values of each traffic parameter. Thus, the available standards from ITU, IEEE, ETSI and DICOM-NEMA are considered for the required performance to measure the achievable QoS.

802.11s provides two path discovery mechanisms upon the way a path discovery is triggered. In the sense of QoS mechanism, the source mesh point needs to wait a transfer request from the upper layer and triggers the path discovery process. This method is only feasible from the nature of reactive path discovery method in 802.11s. The path maintenance is done by scheduling the path discovery activation during an established transmission.

The path management in 802.11s are based on the metric calculation. The proposed modification of 802.11s metric should provide awareness of the link characteristic and at the same time should describe the QoS requirements from the requested traffic. Consequently, the metric should be an objective measurement at each mesh point related to network performance parameter. The multi-metric solution is needed as the performance of each telemedicine services is constrained by several parameters. Nevertheless, the calculation of the metric set in path discovery algorithm should be nondeterministic polynomial time and minimizing the changes in 802.11s.

The resource allocation in 802.11s is scheduled within intermediate mesh point along the selected route by request from the source mesh point. The intermediate nodes should ensure the trade off between available resources and the required resources. Hence, the scheduling and admission control resides on each 802.11s mesh point in the same path. The system runs as a distributed but cooperative algorithm with the resource requirements centralized from the source mesh point.

The intention of 802.11s is to provide semi-infrastructure wireless backhaul. The mesh node presents a minimal mobility and form the backhaul of the entire telemedicine network. Thereby, any challenges affected from the physical location and movement speed of the wireless network are not substantial to be measured for the link quality of the network.

The environment in the wireless medium is shared among mesh nodes. This creates interference and congestion considering the frame losses and high delay. As the mesh network is a managed topology, most common problems from interference and co-channel existence are caused by poor network planning and poorly configured mesh point (Benyamina *et al.*, 2012). Nevertheless, these problems need to be addressed as the link quality awareness from the path discovery metric.

Low energy issues has received more attention in 802.11s by adding a beacon frames for the synchronization and power saving (Lin *et al.*, 2011). The main idea of this process is to transmit the power state of mesh point to its associated mesh point within negotiated times. This research assumes that prior the path management process, each selected mesh point is already in light-sleep state. Thus, the management of energy is done before the path discovery is initialized.

In term of the security issues, the 802.11s standards perform the dictionary attack-proof Simultaneous Authentication of Equals (SAE) algorithm (Hiertz *et al.*, 2010). This authentication is done in a distributed and independent approach between a pair of neighbouring mesh points in a peer management process. The peer management process is the initialization process before any path management process. It is assumed that all mesh point in the system has been authenticated by its neighbour mesh point. The end-to-end encryption or any secure mechanism for telemedicine data is assumed to be done by telemedicine application in upper layer.

The interoperability with other 802.XX network concept is seamlessly integrated in 802.11s. The 802.11s supports transparent delivery of uni-, multi- and broadcast frames to destinations in- and outside the mesh network (Benyamina *et al.*, 2012). Mesh point then forwards frames but do not communicate with non-802.11s stations. However, a mesh point may be collocated with other network by taking action as mesh base station (MBSS). Hence, the flow from MBSS in the 802.11s network could be treated identically as flow from mesh point in the 802.11s network.

The performance analysis in this thesis utilized extensively the open discrete event network simulator of ns-3. As the successor of the famous ns-2 in telecommunication research area, ns-3 is an active open source projects, flexible, provided extended wireless capability and maintained by many network research community (Chaudhary *et al.*, 2012; Sarkar and Halim, 2011; Sterbenz *et al.*, 2013). The result of simulation are evaluated and verified by using real wireless network testbed implementation.

1.5. Important Contribution

In this thesis, we explore the use of 802.11s WMN technology and proposed the scheme for QoS routing protocol and its metrics with the proposed telemedicine data traffic type and parameters. Three important contributions had been identified as the contribution for line of knowledge in telemedicine and 802.11s technology.

First, the preliminary implementation of telemedicine service with wireless mesh network as the infrastructure had been done. Second is the system model of 802.11s for telemedicine services and the new QoS Price metric for 802.11s for QoS provision. Third is the modification of path management and additional resource allocation for 802.11s to support QoS Provision.

Several papers and journals have been published for the research contributions. A preliminary work for telemedicine in wireless mesh network has been publish such as (Supriyanto and Satria, 2009b), (Mulyadi *et al.*, 2009) and with the specific use for prenatal telemonitoring in (Supriyanto and Satria, 2009c).

Also, the joint layer approach for QoS possibilities in wireless telemedicine were published in (Satria *et al.*, 2009) and (Supriyanto and Satria, 2009a). The possibilities of cross layer through data link layer also had been publish in (Putra and Satria, 2011). The QoS provisioning in 802.11s and its model were published in (Satria *et al.*, 2014), with a journal are still in review process at International Journal of Electrical Engineering (IJECE) 2014.

1.6. Outline

The remainder of this thesis is organized as follows.

Chapter 2 gives the background and related work on telemedicine, 802.11s mesh network and the Quality of Service from telemedicine and network point of view. This chapter starts with the description on terminology of telemedicine and the use of wireless technology as the medium to deliver the health service. The second section is all about 802.11s as the extension amendment from the available 802.11

MAC and its detail framework. The third section explains the relation of QoS as the performance parameter from telemedicine services, wireless based telemedicine and the detail literature of the available metrics use for QoS parameters.

Chapter 3 presents the research methodology to ensure that the research is progressing toward successful path. There are five stages of research, initiated by problem formulation and literature review. The first section explains in detail the modelling synthesis method to provide conceptual and mathematical models of general and proposed 802.11s system. The second section explains the implementation and performance analysis as the least stages of methodology.

Chapter 4 presents the implementation of different aspect from the wireless mesh network as the low cost infrastructure backhaul for telemedicine service and its performance measurement in general. In the first section, the proposed telemedicine service architecture is briefly explained and determined the characteristic per mesh points. The second section explains the proposed device traffic parameter. Third section is all about scenario for low cost telemedicine system and its preliminary implementation. Fourth, the performance analysis from common wireless mesh network protocols is analyzed.

Chapter 5 focuses on 802.11s with proposed multi metrics for path selection, path management algorithm and resource allocation for telemedicine services. The first section describes the system model for telemedicine service by segregating the services into intermittent and continuous service. The second section explains the mathematical model of 802.11s for telemedicine infrastructure and its path selection model. The third is the main QoS Price explanation as the multi-metric performance with the mathematical model for three type of cost and path selection algorithm. In this section, the modified extended versions of control messages from 802.11s are also being described. Lastly, the fourth section gives the details about resource allocation and its calculation support from the proposed metric.

Chapter 6 describes the performance analysis of the proposed routing metrics. It started with the explanation of ns-3 as the tool for our analysis. The first section analyzes the impact of protocol overhead introduced by the extended control message as the additional cost. Next, the second analysis is the effect of the interest cost α_M from the medQoS routing protocol. Third is the analysis from the impact of concurrent connections with focusing on diagnostic video data. Fourth is the use of real device testbed to verify the result from the simulation.

Lastly, Chapter 7 is composed by the conclusion of this thesis and future research recommendations.

been introduced by Feng *et al.* (2010). It should be denoted that 802.11s a distributed scheme where channel conditions are different among the mesh point. Thus, The use of multi-channel distribution for WMN in Ghaboosi *et al.* (2008) could provide the initial work of CRN to be implemented in 802.11s.

The 802.11s optional medium of MCCA could be used to provide collision-free and guaranteed channel access in the period of time. There is a high possibility for medQoS-802.11s mechanism to be adopted in MCCA based 802.11s network. However, the dynamic integration approach with intermediate non-MCCA MP should be considered. Several work of the MCCA enhancement for the end-to-end guarantee from the required traffic could be seen from the works of Kolorov *et al.* (2011) and Islam *et al.* (2011).

The inter-working of 802.11s with the heterogeneous network is become prominent to provide a ubiquitous access for telemedicine service. Especially in the ambulance scenario, 802.11s is prone to provide service guarantee in the mobile and fast handoff situation. 802.11s are supported the inter-working with the MAP availability in one or more MP. As a result, the handoff delay then becomes increase when the client of one MAP moves to another MAP. There is a need for the proposed path discovery to provide a fast handoff parameter with the dynamic reservation mechanism based on the mobility parameters. A study from Chi *et al.* (2011) could provide handoff mechanism of 802.11s for the ambulatory scenario. In general, the cost based optimization from Niyato *et al.* (2009) could provides the fundamental framework for the inter-working of telemedicine services in heterogeneous network.

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