ระดับพลวัตสำหรับการตัดสินใจแฮนด์ออฟแนวตั้งที่ใช้เอสไอเอ็นอาร์ในเครือข่ายเฮทเนท

ดามาร์ วิดจายา

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรดุษฎีบัณฑิต

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ปีการศึกษา 2559

DYNAMIC THRESHOLD FOR SINR BASED VERTICAL HANDOFF DECISION IN THE HETNET

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Telecommunication Engineering

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เครือข่ายเฮทเนท (Heterogeneous Network: HetNet) ซึ่งประกอบด้วยเครือข่ายหลายเครือข่ายกำลังถูกพัฒนาในขณะนี้ การทำงานประสานกันของแต่ละเครือข่ายควรจะไม่มีความผิดพลาด โดยเฉพาะการส่งมัลติมีเดียร์ในเครือข่ายไร้สาย ดังนั้นการทำแฮนด์ออฟที่ไร้รอยต่อและมีประสิทธิภาพระหว่างสองเทคโนโลยีที่แตกต่างกันจึงเป็นปัญญาที่ท้าทายและจำเป็นมากที่ต้องทำให้สำเร็จ รูปแบบการทำแฮนด์ออฟระหว่างเครือข่ายนี้เรียกว่า การทำแฮนด์ออฟในแนวตั้ง (Vertical Handoff) วิทยานิพนธ์นี้พิจารณาเครือข่ายท้องถิ่นไร้สายและดับบิวซีดีเอ็มเอเป็นตัวแทนของเครือข่ายเฮทเนท จากการสำรวจปริทรรศน์วรรณกรรมที่ผ่านมาพบว่าเงื่อนไขบางอย่างสำหรับการตัดสินใจทำแฮนด์ออฟแนวตั้งถูกเสนอในหลายรูปแบบ เช่น การใช้ความแรงของสัญญาณที่รับได้ และอัตราส่วนของสัญญาณต่อสัญญาณแทรกสอดและสัญญาณรบกวนหรือเรียกว่าเอสไอเอ็นอาร์ จากงานวิจัยที่ผ่านมาพบว่าการใช้เอสไอเอ็นอาร์ทำให้ระบบมีสมรรถนะด้านปริมาณรับส่งข้อมูลที่สูงที่สุด อย่างไรก็ตามยังมีขีดจำกัดบางอย่างที่ต้องแก้ไข ขีดจำกัดหนึ่งคือการเกิดแฮนด์ออฟที่ไม่จำเป็นสำหรับการใช้เอสไอเอ็นอาร์ วิทยานิพนธ์นี้จึงมีเป้าหมายที่จะลดปัญหาการเกิดแฮนด์ออฟที่ไม่จำเป็นนี้โดยเสนอระดับพลวัตสำหรับการตัดสินใจแฮนด์ออฟแนวตั้งที่ใช้เอสไอเอ็นอาร์ในเครือข่ายเฮท เนทในขณะที่ยังคงปริมาณรับส่งข้อมูลที่ยอมรับได้ ความเร็วในการเคลื่อนที่ของผู้ใช้บริการถูกพิจารณาเป็นอีกหนึ่งปัจจัยที่เพิ่มขึ้นในการศึกษานี้ซึ่งมีความสัมพันธ์กับระดับพลวัตที่เสนอขึ้น หลักการของวิธีการที่นำเสนอคือการกำหนดให้ผู้ใช้บริการที่เคลื่อนที่ช้าควรจะอยู่ในพื้นที่ของเครือข่ายท้องถิ่นไร้สายให้นานขึ้น ส่วนผู้ใช้บริการที่เคลื่อนที่เร็วควรจะอยู่ในพื้นที่ของเครือข่ายดับบิวซีดีเอ็มเอนานขึ้น วิทยานิพนธ์นี้ได้นำเสนอแนวคิดและการวิเคราะห์ปัญหาด้วยการหาความสัมพันธ์ของระดับพลวัตกับความเร็วในการเคลื่อนที่ของผู้ใช้บริการในรูปแบบสมการทางคณิตศาสตร์ จากนั้นประเมินสมรรถนะของเครือข่ายด้วยการจำลองแบบในคอมพิวเตอร์ ผลการศึกษาพบความสัมพันธ์ที่มีนัยสำคัญของปริมาณรับส่ง ข้อมูล จำนวนการทำแฮนด์ออฟ ความน่าจะเป็นที่จะขาดการติดต่อ และแฮนด์ออฟที่ไม่จำเป็น ถึงแม้ว่าค่าเฉลี่ยปริมาณข้อมูลจะตกลงเล็กน้อยแต่วิธีการที่เสนอขึ้นสามารถลดแฮนด์ออฟที่ไม่จำเป็น

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DAMAR WIDJAJA : DYNAMIC THRESHOLD FOR SINR BASED VERTICAL HANDOFF DECISION IN THE HETNET. THESIS ADVISOR : ASSOC. PROF. PEERAPONG UTHANSAKUL, Ph.D., 100 PP.

HETNET/VERTICAL HANDOFF/SINR/USER VELOCITY/DYNAMIC THRESHOLD

A heterogeneous network (HetNet) that consists of various wireless networks is being developed. Integration of the networks should be error free to attain multimedia wireless networks. The seamless and efficient handoff between different access technologies, which is known as vertical handoff (VHO), is essential and remains a challenging problem. This study will consider WLAN and WCDMA in the HetNet. Several criteria for VHO decision have been proposed in the literature, such as Received Signal Strength (RSS) and Signal to Interference plus Noise Ratio (SINR). It has been shown that SINR based VHO has superior performance in terms of throughput. However, there are some limitations in SINR based VHO scheme. Unnecessary handoff (UHO) is one of the problems that still occur. This study aims to overcome those limitations. In this study, we propose a dynamic threshold of SINR based VHO to reduce the number of UHO, while maintaining an acceptable throughput for multimedia data transfer. The user velocity is considered as an additional criterion for SINR based VHO decision and will be represented in the value of additional SINR threshold. The basic principle of the proposed algorithm is that slow speed user should stay longer in WLAN cells and high speed user should stay longer in WCDMA cells. The proposed algorithm assigns the dynamic threshold based upon the user velocity. This study presents an analytical framework for defining relationship between dynamic threshold and user velocity. The simulation platform to evaluate the performance has been set up. The simulation results have been compared with previous study. Simulation results show that there is a tradeoff between average throughput and the number of handoff, dropped call probability, and unnecessary handoff. Although the average throughput is slightly dropped, the velocity consideration gives better performance on the number of handoff and dropped call probability, and significant unnecessary handoff (ping-pong effect) reduction. In this study, optimum threshold is obtained when the high percentage of unnecessary handoffs reduction is reached with an acceptable value of average throughput for multimedia data transfer.

School of Telecommunication Engineering Student's Signature___________________

Academic Year 2016 Advisor's Signature___________________

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Damar Widjaja

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SYMBOLS AND ABBREVIATIONS

3G	=	Third Generation
3GPP	=	Third Generation Partnership Project
4G	=	Fourth Generation
5G	=	Fifth Generation
α_n	=	Weighted value for those calls having *n* handoffs
a	=	Cell radius
ACR	=	Access Control Router
AHP	=	Analytic Hierarchy Process
AP	=	Access Point
BER	=	Bit Error Rate
BS	=	Base Station
CSG	=	Closed Subscriber Group
CRT_{AP}		Cell residence time inside WLAN AP
CRT_{BS}		Cell residence time inside WCDMA BS
δ	=	Handoff threshold (Dynamic threshold)
D	=	Distance in meters between the user and the BS or AP (Distance from UE_S and UE)
D_0	=	Distance from the initial user movement point to UE_S
D_{n_i}	=	Distance between user at point UE_δ to candidate neighbour cell
D_{s_i}	=	Distance from user at point UE_δ to serving cell

SYMBOLS AND ABBREVIATIONS (Continued)

D'_{n_i}	=	Distance from the neighbour AP2/BS2 to UE_S
D'_{s_i}	=	Distance from the serving AP1/BS1 to UE_S
DoS	=	Denial of Service
DT	=	Dwell Time
DVHO	=	Downward Vertical HandOff
$f(t)$	=	Probability density function of traverse time in WLAN coverage region
FLP	=	Fuzzy Logic Processing
γ	=	SINR received at user end when associated with WLAN or WCDMA
γ_{AP}	=	SINR received at user end from associated AP
γ_{BS}	=	SINR received at user end from associated BS
γ_{s_i}		SINR received by the user in the serving cell
Γ	=	dB gap between uncoded QAM and channel capacity minus the coding gain
$G_{(dB)}$	=	Path loss (Channel gain)
$G_{j,i}$	=	Channel gain between i^{th} user and its associated j^{th} AP or BS
G_{s_i}	=	Channel gain between i^{th} user and its serving cell
GPS	=	Global Positioning System
GSM	=	Global System for Mobile Communications

SYMBOLS AND ABBREVIATIONS (Continued)

HetNet	=	Heterogeneous Network
HMC	=	Handoff Management Center
$I_{s_i} = \left(G_{k,i}P_k\right)$	=	Interference received by i^{th} user from other neighbour APs or BSs
IINR	=	Interference to other Interference plus Noise Ratio
LogF	=	Log-normal distributed shadowing with standard deviation of σ =10dB
LTE	=	Long Term Evolution
μ	=	Probability that the signal is below the specified co-channel interference level (in an interference-limited system)
M	=	Highest number of handoffs for those calls
MCHO	=	Mobile Controlled Handoff
MCNA	=	Mobile Controlled Network Assisted
MIH	=	Media-Independent Handoff
MIMO	=	Multiple Input Multiple Output
N	=	Background noise power at user receiving end
N_{s_i}	=	Background noise power at user receiving end in the serving cell
NCHO	=	Network Controlled Handoff
NCMA	=	Network Controlled Mobile Assisted
ND	=	Network Discovery
P	=	Dropped call probability

SYMBOLS AND ABBREVIATIONS (Continued)

P_j	=	Transmit power of j^{th} AP or BS
P_n	=	Probability of a dropped call when the call has gone through n handoffs
P_p	=	Probability of ping-pong
P_{s_i}	=	Transmit power of serving cell received by i^{th} user
QAM	=	Quadrature Amplitude Modulation
QoS	=	Quality of Service
R	=	The maximum achievable data rate
R_{AP}	=	Received data rate from AP
R_{BS}	=	Received data rate from BS
RF	=	Radio Frequency
RSS	=	Received Signal Strength
SAW	=	Simple Additive Weighting
SINR	=	Signal to Interference plus Noise Ratio
$SINR_i$	=	Received SINR from the neighboring BS
$SINR_o$	=	Received SINR from the serving BS
SVHO	=	Soft Vertical HandOff
θ	=	Total downlink throughput
t_δ	=	Time needed to travel from UE_S point to UE point
TTT	=	Time-To-Trigger
UE	=	User Equipment
UE_0	=	Starting point of user movement

SYMBOLS AND ABBREVIATIONS (Continued)

UE_{δ}	=	Point when additional SINR dynamic threshold, δ, is reached
UE_S	=	Point when user receives the same SINR from the serving and the neighbour cell
UHO	=	Unnecessary HandOff
UVHO	=	Upward Vertical HandOff
UMTS	=	Universal Mobile Telecommunications System
v	=	User velocity
VHD	=	Vertical Handoff Decision
VHO	=	Vertical HandOff
W	=	Carrier bandwidth
WCDMA	=	Wideband Code Division Multiple Access
WiBRO	=	Wireless Broadband Internet
WDP	=	Wrong Decision Probability
WLAN	=	Wireless Local Area Network
WPANs	=	Wireless Personal Area Networks
WWAN	=	Wireless Wide Area Network
X_h	=	Handoff point
X_1	=	Point where call starts
X_2	=	Point where call ends

CHAPTER I

INTRODUCTION

1.1 Background

A heterogeneous network that consists of various wireless networks, including Wireless Local Area Network (WLAN), and mobile communications, such as Wideband Code Division Multiple Access (WCDMA), is being developed to achieve high speed transmission (Chang & Chen, 2008). Heterogeneous network can be expanded with some other technologies which are developed for short-range coverage, such as Wireless Personal Area Networks (WPANs), e.g., Bluetooth and Zigbee (Wang and Kuo, 2013).

Heterogeneous network will be so complex towards Fifth Generation (5G) system. It will integrate all the existing technologies, such as Third Generation (3G), Long Term Evolution (LTE) system embodying Fourth Generation (4G), and 5G Base Stations (BS) to provide high-rate and seamless communication service (Qiang *et al*, 2016; Andrews *et al*, 2014). Different 5G architectures are presented with key technologies such as Multiple Input Multiple Output (MIMO), cognitive radios, and visualized as heterogeneous networks (Hasan *et al*, 2016). Jaber *et al* (2016) define 5G networks as a heterogeneous network composed of various wired and wireless links with the ability to dynamically adjust and adapt to the changes in the network.

For seamless communication, the integration of the networks, such as WLAN and 3G WCDMA systems should be error free to achieve the next generation multimedia wireless networks (Yang *et al*, 2007). The seamless and efficient handoff between different access technologies, known as Vertical HandOff (VHO), is essential and remains a challenging problem. VHO schemes provide not only service continuity in the entire network area, but also an effective solution for enhancing cell edge throughput, which is a major issue in 4G standardization (Choi, 2010). Moreover, data rate in 5G is expected to be roughly 1000× compared with current 4G technology, hence the VHO requires a faster processing (Qiang *et al*, 2016). Hybrid 5G environments need a fast, distributed, privacy-preservation and user-centered handoff scheme.

The VHO operation should provide a minimum overhead, authentication of the mobile users, and the connection should be maintained to minimize the packet loss and transfer delay (Bhuvaneswari and Prakash, 2012; Stevens-Navaro and Wong, 2006). A decision algorithm gives a better performance when several parameters are considered. The trade-off is with the increase in decision time and complexity of the algorithm. Up to now, many methodologies have been used on VHO, such as policy-enabled schemes, fuzzy logic, neural networks concepts, etc (He *et al*, 2010). Although some of these methods are quite successful, they are not particularly suitable for real-time applications in the real world applications, since the reliability of them usually depends on complex procedure.

Several criteria for VHO decision have been proposed in the literature and the main criteria are Received Signal Strength (RSS), Signal to Interference plus Noise Ratio (SINR), and available bandwidth (Mardini et al, 2012). Detail of these studies will be described in related work section. Most of the previous works make handoff decisions based on RSS, but yield serious ping-pong effect when a mobile node moves around the overlay area of several heterogeneous wireless networks. The ping-pong effect causes unnecessary handoff and brings some weaknesses, including low network throughput, long handoff delay, and high dropping probability. RSS with hysteresis based VHO has been proposed in many studies to prevent ping-pong effect (Zeng and Agrawal, 2002). However, the first handoff maybe unnecessary if the serving BS is sufficiently strong.

Another criterion that has been extensively studied is SINR based VHO decision. SINR based VHO algorithm gives superior performance in terms of throughput compared to RSS based VHO (Yang *et al*, 2007). However, major drawback of SINR based VHO is that it is dependent on the velocity of the mobile users and performance of the scheme degrades with the increase in velocity (Ahmed *et al*, 2014). Also, this scheme provides high latency and a very high number of unnecessary handoffs. Excessive handoffs come up due to the variation of the SINR and causing ping-pong effect. SINR-only based VHO will increase feedback overhead (Choi, 2010).

Unnecessary HandOff (UHO) is one of the challenging problems that still occur in many proposed VHO algorithm in the previous studies. UHO usually is caused by the terminals dwelling at the edge of cell coverage (Lin *et al*, 2014). Minimizing UHO is as important as handover triggering condition estimation and optimization of handover execution (Hussain *et al*, 2012). If the UHO are not checked, the phenomenon will have adverse effect on the system performance. Not only overhead involved in UHO would consume network resources, but it would also increase the probability of handover failure. Additional risks are present during channel setup and tear down when a VHO is made, such as extra traffic latency, additional network signaling, more User Equipment (UE) power consumption due to simultaneously active network interface to multiple tiers, and higher risk in call drops or degraded Quality of Service (QoS) caused by the lack of radio resource after handoff (Bao and Liang, 2015).

This study considers user velocity as an additional criterion for SINR based VHO decision to improve overall system performance in terms of other parameters, such as number of handoff per call and dropped call probability, while maintaining an acceptable throughput. The formula of handoff decision based on the SINR in (Choi, 2010) will be used as the foundation to build up the proposed algorithm. Consideration of user velocity will be represented in the value of additional SINR threshold. The proposed algorithm is called dynamic threshold for SINR based VHO decision in heterogeneous network. System assigns fixed threshold regardless the user velocity variety and dynamic threshold depending on the user velocity.

The basic principle of the proposed algorithm is that slow speed user should stay longer in WLAN and high speed user should stay longer in WCDMA. There are some advantages that can be achieved by this basic principle. This approach assigns user to appropriate cells so that frequent call handoff from fast-speed users in small cells can be avoided (Huang *et al*, 2011) and signaling overheads and processing load reduced (Kim *et al*, 2010; Shafiee *et al*, 2011). VHO blocking probability can be reduced while maintaining reasonable throughput in the WLAN (Kim *et al*, 2010). It will also reduce ping-pong effect (Rizvi *et al*, 2010; Cha *et al*, 2008) and dropping probability (Dan *et al*, 2012). In this study, we propose a dynamic threshold of SINR based VHO to reduce the number of handoff per call, dropped call probability, and UHO, while maintaining an acceptable throughput for multimedia data transfer.

1.2 Research Rationale

The rationale of the importance of considering user velocity as the additional criterion for SINR based VHO decision is as follows:

1. Additional threshold in basic SINR based VHO is defined as the difference between the qualities of the SINR received from the serving BS and from the neighboring BS.
2. Dynamic threshold is the threshold that has different value for every different user velocity. In this study, the threshold is denoted as δ.
3. Dynamic threshold algorithm will consider individual user velocity in order to give network optimum performance, in terms of throughput, number of handoffs per call, and number of UHO per call.
4. Dynamic threshold will force low velocity users to stay connected in WLAN longer and high velocity users to stay connected in WCDMA longer than it should be, so that the number of handover per call can be decreased.
5. The higher the δ value, the longer the users stay in their velocity associated cells.
6. Users will be forced to stay in the cells associated with their velocity, even the throughput is already getting lower than neighboring cell.
7. The throughput will be lower than combined-SINR based VHO algorithm as the user will perform VHO whenever neighboring cell has the same or higher throughput.
8. To maintain the throughput value in the acceptable level, velocity threshold will be used to divide all users into two groups, low speed users and high

speed users.

9. The lower the velocity threshold, the more users will be defined as high speed users and served by WCDMA that has higher bandwidth. The average throughput will be higher.
10. Eventually, dynamic δ algorithm will improve the whole system performance by reducing average number of handoffs per call, dropped call probability, and UHO, while maintaining acceptable average throughput in the system level.

1.3 Research Objectives

The objectives of this research are as follows:

1. To establish further understanding on the importance of considering user velocity in SINR based VHO decision algorithm.
2. To formulate mathematical equation for relating the dynamic threshold as a function of user velocity and evaluate system performance using system model simulation.
3. To recommend the optimum value of dynamic threshold for achieving optimum system performance.

1.4 Research Scope

The scope of this research is as follows:

1. There will be two steps in developing the proposed velocity considered-SINR based VHO algorithm; the first step is to apply the fixed threshold and the second step is to apply the dynamic threshold.

2. The proposed algorithm will be evaluated and simulated in MATLAB program.
3. The heterogeneous networks that are used in this study consist of WLAN system and WCDMA system.
4. The configuration of WLAN and WCDMA cells for simulation is designed as close as possible to approach the realistic situation. However, there are some limitations on creating a simulation model. This thesis assumes that the simulation area is covered by all WLAN and WCDMA cells with uniform distribution.
5. The users move in a straight line between initial and end points.
6. The WLAN and WCDMA cells have no capacity limit in the simulation scenario.
7. Parameters that are used to evaluate system performance are average throughput, average number of handoff per call, dropped call probability, and UHO.
8. Simulation results of the proposed algorithm will be compared with basic SINR based VHO and combined-SINR based VHO algorithms.

1.5 Research Contribution

The research in this study offers valuable contribution on research novelty in the following areas:

1. This research will gives better understanding about system performance as there are five performance parameters evaluated, i.e. average throughput, average handoff number per call, dropped call probability, average UHO

number per call, and probability of UHO.

2. User velocity, given its importance in VHO decision, will become the main agenda of this study. For that purpose, the basic SINR based VHO decision with additional threshold will be used as a foundation for algorithm development.
3. The simple approach used in this study is expected to bring the research outcomes applicable in the real life networks.
4. Finding the optimum value of dynamic threshold will further help the system to improve their VHO performance in optimum level considering not only SINR value, but also user velocity.

1.6 Chapter Overview

The reminder of this thesis is organized as follows. Chapter 2 extensively reviews the related literature. Subjects discussed include the classification of VHO decision algorithms that have been massively developed in recent years, the basic concept of the algorithms, and the general results of the studies. This chapter also discusses the strong points and weak points of the previous work.

Chapter 3 describes the background theory and basic concept that will be used to support the development of the proposed algorithm. The description will include the topics of evolution of mobile communication system, heterogeneous networks, and vertical handoff.

Chapter 4 provides the development of proposed algorithm and formulation of mathematical equation of additional dynamic SINR threshold. Moreover, this chapter describes performance parameters and simulation scenario that will be used in this study.

Chapter 5 presents the simulation results and discussion. In this chapter, the simulation results of the proposed algorithm will be compared with other algorithms that have been previously proposed.

Chapter 6 provides conclusion of the study and recommendation of parameters setting for optimum system performance.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

This chapter described the previous related works that have been done in the study of VHO decision algorithm. The description is limited to the studies that consider user velocity in the VHO decision, some recent studies about SINR based VHO algorithm, the limitation of SINR based VHO algorithm, and unnecessary handoff reduction algorithm. All these topics are described to give further understanding and detail comprehension about studies of VHO decision algorithm, so that it can be used to support and confirm the novelty and contribution of the proposed algorithm.

2.2 User Velocity Consideration in the Vertical Handoff Decision

There have been many proposed algorithms to consider user velocity in the VHO decision, but not in the study of SINR based VHO algorithm. Some of the studies combine the user velocity and other parameters like cost and RSS to gain the system performance improvement.

Ylianttila (2005) proposed system architecture for VHO in location-aware heterogeneous wireless networks. He performed analysis of VHO algorithm sensitivity to various mobility parameters including velocity, handoff delay, and dwell time using Mobile IP with a fuzzy logic algorithm for VHO. Dwell Time (DT) based VHO algorithm has been compared to RSS based VHO algorithm. Velocity data is collected using GPS, location aware architecture, and geolocation information (distributed location databases). This study aims optimally combining the capacity and services of the current and emerging networks. The results of this study are optimal value for dwell-timer and performance gain over power based algorithm as a function of mean throughput.

Dynamic factors such as RSS and velocity of mobile station simultaneously with static factors like usage expense, link capacity (offered bandwidth) and power consumption have been studied to make the right VHO decision by determining the best network at best time among available networks (Goyal and Saxena, 2008). In this study high speed user is encouraged to perform VHO to large cell. RSS and velocity have been used to select the candidate network. Network Discovery (ND) module, as a part of Handoff Management Center (HMC), have been used to monitor RSS and MS velocity. This study succeeded to improve the whole system performance by reducing the unnecessary handoffs.

Cha *et al* (2008) proposed mobile velocity adaptive VHO in integrated WLAN and Wireless Broadband Internet (WiBRO) according to exact estimation of DT for downward handoff only. DT is defined as a time for UE dwelling in the coverage of the target network, calculated by mobile velocity and it's coordinate. UE always checks the velocity and service cell, calculates DT and forwards it to Access Control Router (ACR). If DT > DTthreshold, UE performs handoff to WLAN. Location and velocity information of UE are achieved with Global Positioning System (GPS). In this case, GPS functionality has to be installed in UE. The goal of this study is to prevent ping-pong handoff taking into account the UE's velocity. This proposed scheme can reduce the number of unnecessary handoff and increase average throughput compared to typical RSS-based scheme.

A new multi-region mobility model has been proposed by Ben Ali and Pierre (2009) in their work entitled On the Impact of Mobility and Soft Vertical Handoff on Voice Admission Control in Loosely Coupled 3G/WLAN Networks. This study defined RSS model as a function of mean velocity. There are two different RSS thresholds for moving in and out of WLAN. The goal of this study is to evaluate the impact of both Soft VHO (SVHO) and WLAN mobility on call blocking and dropping probabilities. The resource-efficient SVHO blocks and drops much less voice calls than the static one when very low mean and high variability of multi-mode mobile station velocities are noticed.

VHO algorithm for heterogeneous networks based on 2-level Analytic Hierarchy Process (AHP) has proposed by Radhika and Reddy (2011). The optimal target network is decided by considering a set of decision parameters (Available bandwidth, Velocity, Throughput, Cost, Security, and User Preference) with AHP. AHP is mathematical tool to make a multiple criteria decision by giving a numerical score to the decision alternatives. This study has simulated 4 different types of applications. The highest priority is given to security, cost, supported velocity and user preference. Weighting value is given to each parameter and case. The network that has the highest composite weight is selected as the target network. This study aims to choose the optimal network based on the type and service requirements demanded by user's application. The algorithm decides the optimal target network among WLAN, WiMax, and CDMA. No performance parameter is measured.

There is a VHO algorithm that based on the mobility profiles including velocity, cost, and transfer time (Shafiee *et al*, 2011). The access cost and transmission time are defined as a function of velocity. The study shows that performing VHOs is an appropriate choice at lower speeds, whereas it would be better to avoid VHO and stay in the cellular network at higher speeds. This algorithm is designed to minimize the cost of transmission or alternatively transmission time. Optimal VHO can minimize data transfer time or traffic cost. The result of this study is that the combination of WLAN and Cellular and Ad Hoc network outperforms any other networking strategies in terms of transmission time and cost.

Two classes of user mobility model, pedestrian and fast, have been defined in load balancing algorithm by VHO (Pourmina and MirMotahhary, 2012). Pedestrian will be forced to perform downward VHO and stay in WLAN, while fast mobile user will be forced to perform upward VHO and stay in Wireless Wide Area Network (WWAN). The model is proposed based on Markov model. Mobile velocity is obtained from estimated Doppler spread. The goal of this study is load balancing and ping pong effect reduction. The result of this study is low VHO rate and low call blocking probability.

Li *et al* (2014) proposed an analytical model for estimating the average achievable individual throughput and the theoretically optimal handoff threshold. Simulation is demonstrated under different conditions in terms of vehicle’s velocity and user quantity. This work recommend whether and when to execute handoff procedure in heterogeneous network.

Kalman filtering and fuzzy logic approaches are used to reduce handoff initiations (Kustiawan and Chi, 2015). RSS, data rate, velocity of mobile terminal, and traffic load are considered as criteria to initiate handoff from WLAN to the cellular network. The proposed method reduces handoff initiations effectively.

Handoff management scheme that efficiently initiates a handover process and selects an optimal network has been proposed (Ahmad *et al*, 2015). UE performs handover triggering based on the RSS optimization and the network selection process is carried out by considering delay, jitter, velocity, network load, and energy consumption. The proposed scheme efficiently optimizes the handoff related parameters.

Jain and Tokekar (2015) present study of inter mobility between integrated Universal Mobile Telecommunications System (UMTS) and WLAN network. The impact of network traffic load, application types, and speed of mobile node on the performance of downward VHO latency is investigated. The result of this study shows that with the increase in network load, handoff latency also increases.

Distance prediction technique for VHO decision is proposed in (Hussain *et al*, 2012) using distance threshold parameters. A distance threshold value for a given speed and a given probability of UHO is obtained using probability distribution of traversal length. This technique can keep the probabilities of handover failure and UHO close to the predetermined designed values.

Energy efficient handoff decision algorithm has been studied to eliminate the UHO while balancing the load (Chowdhury *et al*, 2012). This algorithm determines the balanced threshold level of the RSS from macro BS. This algorithm can reduce the system overhead and monthly energy consumption.

Wrong Decision Probability (WDP) is one of the performances metric which is used to measure the efficiency of handover algorithms in providing such seamless service (Halhalli *et al*, 2014). In this work, probability equations are derived for five network models and probabilities are computed for unnecessary handover, missing handover and wrong decisions. This work significantly improves the reduction of UHO when bandwidth and RSS are considered as performance metric.

The RSS based VHO combine with data rate, mobility, cost, and user preference is proposed in (Tamijetchelvy and Sivaradje *et al*, 2013). The key idea is mainly based on Media-Independent Handoff (MIH) services to monitor the signal status and velocity of the mobile node. The coverage probability is analyzed with respect to path loss. The probability of handover failure and UHO are minimized.

Figure 2.1 summarizes all of the above mentioned studies. Velocity has been considered in combination with other parameters to develop VHO decision. Many performance parameters have been used to show that the proposed algorithms gain a better system performance.

2.3 SINR Based Vertical Handoff

There have been massive studies in SINR based VHO in recent years. It has been proved that SINR based VHO gain a superior average throughput compared to other VHO decision schemes. Some of the studies even merely have been designed to achieve higher throughput.

Yang *et al* (2007) proposed combined-SINR based VHO. In this study, the VHO is triggered while the user is getting higher equivalent SINR from another access network resulting in higher throughput. In other words, whenever user receive higher throughput from candidate cell, VHO will be triggered. This algorithm can be called as throughput based VHO. The higher equivalent SINR is calculated by letting a received data rate from neighboring cell is equal to a received data rate from serving cell and vice versa.

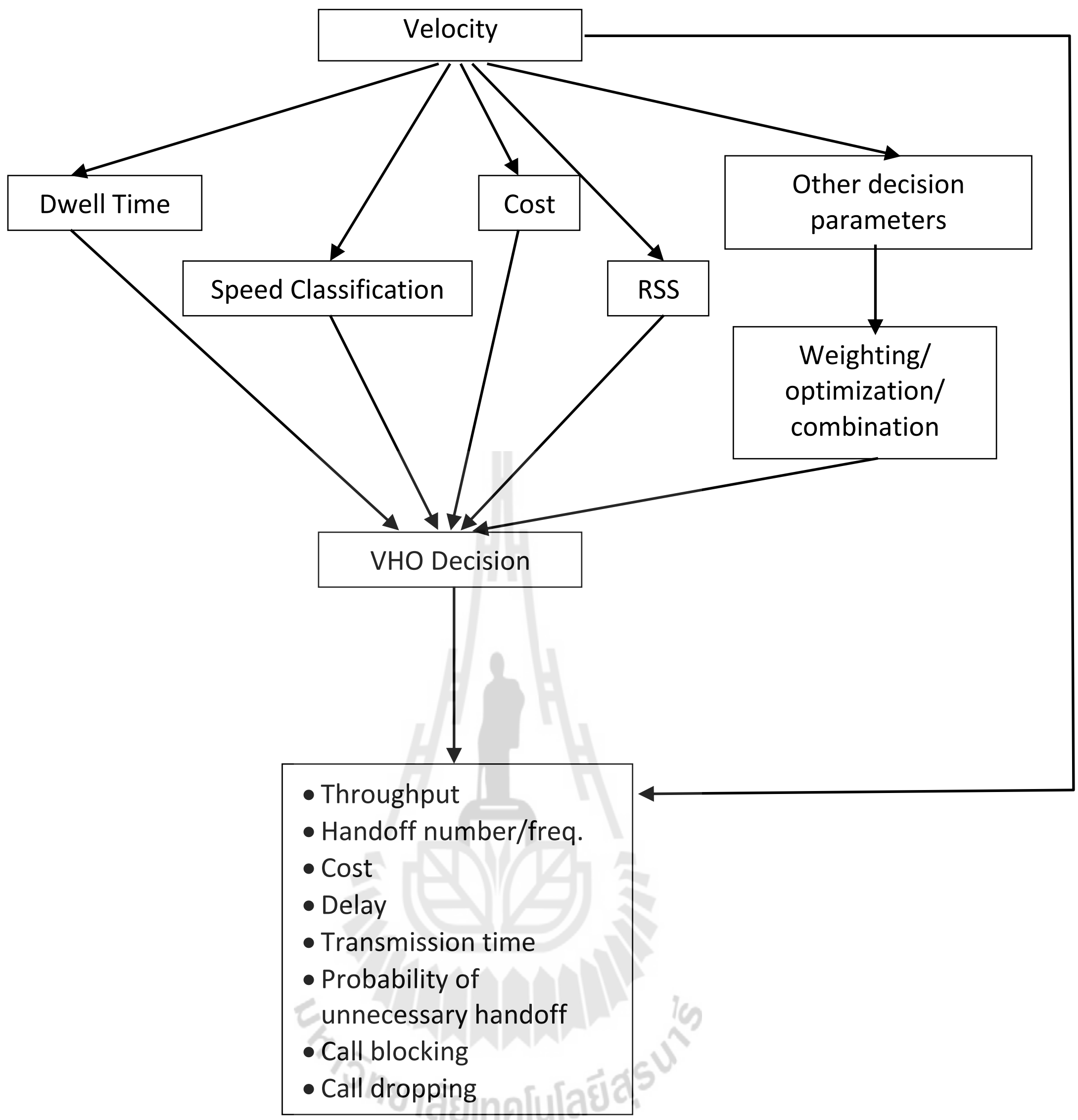


Figure 2.1 Summary of velocity consideration in VHO studies

This study has been developed to consider other parameter metric to perform better VHO (Yang *et al*, 2008; Yang *et al*, 2008-1). Other parameters to be considered in this study are the required bandwidth of user, user cost, maximum downlink bandwidth of each neighboring BS and AP, and network utilization. These studies show a better system performance in terms of throughput, dropping probability, and user average cost compared to RSS based VHO decision.

The same study with Yang *et al* (2007) also has been proposed by Ayyappan *et al* (2009). They showed the additional metric performance that is called as the number of dropped user. The study shows a better system performance in terms of throughput and the number of dropped user compared to RSS based VHO decision. El Fadeel (2012) also studied combined-SINR based VHO using predictive SINR. SINR prediction is done by Gray Model, GM (1, 1). The study shows a better system performance in terms of throughput compared to RSS based VHO decision.

A Simple Additive Weighting (SAW) VHO based on SINR and AHP has been proposed to make VHO decisions for multi-attribute QoS consideration according to the features of traffic (Sheng-mei *et al*, 2010). This study used the combined effects of SINR, user required bandwidth, user traffic cost, and available bandwidth of the participating access networks. The result shows that the proposed scheme can achieve an excellent performance according to the characteristic of the traffic in terms of system throughput and average user cost.

New parameter that is called as Interference to other Interference plus Noise Ratio (IINR) has been introduced in order to have a better VHO decision (Choi, 2010). In this study, VHO will be performed only when a throughput gain exist. This scheme results in an optimal throughput performance and very low feedback overhead.

A new decision criterion based on IEEE 802.21 MIH signaling among WLAN and WiMAX networks which depend on the received SINR has been studied in (Bathich *et al*, 2013). The proposed Vertical Handoff Decision (VHD) provides the knowledge of the achievable bandwidth from both networks by using the received SINR. Simulation-based outputs along with analytical results have confirmed that the proposed VHD offer the end user with better performance during the handover stage.

Naresh et al (2014) proposed local repair on AODV based on signal strength with the aid of VHO for multi radio mesh network. VHO combined with local route repair based on SINR matrix has been proposed to improve performance of 4G-multiradio mesh network. Simulation results depict promising gain in the proposed system in comparison to pure handoff based solution.

SINR based novel VHO procedure to facilitate the LTE-WLAN interworking is introduced in (Ranjan *et al*, 2015). This study illustrated the significance of other handover parameters in addition to SINR in achieving improved system performance, such as Time-To-Trigger (TTT), offset, and moving average of SINR. Extensive simulations were done in ns-3, which have enhanced result to support LTE-WLAN interworking as per the Third Generation Partnership Project (3GPP) standard.

The latest identification of suitable parameters for predicting VHO in heterogeneous wireless networks has been presented in (Rajinikanth and Jayashri, 2015) and user velocity was not shown as an additional criterion in SINR based VHO decision. The most widely used input parameters for decision process are RSS, bandwidth, speed, cost, direction, and SINR for achieving seamless mobility.

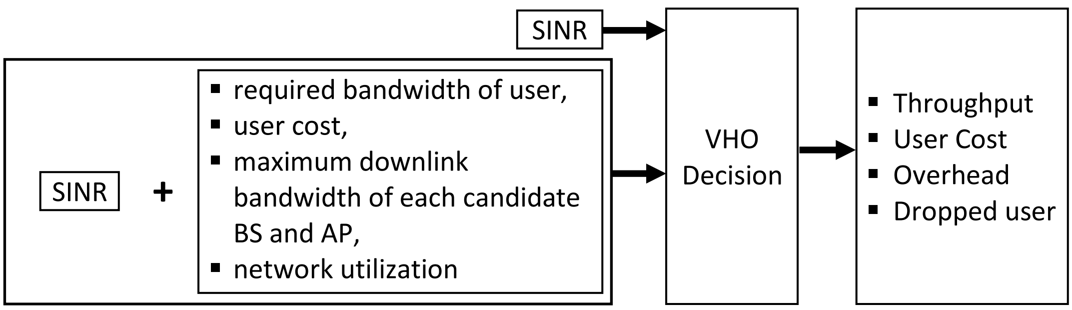


Figure 2.2 Summary of SINR based VHO studies

Figure 2.2. summarizes all of the above mentioned studies. It shows that throughput improvement is the main goal of all studies in SINR based VHO.

2.4 Limitation of SINR Based Vertical Handoff

Some studies show that there are some limitations in SINR based VHO scheme. Ahmed (2014) summarized most of the limitations. Major drawback of SINR based VHO is that it is dependent on the velocity of the mobile users and performance of the scheme degrades with the increase in velocity. Also, this scheme provides high latency and a very high number of unnecessary handoffs. Excessive handoffs come up due to the variation of the SINR and causing ping-pong effect. Choi (2010) imply in his study that SINR-only based VHO will increase feedback overhead. In short, some limitations in this scheme are:

1. Not applicable for high speed
2. Increased handoff latency
3. Ping-pong effect due to variation of SINR
4. Increased feedback overhead

Since there is no velocity parameter that has been considered in the study of SINR based VHO algorithm, so that the user velocity need to be carefully considered to maintain the performance. This study will consider user velocity in the SINR based VHO algorithm and divide the velocity into two groups to overcome the limitations that are mentioned above. These two groups are slow speed user and high speed user.

2.5 Unnecessary Handoff Reduction Algorithm

Many studies have improved the network performance and specifically used unnecessary handoff probability or ping-pong handoff reduction as one of the performance metrics. Three studies in section 2.2 (Goyal and Saxena, 2008; Cha et al, 2008; Pourmina and MirMotahhary, 2012) are some studies which successfully reduce unnecessary handoff probability or ping-pong handoff.

Fuzzy logic and neural network based VHO are the most widely studied to minimize UHO (Lin *et al*, 2014; Yang and Rong, 2011; Kunarak and Suleesathira, 2010; He *et al*, 2010-1; Yang *et al*, 2010; Rizvi *et al*, 2010; Zhang and Wang, 2013; Kunarak and Suleesathira, 2011; He, 2010; Xiaona and Qing, 2014; Singhrova and Prakash, 2012; Peng *et al*, 2011; Khanum and Islam, 2014; He, 2010-1; Ghormade and Shah, 2015). These studies proposed multi-criteria based VHO to obtain certain performance value as a VHO decision criterion. They consider many parameters to be combined with RSS, such as bandwidth, link quality, cost, network delay, user preference, user speed and location, battery consumption, and security. They can achieve lower UHO, eliminate of ping-pong effects, make the handover decision effectively, reduce call dropping, save system overhead, improve GoS and QoS, improve network switch performance, and improve user satisfaction level.

A novel handoff algorithm based on keeping the old path between the source eNB and SGW/MME in E-UTRA networks during ping-pong movement and delaying the completion of handoff is presented (Ghanem *et al*, 2012). This algorithm can reduce ping-pong rate and increase handoff quality, as long as the optimal timer value is chosen carefully.

Feher *et al* (2012) demonstrate an effective way to classify ping-pong and method that can reduce ping-pong effect on the live network measurements. The method combines a sub cell movement detection method and ping-pong detection to decide when to apply handoff threshold tuning effectively without increasing the risk of failed handoff.

An efficient handoff algorithm based on RSS prediction and SINR estimation for two tier macro-femtocell networks is presented in (Ghanem and Alradwan, 2012) to improve the throughput, reduce outage probability, and reduce ping-pong handoff. The result of the simulation shows that the proposed algorithm outperforms the previous ones.

Park *et al* (2013) present new mobility management method based on cross layer architecture of 3GPP LTE-Advance to improve mobility performance in dense small cell environment. The proposed method shows a fewer number of handoffs and lower rate of ping-pong handoff than baseline mobility management.

The combination of Fuzzy Logic Processing (FLP) and AHP is used as VHO algorithm for UMTS and WiMAX overlay networks (Ji *et al*, 2015). FLP is used to evaluate dynamic parameters and AHP is used to construct decision matrix based on the fix parameters. The proposed algorithm can effectively mitigate ping-pong handoff and terminal power consumption.

2.6 Chapter Summary

This chapter describes the studies that consider user velocity in the VHO decision, some recent studies about SINR based VHO, and the limitation of SINR based VHO. The last section of this chapter describes the previous studies of UHO reduction algorithms.

CHAPTER III

BACKGROUND THEORY

3.1 Introduction

This chapter describes some relevant theoretical background to support the development of the proposed algorithm in the next chapter. The description will start with the concept of heterogeneous networks in general and then further explanation about WCDMA and WLAN in specific. Afterwards, the concept of handoff will be described, followed by vertical handoff and the classification and mechanism of vertical handoff. The last part of this chapter describes basic SINR based VHO and some performance metrics to measure the system performance during VHO.

3.2 Heterogeneous Network

Data traffic demand in cellular networks today is increasing at an exponential rate. As the link efficiency is approaching its fundamental limits, further improvements in system spectral efficiency are only possible by increasing the node deployment density (Damnjanovic et al., 2011). In a relatively sparse deployment of macro base stations, adding another base station will not severely increase inter-cell interference, and solid cell splitting gains are easy to achieve. However, in already dense deployments today, cell splitting gains are significantly reduced due to already severe inter-cell interference. Moreover, site acquisition costs in a capacity limited dense urban area can get prohibitively expensive. Challenges associated with the deployment of traditional macro base stations can be overcome by the utilization of base stations with lower transmit power.

One of the most promising and cost effective solutions to improve the system capacity is to deploy low-power nodes such as relays, pico-cells, femto-cells, and remote radio heads overlaid by macro-cell networks. The new architecture is known as heterogeneous networks (Ahmadi, 2014). Heterogeneous Network (HetNet) can provide a flexible and effective way to eliminate the coverage holes in macro-cells and improve system capacity. One of the key issues in HetNet is the handoff performance deterioration in co-channel, where the cell-edge users can experience more serious interference.

Macro base stations have the transmit power typically varied between 5 and 40 W (Damnjanovic et al., 2011). Femto base stations are meant for indoor use with transmit power is typically 100 mW or less. Simulation in this research uses 40 dBm (46.02W) for macro BS transmit power and 20 dBm (100 mW) for WLAN AP transmit power. Femto base stations may be configured with a restricted association, allowing access only to its Closed Subscriber Group (CSG) members. Such femto base stations are commonly referred to as closed femtos. HetNets that consists of a mix of macrocells and low-power nodes is illustrated in Figure 3.1. The base stations are denoted as eNode-B (eNB) and the mobile stations or terminals are denoted as UE. The low-power nodes include pico-cells, femto-cells, and home eNBs (HeNBs).

HetNet is used as a wireless networks to improve performance per area and meet target data rates in LTE (Barbera et al., 2012; Ayyar et al., 2012). LTE was first introduced in 3GPP Release 8 and has later evolved towards Release 9 and LTE-Advanced in Release 10, offering higher peak data rates, better average throughput and coverage.

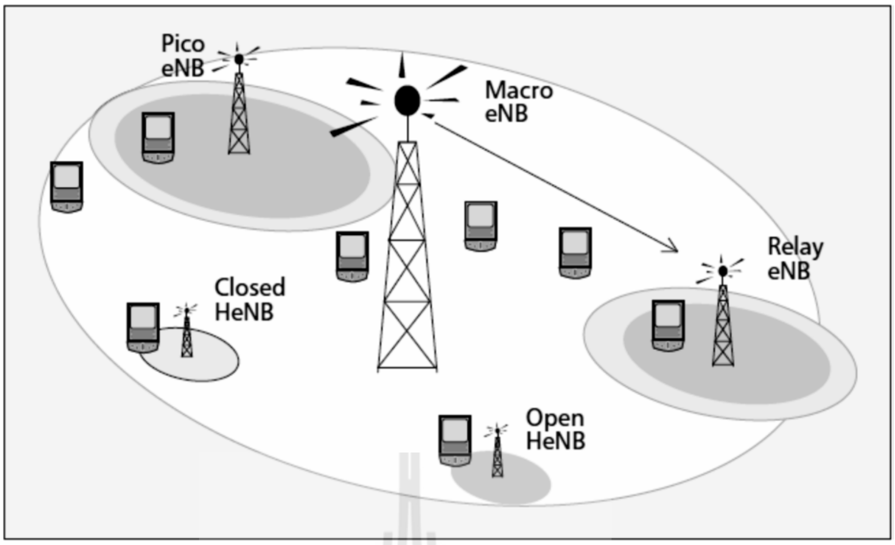


Figure 3.1 HetNet topology utilizing macro and low-power base stations (Damnjanovic et al., 2011)

HetNet that consists of various wireless networks, including WiMAX, Wi-Fi, and mobile communications is rapidly being developed to achieve high-speed transmission (Chang and Chen, 2008). Mobile communications include WCDMA and HSDPA/HSUPA. Multiple technologies are also evolving simultaneously towards providing users with high-quality services of broadband access and seamless mobility (Wang and Kuo, 2013). WWAN evolve from Global System for Mobile Communications (GSM) to Universal Mobile Telecommunications System (UMTS) and beyond 3G, providing wide coverage and good mobility capabilities. On the other hand, a series of standards of WLAN, including IEEE 802.11a, IEEE 802.11b, IEEE 802.11g, IEEE 802.11n, etc., have been established for local-area high-speed economic wireless access. To complement them, WPANs, e.g., Bluetooth and Zigbee, are developed for short-range. These heterogeneous wireless networks obviously have differences in data rates, transmission ranges, traffic classes, and access costs (Chang and Chen, 2008). Vertical handoff is a significant mechanism for fulfilling seamless data transfer when mobile nodes cross the overlay area between adjacent heterogeneous wireless networks.

Internetworking between 3G mobile systems and WLAN systems are gaining increasingly more research interests since they could provide coupled network services for each other (Pei et al., 2010), they are coexist, and many cellular devices have dual Radio-Frequency (RF) interfaces for WLANs and cellular access (Lee et al., 2009). In particular, although admission control and bandwidth reservation are applied to support multimedia services with stringent QoS requirements in the IEEE 802.11e, WLANs still cannot be expected to support the same level of QoS as 3G networks (Pei et al., 2010). Moreover, the 3G systems are able to address the mobility issue for WLAN users. On the other hand, WLAN systems can be a complementary radio-access technology to 3G systems in providing more bandwidth and economic revenues. Mobile nodes in such heterogeneous wireless networks are expected to have the capability of selecting a proper access network to ensure service consistency and continuity.

The internetworking architecture between WLAN and 3G cellular networks can either be a tightly coupled case or a loosely coupled case (Lee et al., 2009; Pei et al., 2010), as shown in Figure 3.2. When the tight coupling scheme is used, the WLAN is connected to the cellular core network in the same manner as any other 3G radio access network so that the mechanisms for the mobility, QoS, and security of the 3G core network such as UMTS can be reused. As a result, a more seamless handoff between cellular and WLAN networks can be expected in the tightly coupled case, compared to that in the loosely coupled case. However, this approach imposes a higher processing load to the cellular core network but leads to shorter handoff latency and more flexible QoS management.

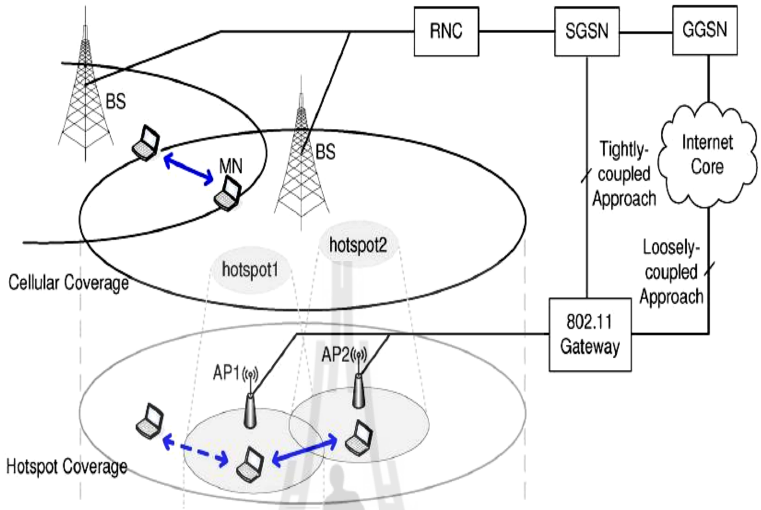


Figure 3.2 Internetworking architecture between WLAN and 3G cellular networks (Lee et al., 2009)

3.3 Handoff in HetNet

In HetNet, there are two types of handoff, horizontal handoff and vertical handoff. Horizontal handoff is a handoff between base stations that are using the same kind of wireless network interface. This is the most common definition of handoff. Vertical handoff is a handoff between base stations that are using different wireless network interfaces (Stemm, 1996). This naming convention follows from the overlay network structure, with increasing cell sizes at higher levels in the hierarchy as shown in Figure 3.3. Vertical handoff is divided into two categories: an Upward Vertical HandOff (UVHO) that is a handoff to a network with a larger cell size and a Downward Vertical HandOff (DVHO) that is a handoff to a network with a smaller cell size.

In HetNet that consists of cellular and WLAN, both cellular and WLAN access are available to mobile nodes within WLAN hotspots that reside within 3G cells. Because every UE in a WLAN can also access the 3G cellular network, handoffs from the cellular network to a WLAN are optional. In a network with limited capacity, the carrier uses these handoffs to enhance QoS, reduce cost, or balance traffic load. Handoff from the 3G cellular network to a WLAN is called DVHO (Lee et al, 2009). An UVHO is a handoff performed from a WLAN to the 3G network.

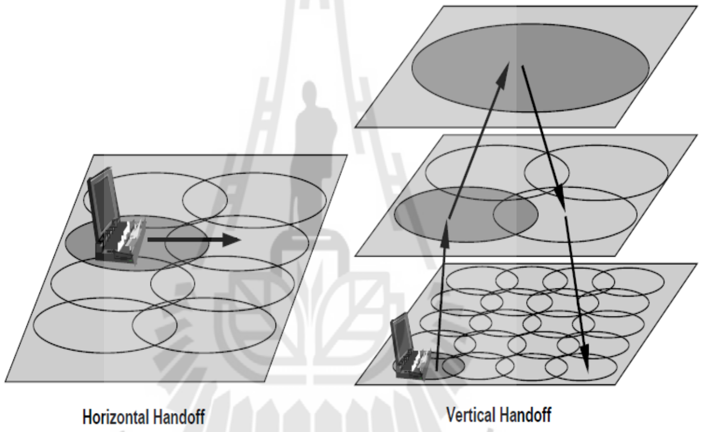


Figure 3.3 Hierarchy of handoff types (Stemm, 1996)

Ahmed et al. (2014) describes three types of handoff; horizontal, vertical and diagonal handoffs. These types are recognized by the type of architecture or technology they use as expressed in Figure 3.4. The Wi-Family is built around IEEE standards and quite a large number of committees are now working to set up wireless technologies linked between them by diagonal handoffs. Diagonal handoff is the combination of horizontal and vertical handoffs. A handoff is said to be diagonal when UE traverses those cells that use a common underlying technology (like for example Ethernet) and it allows a user to continue its applications with the required

QoS from Wi-XX to Wi-YY networks. In IEEE 802.21 working group, this term is proposed for handoff among IEEE networks and broadcast networks (i.e., downlink only networks) and it is usually needed in those cases where, heterogeneous networks share their allocated spectrum. It is also called as MIH.

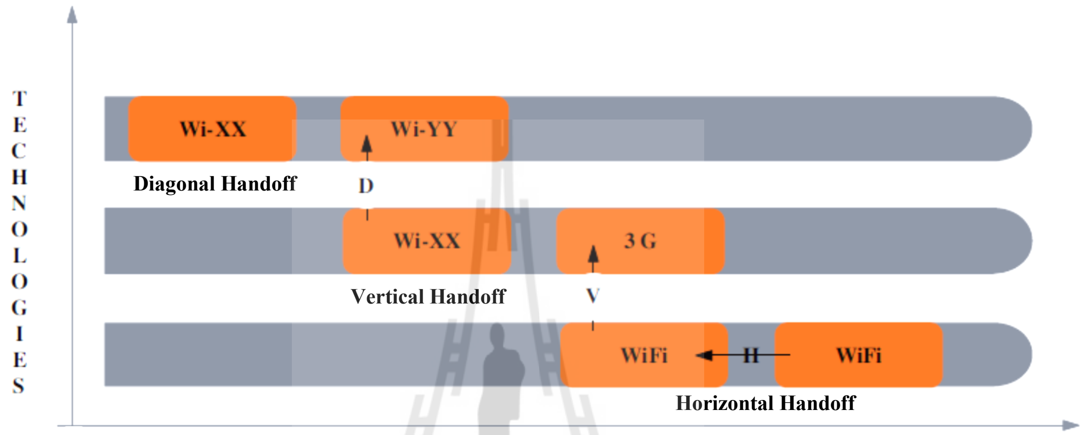


Figure 3.4 Three types of handoff (Ahmed et al., 2014)

Any of the above described handoffs consist of mainly three main phases depicted in Table 3.1, which are crucial for deciding about the efficiency and applicability of the chosen handoff mechanism.

Table 3.1 Handoff phase

Handoff Phase	Description
Handoff Measurement & Initiation	UE or an Access Point (AP) makes the measurements for initiating a handoff towards a new network or towards a new AP in the same network.
Handoff Decision	Measurement results are compared with predefined values to decide whether to perform the handoff or not.
Handoff Execution	New base station is added, power of each channel is adjusted and active set is updated.

Source: Ahmed et al (2014)

3.4 Vertical Handoff

Like common HO phase depicted in Table 3.1., vertical handoff process can also be divided into three main steps (Rizvi et al, 2010; Bhuvaneswari and Raj, 2012):

1. Handoff Initiation/System Discovery Phase:

In order to trigger the handoff event, information to be collected about the network from different layers likes Link Layer, Transport Layer and Application Layer. These layers provide the information such as RSS, bandwidth, link speed, throughput, jitter, cost, power, user preferences and network subscription etc. Information is gathered from different networks to inspect the need of handoff and to find out which wireless network can be reached. Based on this information handoff will be initiated in an appropriate time.

2. Handoff Decision Phase:

The mobile device decides whether the connection to be continued with current network or to be switched over to another one. For this phase a range of parameters can be examined e.g. bandwidth, RSS, velocity of mobile terminal, delay, jitter, monetary cost and battery status. The decision may depend on various parameters which have been collected during handoff initiation phase.

3. Handoff Execution Phase:

In this step the user active connection is switched from the current network to the most suitable network. Existing connections need to be re-routed to the new network in a seamless manner. This phase also includes the authentication and authorization, and the transfer of user’s context information.

A decision algorithm gives a better performance when several parameters are considered, more so when a combination of static and dynamic parameters are considered. However, the tradeoff is with the increase in decision time and complexity of the algorithm. The decision may depend on various groups of parameters such as (Bhuvaneswari and Raj, 2012; Ahmed et al, 2014):

1. Network-related Parameters: Bandwidth, Latency, RSS, SIR, Cost, Security etc.
2. Terminal Related Parameters: Velocity, Battery power, Location Information etc.
3. User-Related Parameters: user profile and preferences
4. Service Related Parameters: service capacities, QoS etc.

These parameters are also categorized as

1. Static: Cost, Security, Power Consumption
2. Dynamic: Bandwidth, Latency, RSS, Throughput (data rate), Bit Error Rate, Reliability, User Preferences, Network Load Balancing, Velocity.

Further descriptions of some parameters are as follow (Bhuvaneswari and Raj, 2012; Ahmed et al, 2014):

1. Bandwidth

Bandwidth is a measure of the width of a range of frequencies. Higher bandwidth means higher capacity and higher capability of the network to handle more calls at a time. It will result in lower call dropping and call blocking probability.

2. Handoff Latency

The time elapses between the last packet received via the old access router and the arrival of the first packet along the new access router after a handoff. This is known as handoff latency. Handoff latency affects the QoS. It is essential to consider handoff latency while designing any handoff technique. Real-time services (e.g., video streaming, voice call) are usually accepted as delay sensitive and this degrades their overall performance. During handoff, packets are usually buffered by the network till the next wireless station is prepared to accept them. This delay proliferates to higher layers and causes sudden upsurges in packet delays.

3. Power Consumption

During handoff, frequent interface activation can cause considerable battery drainage. It is also important to incorporate power consumption factor during handoff decision.

4. Network Cost

A multi criteria algorithm for handoff should also consider the network cost factor. Different charging policies are followed for different type of traffic. So that in some situation cost should also be considered as a factor for decision making. Every network provides certain services to its users which are usually charged against a cost. If two networks provide the same quality of service then the network with lower cost is usually preferred by service users.

5. User Preferences

Based on the application requirements (real time, non-real time), service types (voice, data, video), quality of service, etc., the user may prefer different network according to the network performance which is the important benefit of heterogeneous networks. Preferences can also be defined on application priority executed by the user that can either be high or low (e.g., users usually prefer a connection with high bandwidth, low cost, and reliable).

6. Network Throughput

Network throughput refers to the average data rate of successful data or message delivery over a specific communication link. Handoff to the network which has higher throughput is desirable for the user's concurrent applications.

7. Network Load Balancing

Network load is to be considered during effective handoff. It is important to balance the network load to avoid deterioration in quality of services. Background services (e.g., FTP and email) or streaming services (e.g., real-time video) perform better if higher bandwidth is provided by the network.

8. Network Security

In a wireless environment, the security features provided in some wireless products may be weaker; to attain the highest levels of integrity, authentication, and confidentiality, network security features should be embedded in the handoff policies. It is one of the main issues that arise when networks are converged/ interconnected. This is because each network has its own security and privacy options and a mobile user must comply with them during the handoff process. This needs harmonization of various security policies in heterogeneous wireless networks as networks and terminals have different security levels and characteristics. Handoff process requires improved security and privacy from eavesdropping, registration hijacking, session tear-down and Denial of Service (DoS) attacks.

9. Received Signal Strength (RSS)

RSS is a traditional and unavoidable factor for making handoff decisions. RSS provides information about the power level being received by the antenna. It decreases when a user moves away from the currently accessed networks' AP. The user should handoff to another available network before the connectivity is totally lost. A signal must be strong enough between base station and mobile unit to maintain signal quality at receiver. The RSS should not be below a certain threshold in a network during handoff. Traditional handoff initiation is concerned with measurement of RSS.

10. Velocity

Velocity of the host should also be considered during handoff decision. Because of the overlaid architecture of heterogeneous networks, handing to the small cell area, travelling at high speeds is discouraged since a handoff back to the original network would occur very shortly afterwards.

11. Bit Error Rate (BER):

BER is the number of received bits that have been altered due to noise and interference, divided by the total number of transferred bits during a time interval. BER of a network may be improved by choosing a network with stronger signal in order to improve the QoS.

12. Signal to Noise Ratio (SNR):

SNR is another very important parameter and it affects and reflects the QoS of a network.

A good handoff mechanism decision model should have both dynamic and non-dynamic metrics. However, it is important to consider maximum number of static and dynamic requirements during VHO but it is difficult to include all the metrics in a single decision model due to complexity of algorithms and conflicting issues of multiple metrics. The classification of VHO decision schemes is summarized in Figure 3.5.

VHO can be classified into four types based up on its direction, process, control and decision (Bhuvaneswari and Raj, 2012):

1. Upward and Downward Handoffs:

In VHO, if the mobile switches from the network with a small coverage to a network of larger coverage, it is termed as upward handoff. On the other hand, a downward handoff occurs in the reverse direction, i.e. from a network of larger coverage to a network of smaller coverage.

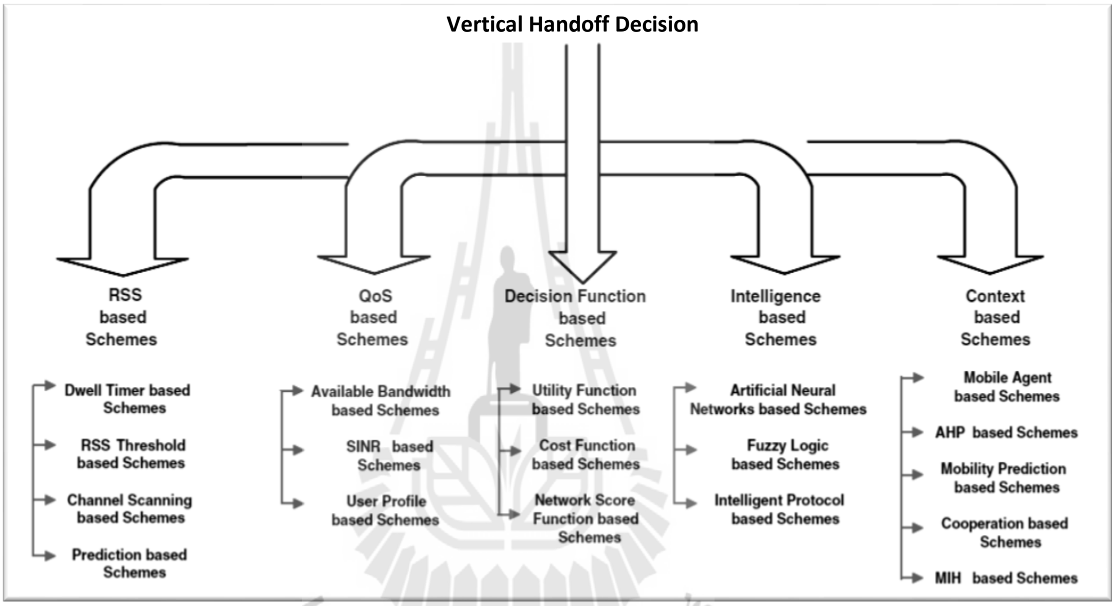


Figure 3.5 Classification of VHO decision schemes (Ahmed et al, 2014).

2. Hard and Soft handoffs:

When the mobile node switches to the target network only after the disconnection from current network is called as hard handoff or break before make. On the other hand, in soft handoff a mobile node maintains the connection with the previous base station till its association with the new base station is completed. This process is also termed as make before break.

3. Imperative and Alternative handoffs:

When there is loss of signal strength an imperative handoff occurs. For imperative handoff the RSS is sufficient to be considered. On the other hand, an alternative vertical handoff is initiated to provide the user with better performance. For alternative handoffs several other network parameters such as available bandwidth, supported velocity and cost of the network are to be considered in addition to the device parameters such as quality of service demanded by the application and user preference.

4. Mobile and Network Controlled Handoffs:

VHO can be classified based on who controls the handoff decision. If mobile node controls the handoff decision, it is termed as Mobile Controlled Handoff (MCHO). In Network Controlled Handoff (NCHO) networks control the handoff decision. The handoff decision control is shared between the network and mobile in case of Mobile Controlled Network Assisted (MCNA) and Network Controlled Mobile Assisted (NCMA) handoffs. MCNA handoffs are more suitable because only mobile nodes have the knowledge about the network interfaces they are equipped with and user preferences can be taken into consideration.

3.5 SINR Based Handoff

Handoff decision algorithms have been designed mainly to guarantee continuity of service (Choi, 2010). A basic principle of the algorithms is to use the difference between the quality of the signal received from the serving BS and from the neighboring BS. The SINR based handoff decision algorithm then can be simply expressed as

$$|\mathrm{SINR_o} - \mathrm{SINR_i}| < \delta \tag{3.1}$$

where $SINR_o$ is a received SINR from the serving BS and $SINR_i$ is a received SINR from the neighboring BS, and δ is the handoff additional threshold determined by the system.

Neighboring cells that satisfy (3.1) will be designated by UE as candidate cells for handoff. If the UE reports the identity and SINR information of candidate cells to its serving BS, then the serving BS finally determines a target cell among the reported candidate cells. In this study, the handoff threshold, δ, will be used to force the MS with the certain velocity value to stay longer in the certain cell according their velocity.

The SINR received by i^{th} user from its associated j^{th} WLAN Access Point (AP) or j^{th} WCDMA Base Station (BS) is (Yang *et al*, 2007; Ayyappan *et al*, 2009)

$$\gamma_{j,i} = \frac{G_{j,i}P_j}{N+I} = \frac{G_{j,i}P_j}{N+\sum_{\substack{k\neq j \\ k\in AP/BS}} G_{k,i}P_k} \qquad (3.2)$$

where $\gamma_{j,i}$ is the SINR received by the user, $G_{j,i}$ is the channel gain between i^{th} user and its associated j^{th} AP or BS, P_j is the transmit power of j^{th} AP or BS, N is the background noise power at user receiving end, and the summation of $G_{k,i}P_k$ is the interference received by i^{th} user from other neighbour APs or BSs.

3.6 Average Throughput in VHO

For SINR based VHO decision, average throughput calculation is based on the maximum achievable data rate for a given carrier bandwidth and SINR can be determined with the help of Shannon capacity formula (Yang *et al*, 2007; Ayyappan *et al*, 2009). The maximum achievable data rate R is given by:

$$R = W \log_2 \left(1 + \frac{\gamma}{\Gamma}\right) \quad (3.3)$$

where W is the carrier bandwidth, γ is SINR received at user end when associated with WLAN or WCDMA. For WLAN, Γ is the dB gap between uncoded Quadrature Amplitude Modulation (QAM) and channel capacity (6.5 dB for WLAN) minus the coding gain (3.5 dB), or the gap $\Gamma = 3$ dB. Transmitter is assumed to use variable-rate M-QAM, as one of modulation techniques in IEEE 802.11 standard, and trellis coding (Toumpis and Goldsmith, 2003). WCDMA transmitter is assumed to use 16-QAM, as in 3GPP standard release 5, and the gap $\Gamma = 16$ dB (Holma and Toskala, 2004).

The average throughput calculation in the combined-SINR based VHO decision algorithm (Yang *et al*, 2007; Ayyappan *et al*, 2009), will be used as the reference calculation. VHO is triggered when the user gets equivalent SINR from another access network. The equivalent SINR is calculated when received data rate from BS is equal to received data rate from AP, $R_{AP} = R_{BS}$, and the relationship between γ_{AP} and γ_{BS} is determined as

$$\gamma_{AP} = \Gamma_{AP} \left(\left(1 + \frac{\gamma_{BS}}{\Gamma_{BS}}\right)^{\frac{W_{BS}}{W_{AP}}} - 1 \right) \quad (3.4)$$

The VHO is taken place at handoff point X_h as shown in Figure 3.6 and the total downlink throughput, θ, can be represented as appear in equation (3.5).

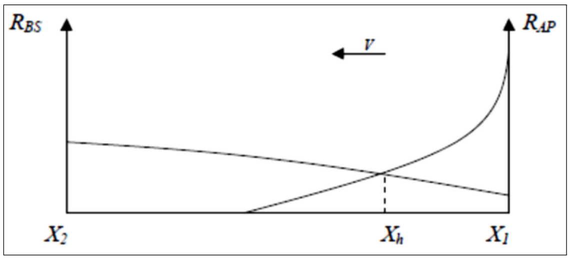


Figure 3.6 Point to point model (Yang et al., 2007)

$$\theta = \left(CRT_{AP} \times \int_{X_1}^{X_h} R_{AP}(x)dx \right) + \left(CRT_{BS} \times \int_{X_h}^{X_2} R_{BS}(x)\,dx \right) \quad (3.5)$$

where X_1 is the point where call starts and served by AP and X_2 is the point where call ends and served by BS, CRT_{AP} and CRT_{BS} are the cell residence time inside WLAN AP and WCDMA BS, respectively.

3.7 Dropped Call

The definition of a dropped call is after the call is established but before it is properly terminated (Lee, 2006). There is a possibility that a call will drop due to the poor signal of the assigned voice channel. This case can happen when the mobile or portable units are at a standstill and the radio carrier is changed from a strong setup channel to a weak voice channel due to the selective frequency fading phenomenon.

Dropped call probability is calculated based on the highest number of handoffs for all calls in the network. The general formula of dropped call probability P in a whole system can be expressed as:

$$P = \sum_{n=0}^{M} \alpha_n . P_n = \sum_{n=0}^{M} \alpha_n . (1 - X^n) \quad (3.6)$$

where M is the highest number of handoffs for those calls, α_n is the weighted value for those calls having n handoffs with $\sum_{n=0}^{M} \alpha_n = 1$, P_n is the probability of a dropped call when the call has gone through n handoffs, and $X = (1 - \mu)$, where μ is probability that the signal is below the specified co-channel interference level (in an interference-limited system). In this study, μ is set equal to 1.45% as in Lee (2006).

3.8 Unnecessary Handoff

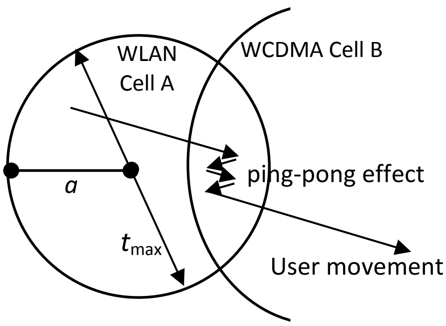
Unnecessary HandOff (UHO) is one of the challenging problems that still occur in many proposed VHO algorithm in the previous studies. UHO usually is caused by the terminals dwelling at the edge of cell coverage (Lin *et al*, 2014). Minimizing UHO is as important as handoff triggering condition estimation and optimization of handoff execution (Hussain *et al*, 2012). If the UHO is not checked, the phenomenon will have adverse effect on the system performance. Not only overhead involved in UHO would consume network resources, but it would also increase the probability of handoff failure.

An UHO occurs when the total time of an UE within a WLAN coverage cell is smaller than the total handoff latency for moving in and moving out (Hussain *et al*, 2012; Hussain *et al*, 2013; Omoniwa and Hussain, 2014). In this case, the UE bears the cost of handoffs signalling, but it does not get any benefit of hand-in to the network.

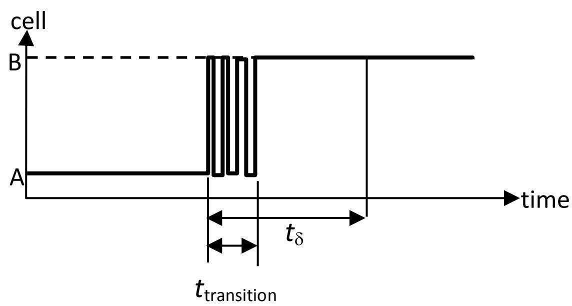
Another kind of undesirable phenomenon of UHO is ping-pong effect occurrence or ping-pong handoff. Ping-pong handoff occurs when UE performs frequent handoffs between the same pair of cells back and forth, in a short time period (Fehér *et al*, 2012). Ping-pong can be happened naturally, when UE is moving and passing obstacles. In this case, the effect of ping-pong is much less than if the UE is being completely stationary. If the UE is stationary, there is no need for such handoffs.

Ping-pong handoff can cause inefficiency, call dropping, and degrading of network performance (Ghanem *et al*, 2012). Ping-pong handoff disperses the resource between releasing and reserving, and as a result, decreasing QoS. Extra capacity of packet switched mobile system is required to serve large number of ping-pong handoff comes with a non-negligible cost (Fehér *et al*, 2012). The amount of ping-pong handoff can be reached around 40-60% of all handoffs based on measurements in numerous networks. In this study, calculation of the UHO number and the probability of UHO are based on the number of ping-pong effect occurrence.

The probabilistic model uses the dwell time in the WLAN cell, t_{max}, and time threshold, t_{δ}, as depicted in Fig. 3.7. In Figure 3.7 (a), user move from WLAN cell A to WCDMA cell B. During movement, UE experiences ping-pong effect in the cells border. Figure 3.7 (b) shows the timing diagram of user movement. UE experiences ping-pong effect at $t_{\text{transition}}$ second. Threshold time, t_{δ}, can be set longer or faster than $t_{\text{transition}}$. Maximum value of t_{δ} is the same as $t_{\max}$.



(a)



(b)

Figure 3.7 (a). User movement (b). Timing diagram of user movement

Referring to (Hussain *et al*, 2013), the probability density function of traverse time in WLAN coverage region would be

$$f(t) = \frac{2v}{\pi\sqrt{4a^2 - v^2t^2}}, \quad 0 \le t \le t_{max} \tag{3.7}$$

where v is user velocity, a is cell radius, and $t_{\max} = 2a/v$.

Based on Fig. 3.7 (b), ping-pong effect occurs when $t_{\text{transition}}$ exceeds the time threshold t_δ. The probability of ping-pong is

$$P_p = \begin{cases} P_r[t_{transition} > t_\delta], & 0 < \mathrm{t_{transition}} < \mathrm{t_{max}} \\ 0, & \text{otherwise} \end{cases} \tag{3.8}$$

If $t_\delta = 10$ second, then

$$P_r[t_{transition} > t_\delta] = P_r[10 < t_{transition} < 2a/v] \tag{3.9}$$

$$= \int_{10}^{2a/v} f(t)\, dt$$

$$= \int_{10}^{2a/v} \frac{2v}{\pi\sqrt{4a^2 - v^2t^2}} dt$$

$$= \frac{2}{\pi}\left(\arctan\left(\frac{v(2a/v)}{\sqrt{4a^2 - v^2(2a/v)^2}}\right)\right)$$

$$- \left(\arctan\left(\frac{v(10)}{\sqrt{4a^2 - v^2(10)^2}}\right)\right)$$

$$= \frac{2}{\pi}\left(\arctan\left(\frac{2a}{\sqrt{4a^2 - 4a^2}}\right)\right) - \frac{2}{\pi}\left(\arctan\left(\frac{10v}{\sqrt{4a^2 - 100v^2}}\right)\right)$$

$$= \left(\frac{2}{\pi} \times \frac{\pi}{2}\right) - \frac{2}{\pi}\left(\arctan\left(\frac{10v}{\sqrt{4a^2 - 100v^2}}\right)\right)$$

$$= 1 - \frac{2}{\pi}\left(\arctan\left(\frac{10v}{\sqrt{4a^2 - 100v^2}}\right)\right)$$

$$= 1 - \frac{2}{\pi}\left(\arctan\left(\frac{10}{\sqrt{4a^2/_{v^2} - 100}}\right)\right)$$

If no SINR threshold is applied or the VHO decision uses basic SINR algorithm, it means $t_\delta = 0$ second, then

$$P_r[t_{transition} > t_\delta] = P_r[0 < t_{transition} < 2a/v] = 1 \quad (3.10)$$

3.9 Chapter Summary

This chapter describes all background theory of the topics needed to develop the proposed algorithm. These topics include Hetnets in general, that are types of technologies and configurations. Many types of handoffs that are usually performed in HetNets are also described in this chapter. After describing handoffs in general, this chapter specifically describes many types of VHO decision scheme, their mechanism and classification, including basic SINR based VHO. The last part of this chapter is introduction to performance metrics to measure the system performance during VHO.

CHAPTER IV

PROPOSED ALGORITHM

4.1 Introduction

This chapter describes the proposed algorithm for SINR based VHO decision using dynamic threshold as a parameter for considering user velocity. This chapter also describes the simulation scenario and parameter setting as a platform to gain the supporting data. The fixed threshold will be evaluated prior to the dynamic threshold. The result of system performance using fixed threshold and other SINR based VHO algorithms will be used as a comparison reference.

4.2 Handoff Decision Algorithm

The basic principle of this algorithm is that slow speed UE should stay longer in WLAN and high speed UE should stay longer in WCDMA. The proposed VHO decision algorithm is depicted as a flow chart in Figure 4.1.

When UE is categorized as low speed user (lower than velocity threshold) and starts to make a call in WLAN coverage area, the system will force UE to stay longer in WLAN until SINR of the neighbour WCDMA cell has higher value than the pre-set additional threshold. When the pre-set threshold is reached, the handoff is triggered. If the pre-set threshold is not reached, VHO will not be triggered and UE will stay in the current serving cell until the call is finished. The low speed UE will stay in WCDMA cell until SINR of the neighbour WLAN cell has higher value than SINR of serving WCDMA cell. The next handoff will be triggered without any pre-set threshold. If the

SINR of the neighbour WLAN cell never gets higher value than SINR of serving WCDMA cell, the next VHO will not be triggered and UE will stay in the current serving cell until the call is finished.

The same way will work on high speed user (higher than velocity threshold) that is initially served by WCDMA cell. System will force UE to stay longer in WCDMA until SINR of the neighbour WLAN cell has higher value than the pre-set threshold and the handoff is triggered. If the pre-set threshold is not reached, VHO will not be triggered and UE will stay in the current serving cell until the call is finished. The high speed UE will stay in WLAN cell until SINR of the neighbour WCDMA cell has higher value than SINR of serving WLAN cell. The handoff will be triggered without any pre-set threshold. If the SINR of the neighbour WCDMA cell never gets higher value than SINR of serving WLAN cell, then the next VHO will not be triggered and UE will stay in the current serving cell until the call is finished.

4.3 Dynamic SINR Threshold (δ)

Based on equation (3.2), SINR received by the user in the serving cell can be expressed as

$$\gamma_{s_i} = \frac{G_{s_i}P_{s_i}}{N_{s_i}+I_{s_i}} = \frac{G_{s_i}P_{s_i}}{P_B+\sum_{\substack{k\neq i\\ k\in AP/BS}} G_{s_k}P_{s_k}} \tag{4.1}$$

where where G_{s_i} is the channel gain between i^{th} user and its serving cell, P_{s_i} is the transmit power of serving cell received by i^{th} user, N_{s_i} is the background noise power at user receiving end, and I_{s_i} is the interference received by i^{th} user from other neighbour APs or BSs. Notation s is indicating the serving cell.

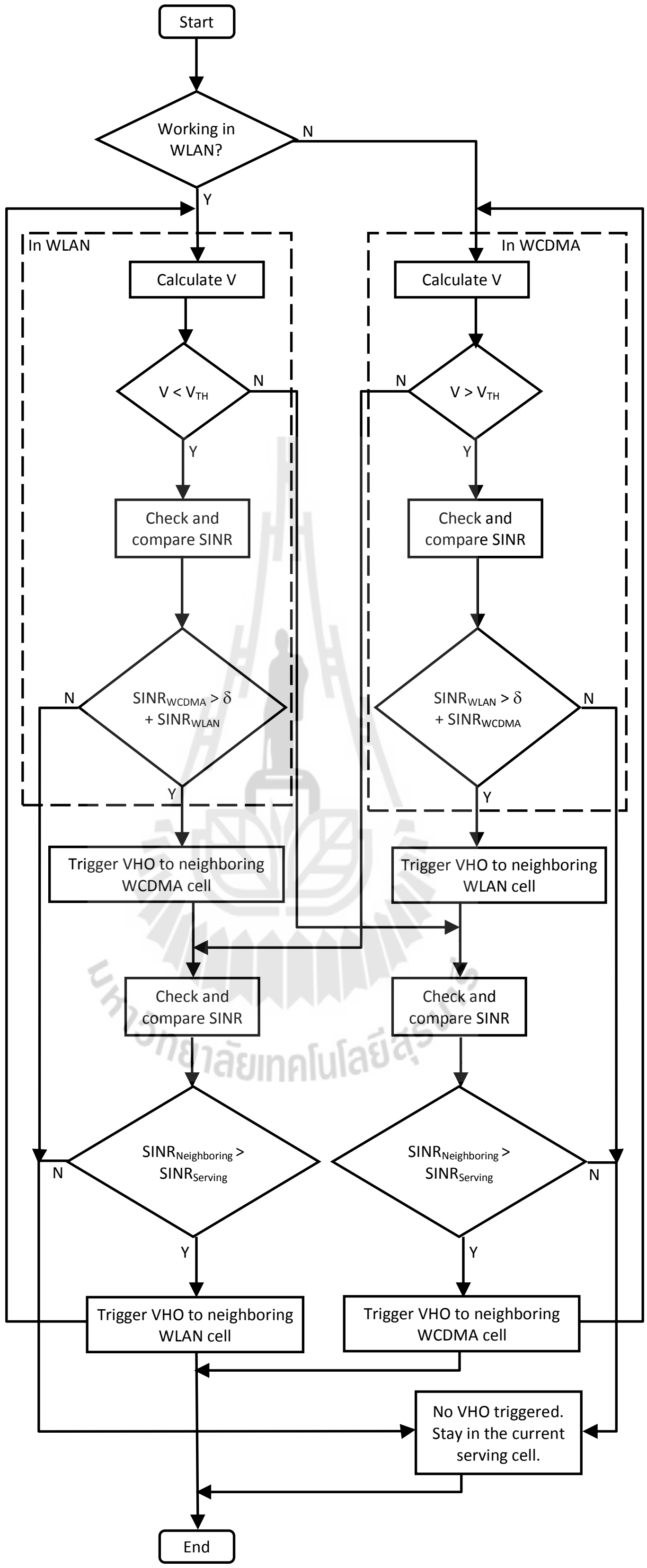


Figure 4.1 VHO decision algorithm

SINR received by the user from the neighbour cell can be expressed as

$$\gamma_{n_i} = \frac{G_{n_i}P_{n_i}}{N_{n_i}+I_{n_i}} = \frac{G_{n_i}P_{n_i}}{P_B+\sum_{\substack{k\neq i \\ k\in AP/BS}} G_{n_k}P_{n_k}} \tag{4.2}$$

where notation *n* is indicating the neighbour cell.

Basic path loss model, which is used for channel gain calculation in this study, is a macro-cell propagation model for urban and suburban areas. For the antenna height of 15 meters, the path loss is (Yang *et al*, 2007; Ayyappan *et al*, 2009)

$$G_{(dB)} = 58.8 + 21\log_{10}(f) + 37.6\log_{10}(D) + \text{LogF} \tag{4.3}$$

where *f* is the carrier frequency (2GHz for WCDMA, 2.4GHz for WLAN), *D* is the distance in meters between the user and the BS or AP, and LogF is the log-normal distributed shadowing with standard deviation of σ =10dB.

Based on equation (3.1), the dynamic threshold for SINR based VHO, δ, can be defined by

$$\delta = \gamma_{n_i} - \gamma_{s_i} \tag{4.4}$$

Substituting equation (4.1) and equation (4.2) to equation (4.4), then

$$\delta = \frac{G_{n_i}P_{n_i}}{N_{n_i}+I_{n_i}} - \frac{G_{s_i}P_{s_i}}{N_{s_i}+I_{s_i}} \tag{4.5}$$

Substituting path loss equation (4.3) in the ratio (antilog) form, it will become

$$\delta = \frac{10^{\left(\left(37.6\log_{10}\left(D_{n_i}\right)+G_n\right)/10\right)}\times P_{n_i}}{N_{n_i}+I_{n_i}} - \frac{10^{\left(\left(37.6\log_{10}\left(D_{s_i}\right)+G_s\right)/10\right)}\times P_{s_i}}{N_{s_i}+I_{s_i}} \qquad (4.6)$$

where $G_n = 58.8 + 21\log(f_n) + LogF$ and $G_s = 58.8 + 21\log(f_s) + LogF$.

Additional SINR threshold, δ, is used as forcing parameter for user to stay longer in the appropriate cell according to its velocity. Velocity will come up in the calculation of D_{n_i} and D_{s_i} in (4.6). System model in Figure 4.2 is used to define the relation between δ and user velocity.

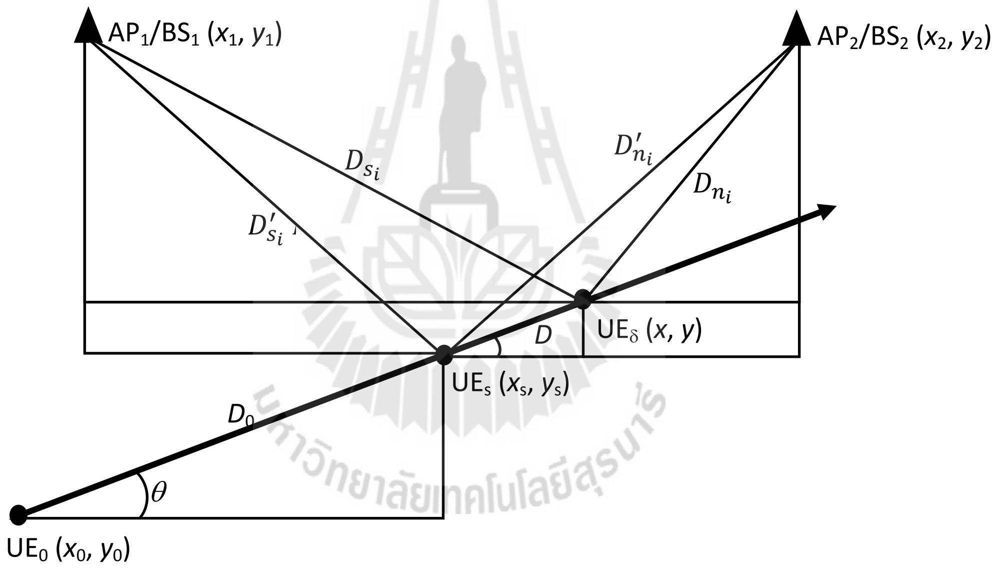


Figure 4.2 System model to define the relation between δ and user velocity

AP_1/BS_1 is a serving cell and AP_2/BS_2 is a neighbour cell. UE_0 is the starting point of user movement. UE_S is the point when user receives the same SINR from the serving and the neighbour cell. UE_δ is the point when additional SINR threshold, δ, is reached. D_0 is the distance from the initial user movement point to UE_S. D is the distance from UE_S and UE. D'_{s_i} is the distance from the serving AP1/BS1 to UE_S. D'_{n_i}

is the distance from the neighbour AP2/BS2 to UE$_S$. D_{n_i} is the distance between user at point UE$_\delta$ to candidate neighbour cell and the D_{s_i} is the distance from user at point UE$_\delta$ to serving cell and defined as

$$
\begin{aligned}
D_{n_i} &= \sqrt{(x_2 - x)^2 + (y_2 - y)^2} \\
&= \sqrt{\left(x_2 - (x_s + D\cos\theta)\right)^2 + \left(y_2 - (y_s + D\sin\theta)\right)^2} \\
&= \sqrt{\left(x_2 - (x_s + (v.t_\delta)\cos\theta)\right)^2 + \left(y_2 - (y_s + (v.t_\delta)\sin\theta)\right)^2} \qquad (4.7)
\end{aligned}
$$

and

$$
\begin{aligned}
D_{s_i} &= \sqrt{(x_1 - x)^2 + (y_1 - y)^2} \\
&= \sqrt{\left(x_1 - (x_s + D\cos\theta)\right)^2 + \left(y_1 - (y_s + D\sin\theta)\right)^2} \\
&= \sqrt{\left(x_1 - (x_s + (v.t_\delta)\cos\theta)\right)^2 + \left(y_1 - (y_s + (v.t_\delta)\sin\theta)\right)^2} \qquad (4.8)
\end{aligned}
$$

where v is user velocity, t_δ is the time needed to travel from UE$_S$ point to UE point, and the other notations are geometrical notations derived from the system model. Hence, the relation between δ and user velocity can be expressed as

$$
\delta = \frac{10^{\left(\left(37.6\log_{10}\left(\sqrt{\left(x_2-(x_s+(v.t_\delta)\cos\theta)\right)^2+\left(y_2-(y_s+(v.t_\delta)\sin\theta)\right)^2}\right)+G_n\right)/10\right)} \times P_{n_i}}{N_{n_i} + I_{n_i}}
- \frac{10^{\left(\left(37.6\log_{10}\left(\sqrt{\left(x_1-(x_s+(v.t_\delta)\cos\theta)\right)^2+\left(y_1-(y_s+(v.t_\delta)\sin\theta)\right)^2}\right)+G_s\right)/10\right)} \times P_{s_i}}{N_{s_i} + I_{s_i}} \qquad (4.9)
$$

Equation (4.9) implies that for every value of velocity, v, the same value of t_δ will result in different value of δ. Different δ is called as dynamic threshold.

The coordinate of UE_S point is needed to start applying t_δ and it can be found when user receives the same SINR form the serving and the neighbour cell or when

$$\delta = 0 \tag{4.10}$$

$$\gamma_{n_i} - \gamma_{s_i} = 0 \tag{4.11}$$

$$\gamma_{n_i} = \gamma_{s_i} \tag{4.12}$$

$$\frac{G_{n_i} P_{n_i}}{N_{n_i} + I_{n_i}} = \frac{G_{s_i} P_{s_i}}{N_{s_i} + I_{s_i}} \tag{4.13}$$

Substituting path loss equation (4.3) in the ratio (antilog) form, (4.13) will become

$$\frac{10^{\left(\left(37.6\log_{10}\left(D'_{n_i}\right) + G_n\right)/10\right)} \times P_{n_i}}{N_{n_i} + I_{n_i}} = \frac{10^{\left(\left(37.6\log_{10}\left(D'_{s_i}\right) + G_s\right)/10\right)} \times P_{s_i}}{N_{s_i} + I_{s_i}} \tag{4.14}$$

where

$$D'_{n_i} = \sqrt{(x_2 - x_s)^2 + (y_2 - y_s)^2}$$

$$= \sqrt{\big(x_2 - (x_0 + D_0 \cos\theta)\big)^2 + \big(y_2 - (y_0 + D_0 \sin\theta)\big)^2}$$

$$= \sqrt{\big(x_2 - (x_0 + (v.t)\cos\theta)\big)^2 + \big(y_2 - (y_0 + (v.t)\sin\theta)\big)^2} \tag{4.15}$$

and

$$D'_{s_i} = \sqrt{(x_1 - x_s)^2 + (y_1 - y_s)^2}$$

$$= \sqrt{\left(x_1 - (x_0 + D_0 \cos\theta)\right)^2 + \left(y_1 - (y_0 + D_0 \sin\theta)\right)^2}$$

$$= \sqrt{\left(x_1 - (x_0 + (v.t)\cos\theta)\right)^2 + \left(y_1 - (y_0 + (v.t)\sin\theta)\right)^2} \quad (4.16)$$

Substituting equation (4.15) and equation (4.16) to equation (4.14), then

$$10^{\left(\left(37.6\log_{10}\left(\sqrt{(x_2-x_s)^2+(y_2-y_s)^2}\right)+G_n\right)/10\right)} \times \frac{P_{n_i}}{N_{n_i}+I_{n_i}}$$

$$= 10^{\left(\left(37.6\log_{10}\left(\sqrt{(x_1-x_s)^2+(y_1-y_s)^2}\right)+G_s\right)/10\right)} \times \frac{P_{s_i}}{N_{s_i}+I_{s_i}} \quad (4.17)$$

Hence, (x_s, y_s) is the point where t satisfies this relation:

$$10^{\left(\frac{\left(37.6\log_{10}\left(\sqrt{\left(x_2-(x_0+(v.t)\cos\theta)\right)^2+\left(y_2-(y_0+(v.t)\sin\theta)\right)^2}\right)+G_n\right)}{10}\right)} \times \frac{P_{n_i}}{N_{n_i}+I_{n_i}}$$

$$= 10^{\left(\frac{\left(37.6\log_{10}\left(\sqrt{\left(x_1-(x_0+(v.t)\cos\theta)\right)^2+\left(y_1-(y_0+(v.t)\sin\theta)\right)^2}\right)+G_s\right)}{10}\right)} \times \frac{P_{s_i}}{N_{s_i}+I_{s_i}}$$

(4.18)

To rearrange equation (4.18), let

$$\mathrm{C}_1 = \frac{\mathrm{P}_{\mathrm{n_i}}}{\mathrm{N}_{\mathrm{n_i}}+\mathrm{I}_{\mathrm{n_i}}} \quad (4.19)$$

$$C_2 = \left(37.6\log_{10}\left(\sqrt{\left(x_2-(x_0+(v.t)\cos\theta)\right)^2+\left(y_2-(y_0+(v.t)\sin\theta)\right)^2}\right)+\ G_n\right)/10$$

(4.20)

$$C_3 = \frac{P_{s_i}}{N_{s_i}+I_{s_i}} \tag{4.21}$$

$$C_4 = \left(37.6\log_{10}\left(\sqrt{\left(x_1-(x_0+(v.t)\cos\theta)\right)^2+\left(y_1-(y_0+(v.t)\sin\theta)\right)^2}\right)+\ G_s\right)/10$$

(4.22)

Equation (4.18) then can be simplified as

$$C_1 10^{C_2} = C_3 10^{C_4} \tag{4.23}$$

and

$$C_4 - C_2 = \log\left(\frac{C_1}{C_3}\right) \tag{4.24}$$

Finally, equation (4.18) can be rearranged as

$$\left(37.6\log_{10}\left(\sqrt{\left(x_1-(x_0+(v.t)\cos\theta)\right)^2+\left(y_1-(y_0+(v.t)\sin\theta)\right)^2}\right)+\ G_s\right)-$$

$$\left(37.6\log_{10}\left(\sqrt{\left(x_2-(x_0+(v.t)\cos\theta)\right)^2+\left(y_2-(y_0+(v.t)\sin\theta)\right)^2}\right)+\ G_n\right)=$$

$$10\log\left(\left(\frac{P_{n_i}}{N_{n_i}+I_{n_i}}\right)/\left(\frac{P_{s_i}}{N_{s_i}+I_{s_i}}\right)\right) \tag{4.25}$$

The additional threshold, δ, can be shown in the graph that consists of the

SINR received from serving cell and neighboring cell as in Figure 4.3. The value of δ will depend on the time, t_δ, after reaching UE_s point in t second from initial movement point UE_0.

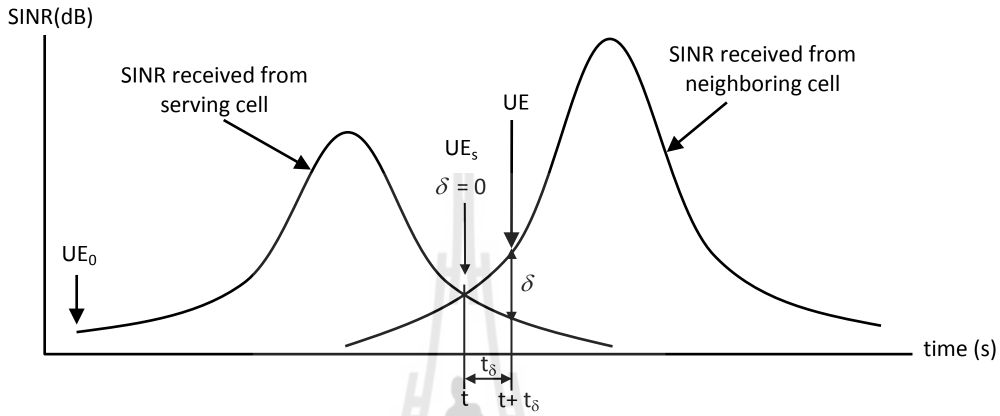


Figure 4.3 Dynamic threshold value, δ, according to time, t_δ

4.4 Simulation Scenario

Simulation scenario in this study has the same scenario as in many studies, such as presented in (Yang *et al*, 2007; Yang *et al*, 2008; Yang *et al*, 2008-1; Ayyappan *et al*, 2009; El-Fadeel *et al*, 2012). There are 7 WCDMA BS (denoted as triangle) and 12 WLAN AP (denoted as rectangle) at fixed places. The 200 UE are randomly generated inside the simulation area for both WCDMA BS and WLAN AP cells. The number of UE is exactly the same as in the previous studies that are mentioned above as the simulation program needs to be calibrated to ensure that the simulation is right. The simulation area is depicted in Figure 4.4. The UE position changes every time interval, depending on their moving speed and direction. The simulation parameters for each of WCDMA and WLAN cells are shown in Table 4.1.

In this study, user velocity is randomly generated in the simulation scenario. In practical level, some studies suggested that UE is equipped with digital map and GPS to ease the task of speed estimation (Shafiee *et al*, 2011; Cha *et al*, 2008). Digital map and GPS can inform the locations, street names, and the velocity of vehicles.

For indoor user with low speed movement, the velocity can be obtained from estimated Doppler spread as suggested in (Radhika and Reddy, 2011). It is well known that fast speed UE cause high Doppler spread while slow speed UE cause low Doppler spread. Radhika and Reddy (2011) classify user's mobility model into two classes, pedestrian and fast.

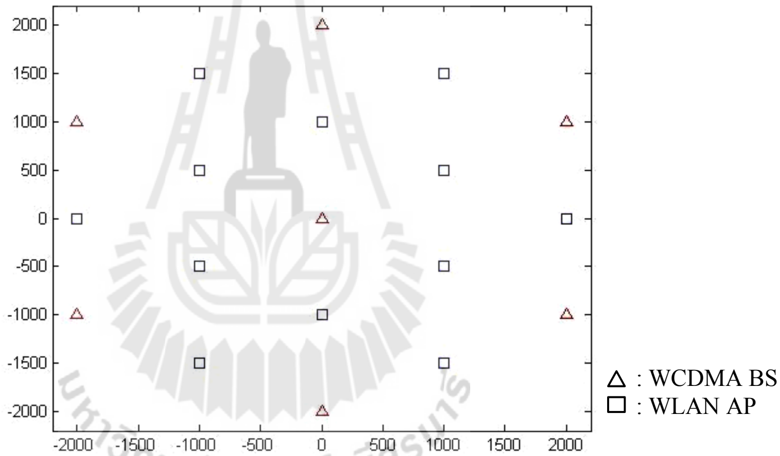


Figure 4.4. Simulation area

This study will use two values of velocity threshold. Firstly, V_{th} = 5 m/s is used to divide user velocity as slow speed and high speed user. This value was used to classify user's mobility into two classes, pedestrian and fast (Shafiee *et al*, 2011). It was also used as VHO decision parameter and assumed as the lowest vehicular speed that can access WLAN cell in (Pourmina and MirMotahhary, 2012). Secondly, V_{th} = 11 m/s is also used to evaluate if slow speed users are defined as users that have velocity below 11 m/s. This value was also used in (Goyal and Saxena, 2008).

Table 4.1 Simulation parameters

WCDMA	**WLAN**	**USER**
• Maximum BS transmitting power is 40dBm • The ratio of total allocated BS transmits power to HSDPA channel is 50%. • Average downlink load factor is 75% • Background noise power equals to -111 dBm • Carrier frequency is 2GHz • Channel bandwidth is 5MHz • Gap between uncoded QAM and channel capacity is 16 dB	• Maximum AP transmitting power is 20dBm. • Background noise power equals to -96 dBm • Carrier frequency is 2.4GHz • Channel bandwidth is 1MHz • Gap between uncoded QAM and channel capacity is 3 dB	• Number of user is 200. • User velocity is randomly generated (1 m/s - 22.2 m/s) or (3.6 km/h - 80 km/h)

Simulation will be done in three phases. The first phase is building the simulation platform. The second phase is applying the fixed threshold. All users will have the same threshold. The third phase is applying the dynamic threshold. Different user velocity will use different threshold.

Simulation steps are depicted in the flow chart Figure 4.5. The first step is setting all simulation parameters and randomizing user initial and target positions and moving velocity. The next step is measuring distance and path loss between user and all BS and AP in every moving step. Simulation program also measures signal strength (RSS), interference signal, and noise power received by every user and calculates SINR. Measurements were done every time user takes one step further in 1 second when it is moving towards target position. This step is done for all 200 users. The last step is collecting all data and averaging it from 200 users.

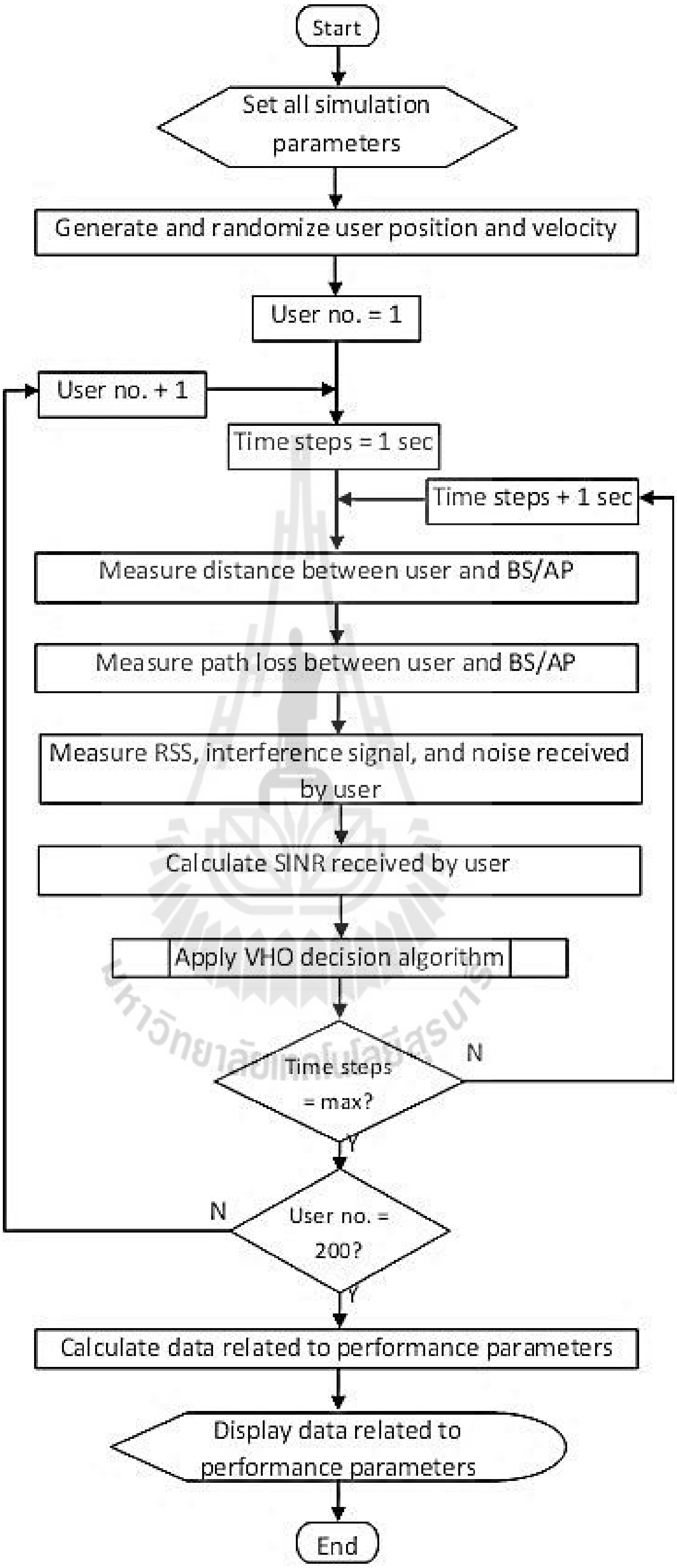


Figure 4.5 Simulation steps

To simplify the simulation without changing the system performance, the dynamic threshold firstly will be calculated without doing calculation as in equation (4.9), but with simple equations such that the δ value will be in the range around 0 to 20 dB like in (Choi, 2010). There are two types of simple dynamic δ defined from

$$\delta_1 = \frac{v}{3600} \tag{4.26}$$

and

$$\delta_2 = \frac{v}{7200} \tag{4.27}$$

Since the user velocity is randomly generated from 3,600 m/hrs to 80,000 m/hrs, then equation (4.26) will give δ value from 1 to 22.22 dB and equation (4.27) will give δ value from 0.5 to 11.11 dB.

4.5 Validation of Simulation Program

The validation of the simulation program has been done in single user basis. In this step, path loss calculation will not include log-normal shadowing factor. The simulation result is shown in the following figures. Figure 4.6 shows user movement from BS4 coverage area to AP7 coverage area. The speed of this user is randomly generated at 65.845 km/h while V_{th} is set to 18 km/h. User travels in straight line from initial position to end position. These positions are randomly generated as well.

Figure 4.7 shows SINR received by the user. Figure 4.7 (a) is the basic SINR based VHO with $\delta = 0$ dB. Whenever the SINR received from candidate neighbor cell is higher than SNIR received from the serving cell, the VHO will be triggered. Figure

4.7 (b) is combined-SINR based VHO. Whenever the SINR received from candidate neighbor cell resulting in higher throughput than the serving cell, the VHO will be triggered. Figure 4.7 (c) is the proposed algorithm applying δ. It means that whenever the SINR received from candidate neighbor cell is higher than preset SNIR threshold received from the serving cell, the VHO will be triggered.

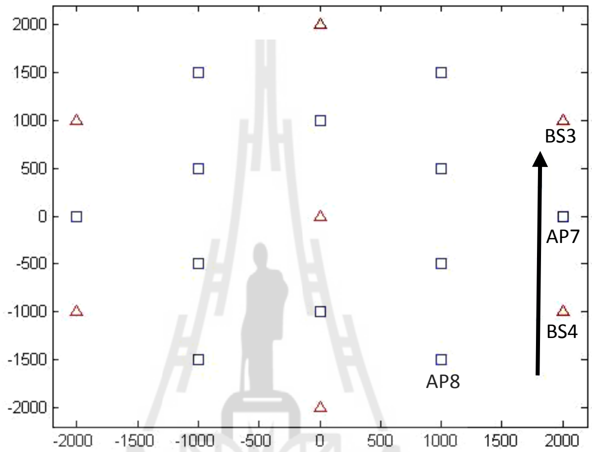
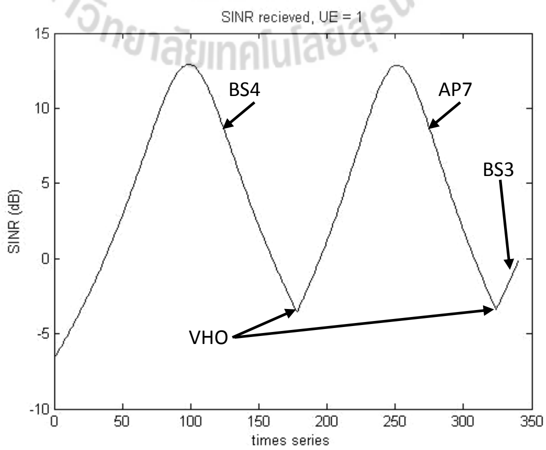


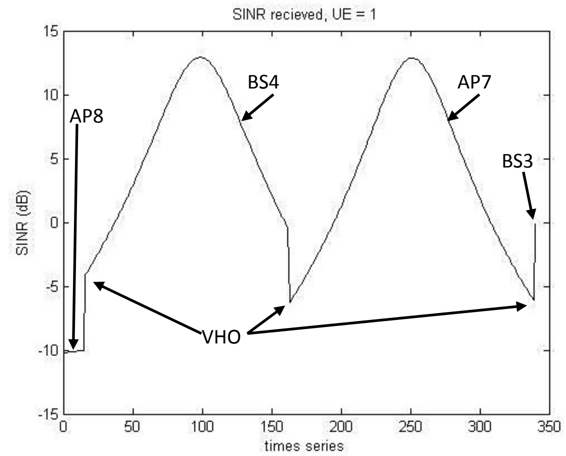
Figure 4.6 User movements from BS4 coverage area to AP7 coverage area



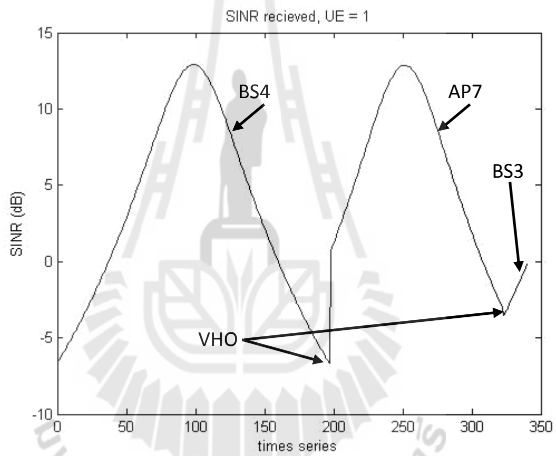
(a)

Figure 4.7 (a) Basic SINR based VHO (b) Combined-SINR based VHO

(c) Proposed algorithm (cont’d)



(b)

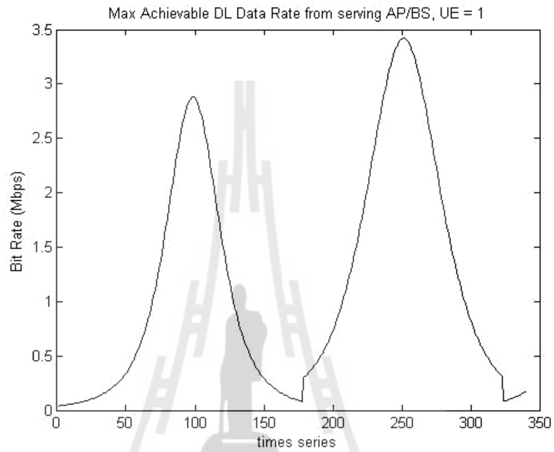


(c)

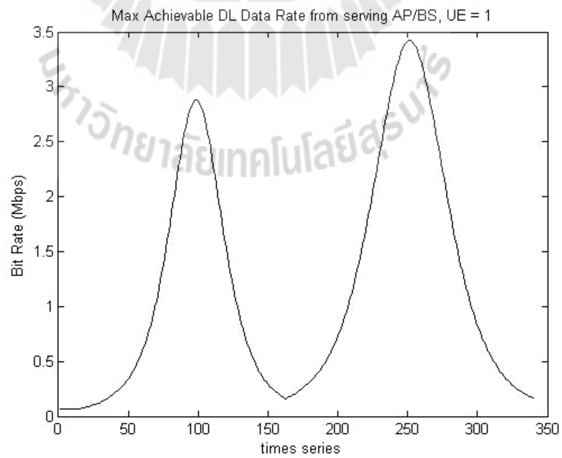
Figure 4.7 (a) Basic SINR based VHO (b) Combined-SINR based VHO (c) Proposed algorithm

Figure 4.8 shows maximum achievable down link data rate from serving cell based on the received SINR. Calculation of average throughput is based on equation (3.5). The same data rate during VHO is achieved only in combined-SINR based VHO in Figure 4.8.(b), which is basically designed for throughput improvement. Regardless of the SINR values that are received from the serving and neighbor cells, VHO will be triggered when user receives higher throughput from candidate cell.

Figure 4.8.(c) shows the maximum achievable down link data rate based on proposed algorithm. When δ is applied in the VHO decision, it will give more time for the user to stay longer in the associated cell with lower data rate. Since the SINR from BS4 is higher than SINR from AP8, this user is initially served by BS4.



(a)

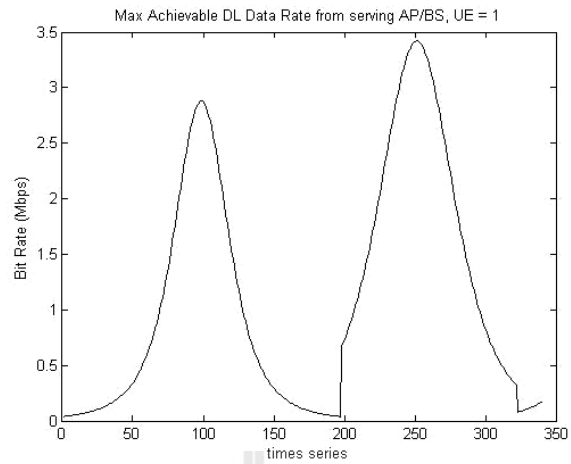


(b)

Figure 4.8 Maximum achievable down link data rate based on

(a) Basic SINR based VHO (b) Combined-SINR based VHO

(c) Proposed algorithm (cont'd)



(c)

Figure 4.8 Maximum achievable down link data rate based on

(a) Basic SINR based VHO (b) Combined-SINR based VHO

(c) Proposed algorithm

BS4 will act as serving cell until the SINR from AP7 is higher than SINR from BS4 plus additional threshold, δ. In this case, the user stays 20 seconds longer in BS4 compare to the basic SINR based VHO. The simulation program starts counting these 20 seconds since the user received the same SINR values from serving and candidate neighbor cell until δ value is reached.

In this study, simulation will be done in three steps. First step is to build the simulation platform as a foundation of the proposed algorithm. This platform has been validated in the previous description. Second step is applying the fixed additional threshold. It means that all user, regardless their velocity, will have the same additional threshold, δ. Third step is applying the dynamic threshold. Different user with different velocity will have different additional threshold.

4.6 Chapter Summary

This chapter presents the proposed algorithm for VHO decision considering user velocity. This algorithm comes up with dynamic SINR threshold as a forcing parameter for each user to stay longer in their associated cell according to their velocity. The detail threshold calculation has been approached mathematically. Simulation scenario has been developed and validated to confirm that the objective of the proposed algorithm can be reached. To practically confirm the proposed algorithm, next chapter will show the simulation results and discussion.

CHAPTER V

SIMULATION RESULTS AND DISCUSSION

5.1 Introduction

This chapter describes the simulation result of proposed algorithm. The discussion will compare the parameter performance as an outcome of the proposed algorithm with the performance from combined-SINR based VHO and basic SINR based VHO. The discussion will be divided into two sections. Firstly, it will discuss about system performance when variety value of fixed SINR threshold and velocity threshold are applied. Secondly, it will describe the system performance as an outcome of applying dynamic SINR threshold.

5.2 Impact of Fixed SINR Threshold on the System Performance

The average throughput under different noise power of WLAN with velocity threshold V_{th} = 5m/s is shown in Figure 5.1. The average throughput becomes lower with higher noise power. The average throughput of proposed algorithm is lower than the average throughput of combined-SINR based VHO, which is denoted as Comb SINR. The proposed SINR threshold is denoted as δ_V.

The proposed algorithm will force low speed users to stay connected in WLAN longer and high speed users to stay connected in WCDMA longer than it should be. The higher the δ value, the longer the users stay in their velocity associated cells. User will be forced to stay in the cells associated with their velocity; even the throughput is lower than candidate neighbour cell. For the combined-SINR based

VHO, the user will directly handoff to neighbour cell that has SINR equivalently higher than current cell and have the same throughput.

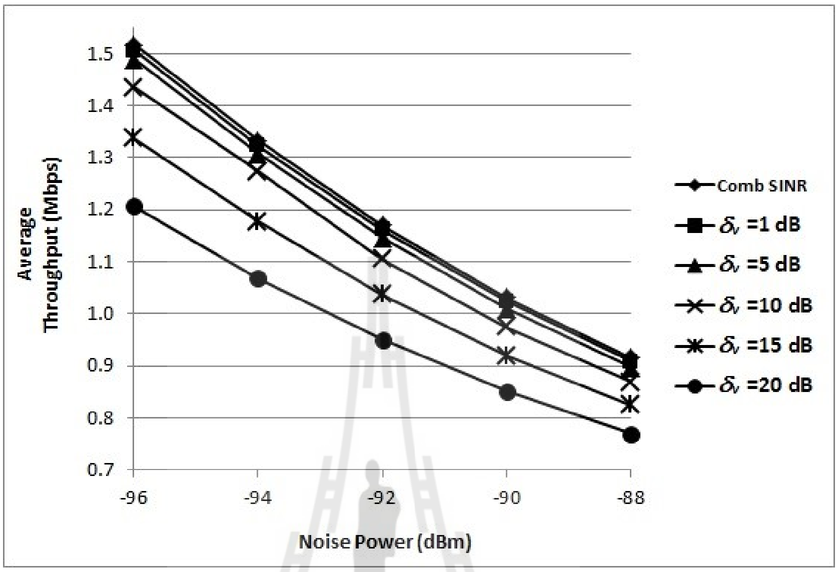


Figure 5.1 Average throughput for variable δ_v at V_{th} = 5m/s

The impact of different δ_v values on the average number of handoff per call is depicted in Figure 5.2. It shows that the higher the δ_v, the lower the average number of handoff per call. When the δ_v value is high, then the system will force the user to stay much longer in the associated velocity cell. If the candidate neighbour cell has small coverage and will be passed by the user in a short time (shorter than additional staying period), the user will not handoff in this cell. Instead, the user will directly handoff to the next candidate cell. In this case, one handoff process will be passed. When δ_v value is set from 10 to 20, the average number of handoff per call in the proposed algorithm is lower than in the combined-SINR based VHO algorithm.

Figure 5.3 shows the average number of the users that are categorized as low speed user in the simulation. It can be seen that when V_{th} = 1 m/s, no user is categorized as low speed user. It means that all of users will be forced to stay longer in WCDMA cells. For V_{th} = 11 m/s, there are 45.8% of users categorized as low speed users. It means that only 45.8% of users will be forced to stay longer in WLAN cells.

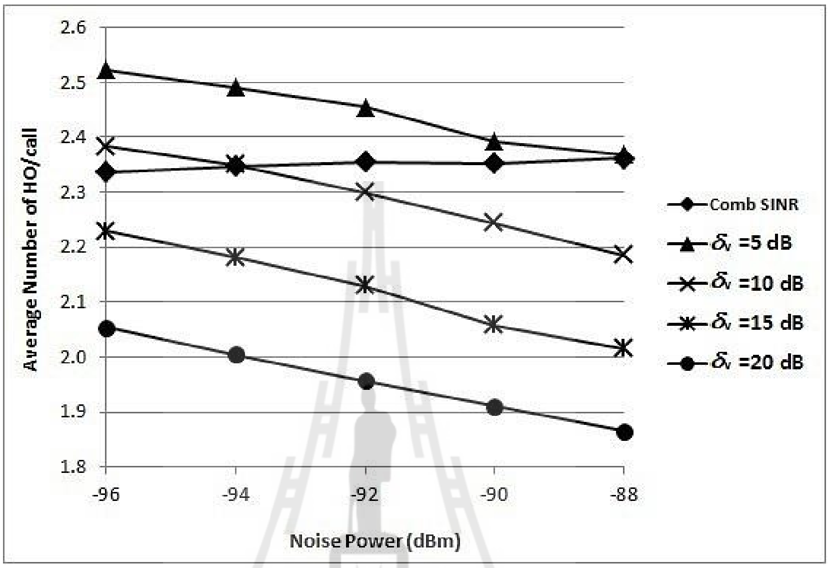


Figure 5.2 Average number of handoff per call for variable δ_v at V_{th} = 5m/s

Figure 5.4 shows the impact of different velocity threshold on the average throughput at δ = 15 dB. The range of recommended δ is 1 to 20 dB (Choi, 2010). This simulation uses four values of δ as shown in Figure 5.5. At δ = 5 dB and δ = 10 dB the difference between the lines is not so visible, so that it is difficult to explain. At δ = 15 dB, the graph starts to have more visible difference between the lines.

At V_{th} = 5m/s, 18.9% of users are categorized as slow speed users and forced to stay in WLAN longer. As WLAN has higher bandwidth compared to WCDMA, so that most of the time during call period, fewer users will be served by higher bandwidth or more users will be served by lower bandwidth and it will result low average throughput. At V_{th} = 11m/s, 45.8% of users are categorized as slow speed users and forced to stay in WLAN longer. It means that most of the time during call period, 45.8% of users will be served in WLAN cell that has higher bandwidth. It results in higher average throughput compare to the lower velocity threshold.

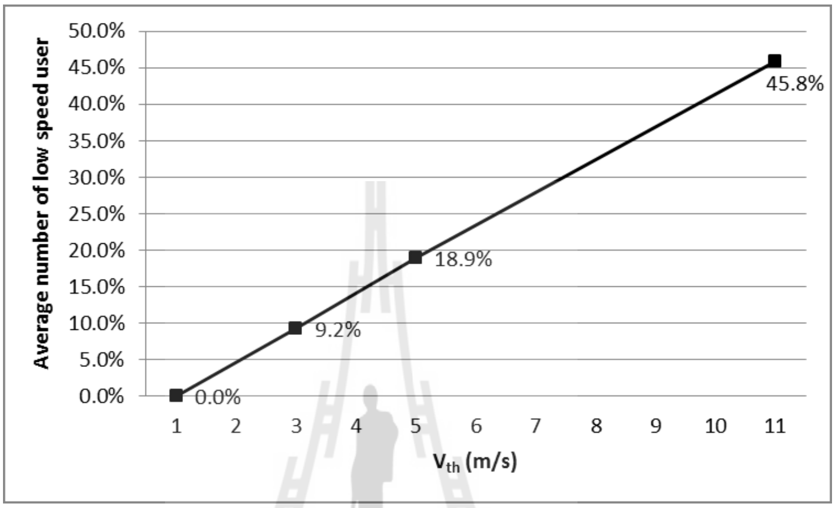


Figure 5.3 The average number of low speed user (in %)

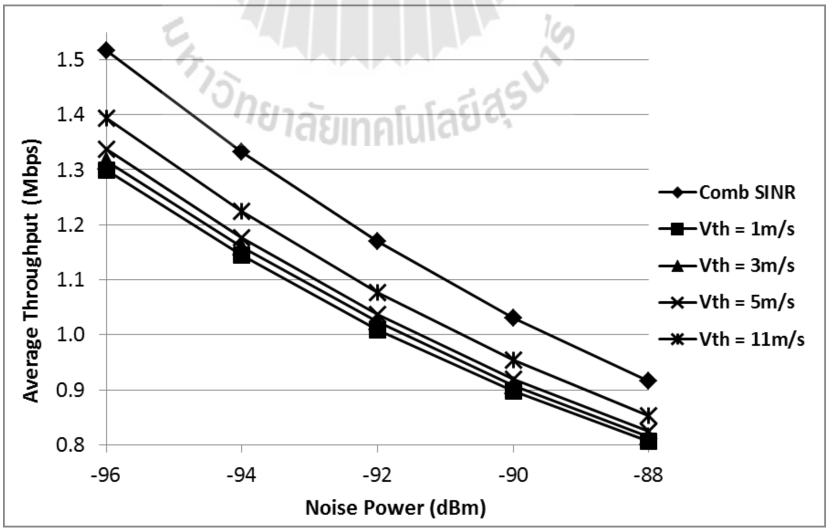


Figure 5.4 Average throughput for different V_{th} at δ= 15 dB

The impact of different V_{th} values on the average number of handoff per call is shown in Figure 5.5. Low V_{th} value will result more high speed users. High speed users with additional threshold will pass the next candidate cell without performing handoff, if the handoff period takes shorter time compare to the time to reach the threshold. Vth = 1 m/s result in lowest average number of handoff per call.

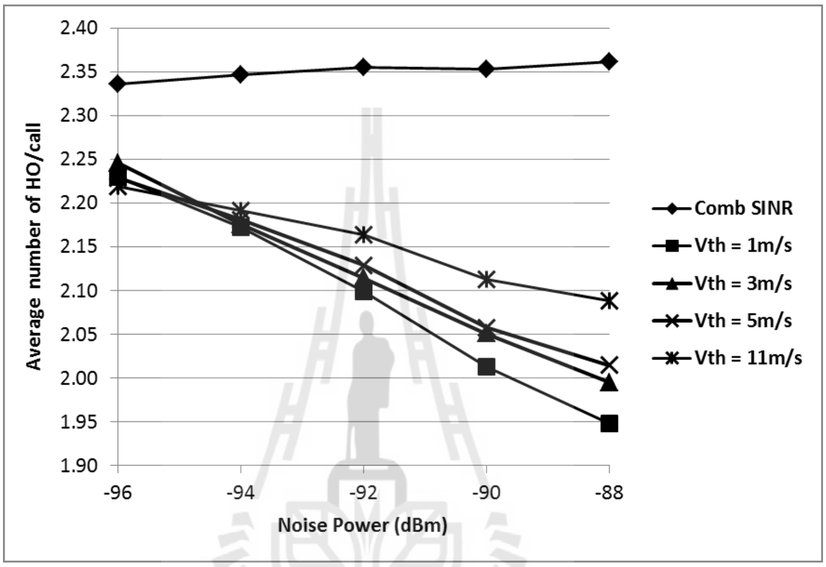


Figure 5.5 Average number of handoff per call for variable V_{th} at δ = 15 dB

Figure 5.6 shows the average throughput comparison of three algorithms. These three algorithms are basic SINR based VHO according to equation (3.1), denoted as δ_S, proposed algorithm (denoted as δ_V), and combined-SINR based VHO (denoted as Comb SINR). The proposed algorithm improves the average throughput from the basic SINR based VHO as the algorithm only applies the threshold δ when user stays in the velocity associated cell. Basic SINR based VHO always applies δ during handoff process, so that user will always receives lower throughput before it can perform handoff.

Figure 5.7 shows the average number of handoff per call comparison of three algorithms as in Figure 5.6. The proposed algorithm has better performance than combined-SINR based VHO in the high noise power environment. In the proposed algorithm, handoff will not be initiated, even when SINR and throughput of neighbor cell is higher, as long as δ is not reached yet. In the combined-SINR based VHO, user will initiate handoff process whenever equivalent neighbor SINR is higher than current serving cell or in other words, whenever the neighbor cell reaches the same throughput. This handoff will be repeated as long as the condition is satisfied, even the last handoff just performed in a short period.

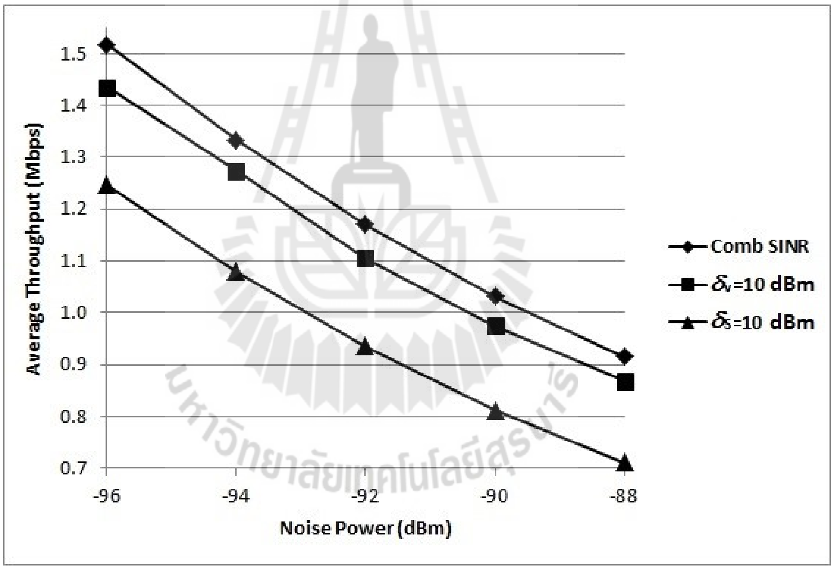


Figure 5.6 Average throughput comparison of the three algorithms at V_{th} = 5m/s

5.3 Impact of Dynamic SINR Threshold on the System Performance

The first part of this section describes the impact of applying simple dynamic threshold base on the simple linear equations in (4.26) and (4.27). The second part of this section describes the impact of applying dynamic threshold base on the equation in (4.9) by setting the time t_{δ}.

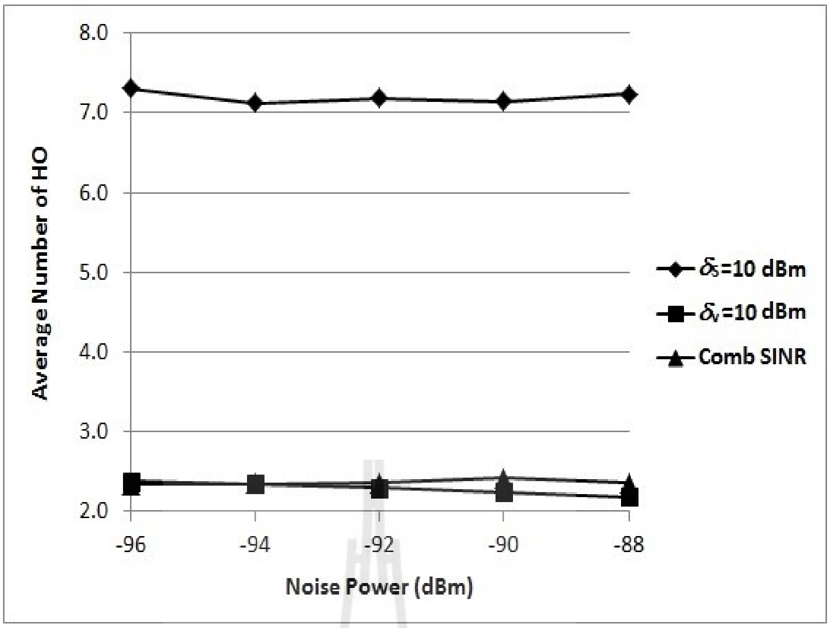


Figure 5.7 Average number of handoff per call comparison of the three algorithms at V_{th} = 5m/s

Figure 5.8 to Figure 5.10 show the system performance comparison between basic SINR based VHO according to equation (3.1), proposed algorithm, and combined-SINR based VHO. Basic SINR based VHO is denoted as δ_S. There are two types of thresholds for proposed algorithm; fixed threshold (denoted as δ_v) and simple dynamic threshold (denoted as δ_1 and δ_2). Combined-SINR based VHO is denoted as Comb SINR.

Table 5.1 Symbols that are used in the figures in this section

Algorithm	Denoted as	Based on
Basic SINR based VHO	δ_S	Choi (2010)
Combined-SINR based VHO	Comb SINR	Yang *et al* (2007)
Proposed algorithm, fixed threshold	δ_v	Fixed value of δ_v
Proposed algorithm, simple dynamic threshold	δ_1 δ_2	Equation (4.26) Equation (4.27)
Proposed algorithm, dynamic threshold	t_δ	Equation (4.9)

The number of handoff is calculated without considering log-normal distributed shadowing (LogF) in (4.3), while the number of unnecessary handoff is calculated with LogF. Summary of the symbols that are used in the figures in this section is shown in Table 5.1.

The average throughput under different noise power of WLAN with velocity threshold V_{th} = 5m/s is shown in Figure 5.8. Average throughput of proposed algorithm is always lower than the average throughput of combined-SINR based VHO. The proposed algorithm force users to stay in their velocity associated cell longer; i.e. low velocity users to stay connected in WLAN longer compare to staying time of the combined-SINR based VHO algorithm. For the combined-SINR based VHO, the user will directly handoff to neighbour cells that have equivalen SINR and same throughput. The proposed algorithm improves the average throughput from the basic SINR based VHO algorithm. The basic SINR based VHO algorithm always applies the threshold during handoff process, so user always receives lower throughput before it can perform handoff.

In the proposed algorithm, the higher the δ_v value, the longer the users stay in their velocity associated cells, even though throughput received from serving cell is lower than throughput received from neighbour candidate cell. The higher the δ_v value, the lower the throughput will be received.

The proposed algorithm with δ_v = 0 dB means there is no forcing parameter for considering user velocity. In other words, user velocity is not considered in this algorithm. User will perform VHO whenever SINR from candidate neighbor cell is higher than SINR from serving cell. Throughput received in this algorithm will not drop too low before it gets higher throughput after performing VHO.

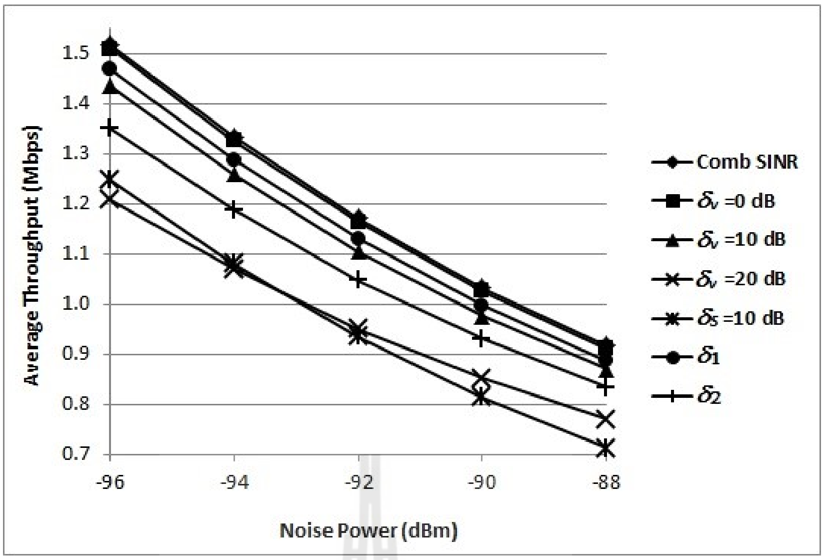


Figure 5.8 Average throughput comparison at V_{th} = 5m/s

The basic SINR based VHO with additional threshold δ_S = 10 dB has the worst average throughput, since user will always perform VHO whenever the threshold is reached, whether the candidate cell is WCDMA or WLAN. User will always extend their stay in current cell longer with very low throughput before it gets higher throughput after performing VHO.

Figure 5.9 shows performance comparison of three algorithms in term of average number of VHO per call. When fixed threshold is applied in the proposed algorithm, it shows that the higher the δ_V value, the lower the value of the average number of handoff per call. When δ_V value is high, system will force the user to stay much longer in the associated velocity cell. If the neighbour candidate cell has small coverage, it might be passed by the user in shorter time than additional staying period, and the user will not handoff in this cell. The users will directly handoff to the next candidate cell. In this case, two handoff processes will be missed. When δ_V value is set from 10 to 20, the average number of handoff per call is lower than the average number of handoff per call in combined-SINR based VHO algorithm.

Proposed algorithm with dynamic threshold δ_2 has superior performance compared to other algorithm, except with δ_V= 20 dB. This threshold value will force the user to stay longer in the appropriate cell according to its velocity until the condition is satisfied and might be passed many cells before the user performs VHO.

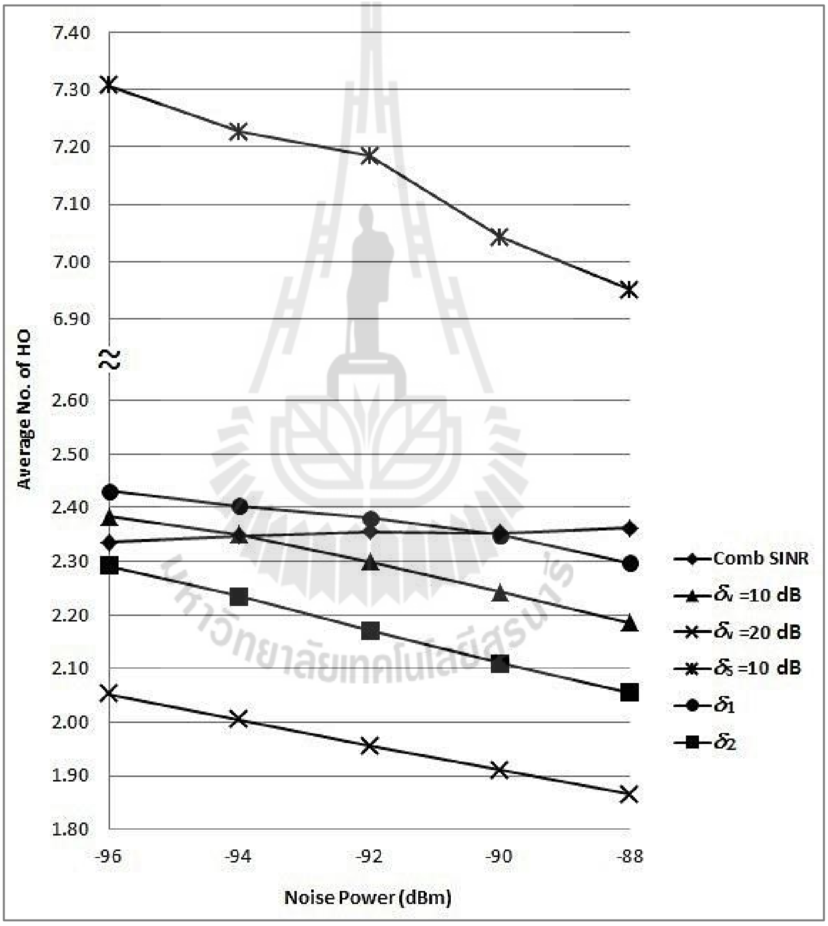


Figure 5.9. Average number of handoff per call comparison at V_{th} = 5m/s

Figure 5.10 shows performance comparison of three algorithms in term of dropped call probability based on (3.6). This dropped call probability trend is in line with the average number of handoff per call trend as it has directly proportional relation in the equation. Referring to the basic SINR based VHO, the highest dropped call probability reduction for proposed algorithm with fixed threshold is 68.63%, at δ_v = 20 dB, noise power -90 dBm. The highest dropped call probability reduction for proposed algorithm with dynamic threshold is 68.02%, at δ_1, noise power -88 dBm.

The average throughput under different noise power of WLAN with two different velocity thresholds V_{th} = 5 m/s and V_{th} = 11 m/s are shown in Figure 5.11. The average throughput becomes lower with higher noise power. The average throughput of proposed algorithm with different time threshold t_δ is always lower than the average throughput of basic-SINR based VHO, δ.

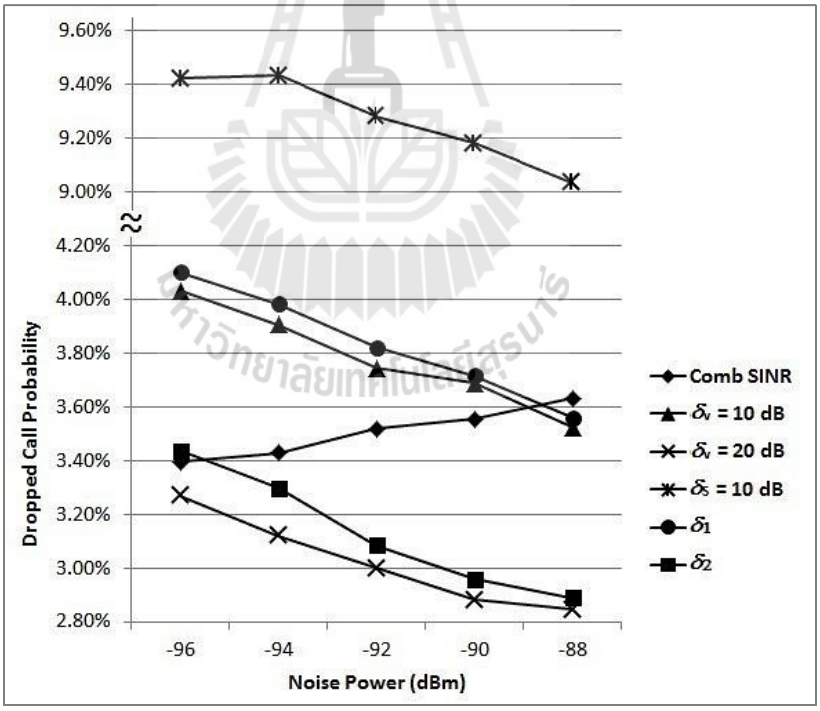


Figure 5.10 Dropped call probability comparison at V_{th} = 5m/s

In this part, the proposed algorithm has four values of t_δ (5 sec, 10 sec, 30 sec, and 50 sec) that will result in different δ for each velocity. The higher the t_δ, the longer the users stay in the cells according to their velocity, even if the received throughput is lower than the throughput from the candidate neighbour cell. The higher the V_{th}, the more users are classified as slow speed users and force to stay longer in WLAN which has higher bandwidth. Therefore, the higher the V_{th}, the higher the average throughput can be received by the user.

For the basic-SINR based VHO, the user will perform VHO whenever SINR from candidate neighbour cell is higher than SINR from serving cell, since $\delta = 0$ dB (no forcing parameter to consider user velocity). The received throughput will not drop too low before it gets higher throughput after performing VHO.

The degradation of average throughput is still acceptable according to the minimum requirement of throughput for transferring multimedia data, such as video streaming. For the lowest quality of video that has 240p and resolution of 426x240, the video bit rate range is 300–700 Kbps. It means that the lowest average throughput in this study is more than enough for transferring process, even in the highest noise power environment. The highest video quality that can be handled by the system is a video that has 480p, resolution of 854x480, and the video bitrate range is 500 - 2,000 Kbps. In this case, V_{th} should be at 11 m/s and t_δ should be set at 10 second to give minimum average throughput 1.2 Mbps which is in the video bitrate range.

The impact of different t_δ on the average number of handoff per call is depicted in Figure 5.12. It shows that by applying t_δ, the system has the lower value of the average number of handoff per call or superior performance compared to basic-SINR based VHO. This threshold value will force the user to stay in the appropriate cell, according to its velocity; longer until the condition is satisfied and might be missed many cells before the user perform VHO. If the neighbour candidate cell has a coverage that will be passed by the user in a shorter time than additional staying period, the user will not handoff in this cell, but directly handoff to the next candidate cell. In this case, one handoff process will be missed.

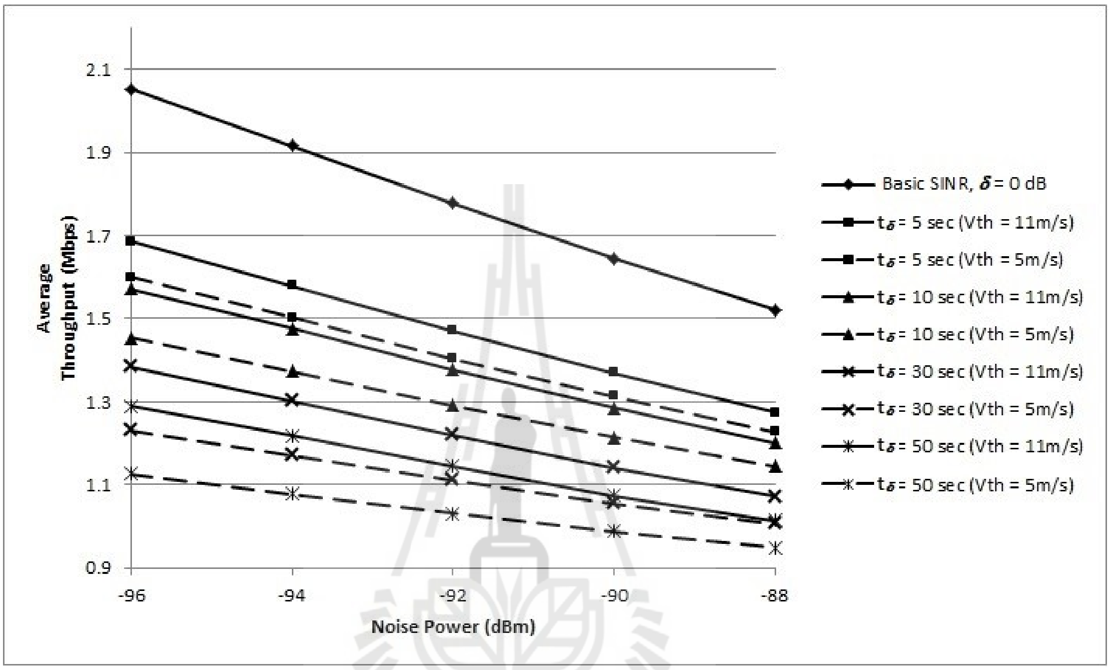


Figure 5.11 Average throughput for 200 UEs

Figure 5.12 shows that t_δ = 30 second has the best performance or the lowest value of average handoff per call at two different V_{th} values. In many cases during simulation, t_δ = 50 second is too long for user to perform handoff. When the time to perform handoff comes, there is another condition satisfied to perform another handoff in a short time. This handoff could be horizontal handoff or even VHO as the same condition in lower part of flowchart in Figure 4.1.

Figure 5.13 shows the average number of unnecessary handoff per call. The proposed algorithm significantly reduces the number of unnecessary handover compare to the basic-SINR based VHO at two different V_{th} values. In the basic-SINR based VHO, user will initiate handoff process whenever neighbour SINR is higher than current serving cell or in other words. This handoff will be repeated as long as the condition is satisfied, even the last handoff just performed in a short period and causing very high number of unnecessary handoff.

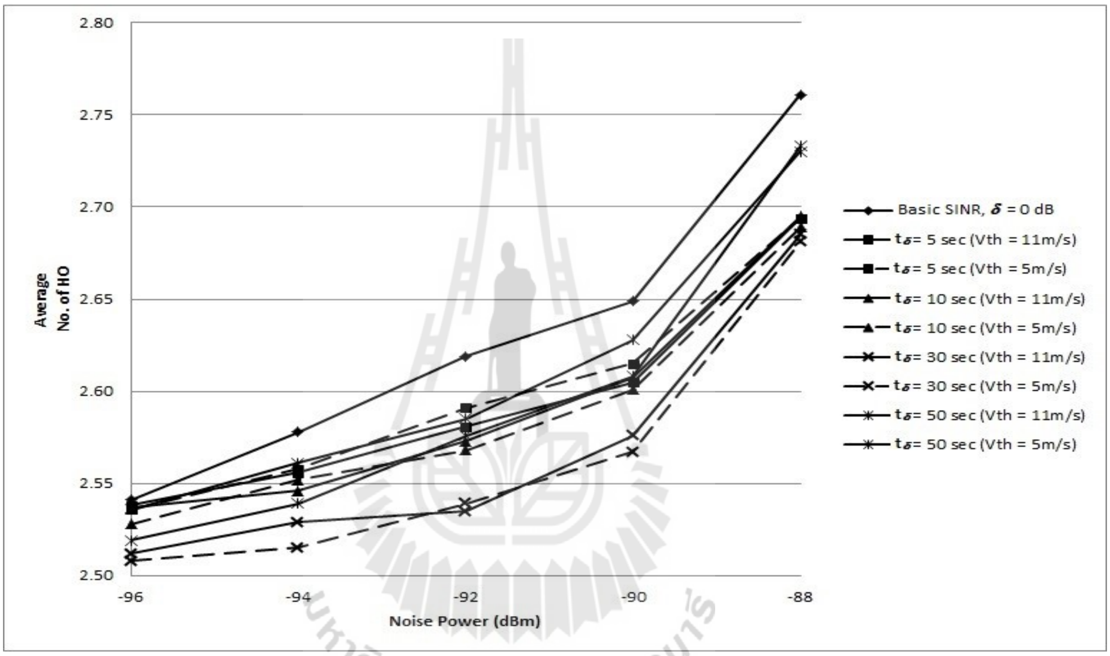


Figure 5.12 Average number of handoff per call for 200 UEs

At noise power -88 dBm, the average number of unnecessary handoff in the basic-SINR based VHO is 320 per call, while in the proposed algorithm at t_δ = 5 seconds is 30.5 per call, t_δ = 10 seconds is 9.7 per call, t_δ = 30 seconds is 0.9 per call, and t_δ = 50 seconds is 0 per call (no unnecessary handoff occur) for V_{th} = 5 m/s. The average number of UHO per call for V_{th} = 11 m/s t_δ = 5 seconds is 28.7 per call, t_δ = 10 seconds is 9.3 per call, t_δ = 30 seconds is 1 per call, and t_δ = 50 seconds is 0 per call. It is not much different in the average number of UHO at the highest noise power environment between two different values of V_{th}.

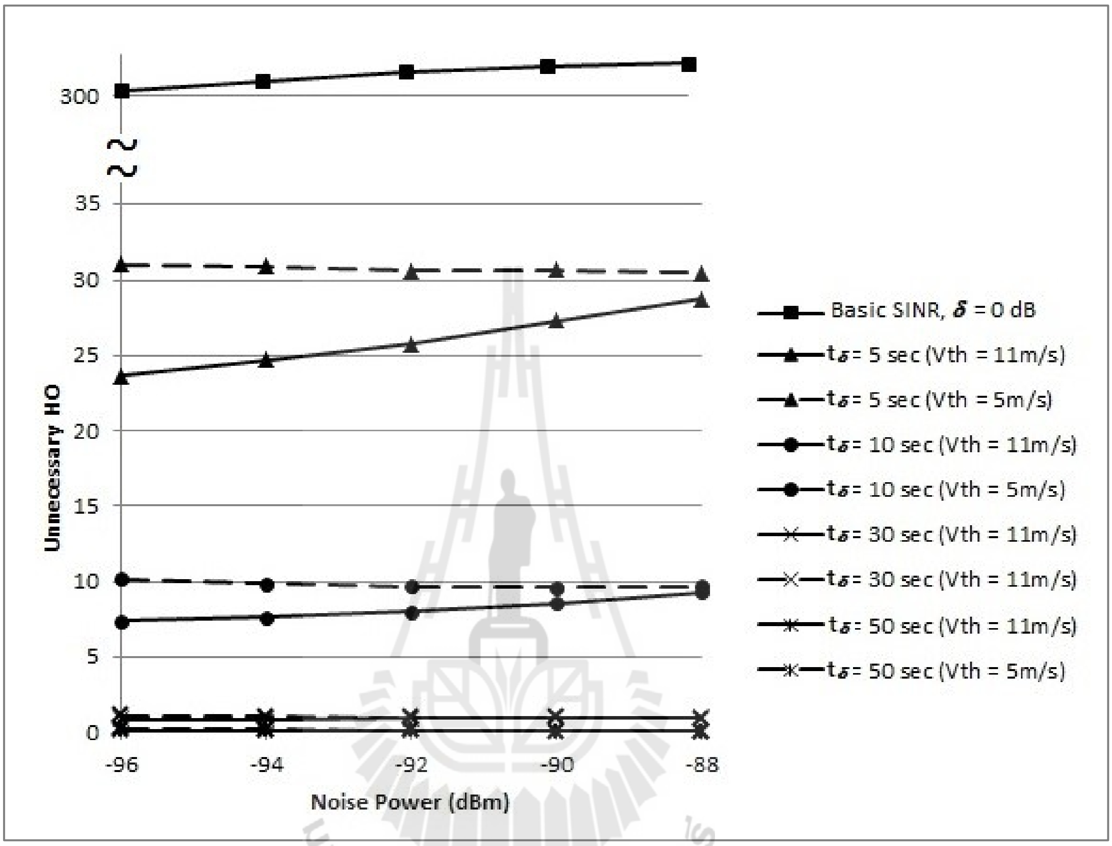


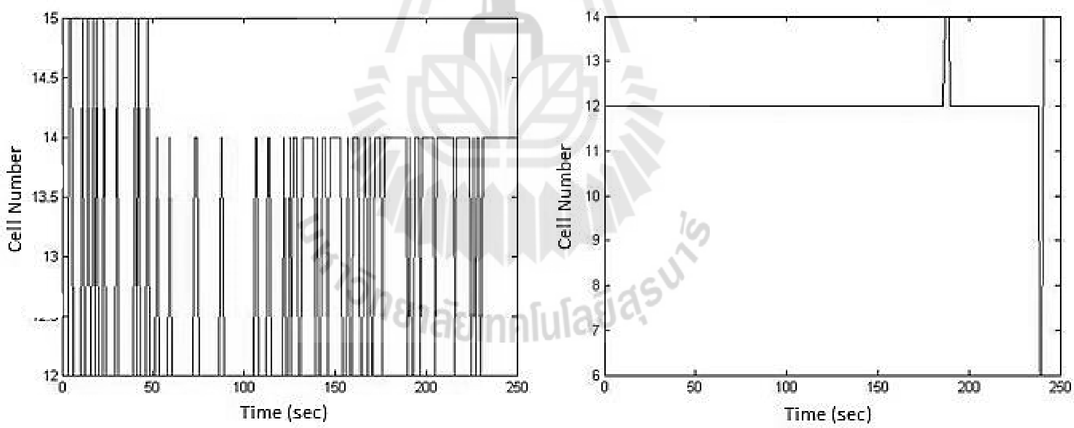
Figure 5.13 Average number of unnecessary handoff per call for 200 UEs

5.4 Probability of Unnecessary Handoff

Figure 5.14 shows the timing diagram of user movement at the speed of 10 m/s. It is shown to confirm the comprehension depicted in Figure 3.7 (b). Two different VHO decision algorithms are applied to the same user, basic-SINR algorithm in Figure 5.14 (a). and the proposed algorithm with dynamic threshold at $t\delta = 10$ sec in Figure 5.14 (b). The basic-SINR algorithm results in 74 handoffs for 250 seconds. The user changes the serving cell rapidly from cell number 12 to cell number

15 for about 50 seconds then change to cell number 14 for about 200 seconds. It is clear that this phenomenon is ping-pong effect phenomenon. In the other hand, the proposed algorithm will maintain the user camp on the serving cell number 12 for about 180 seconds and results in only 4 handoffs. It shows that proposed algorithm can effectively reduce ping-pong effect.

Figure 5.15 shows the difference of average number of UHO per call between basic-SINR algorithm and proposed algorithm with t_δ = 10 seconds. UHO reduction at low speed users is higher than high speed users. However the number of UHO in high speed users is very low for proposed algorithm implementation, only 1.82 UHO per call at 25 m/s.



(a) (b)

Figure 5.14 Number of handoff using

(a). Basic-SINR algorithm (b). Proposed algorithm with t_δ = 10 sec

Figure 5.16 shows the difference of probability of UHO per call between basic-SINR algorithm and proposed algorithm with t_δ = 10 seconds based on (3.9) and (3.10). Probability of UHO has the lowest value of 37.25% at user velocity 25 m/s with the cell radius of 150 m. Probability of UHO for basic-SINR algorithm is always at 100% for every user velocity.

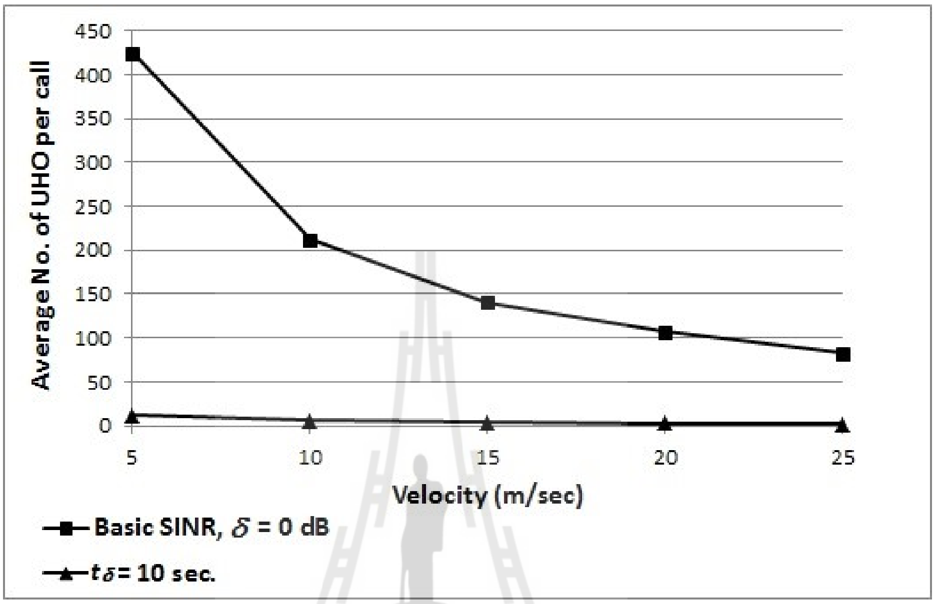


Figure 5.15 Average number of UHO for 200 UEs

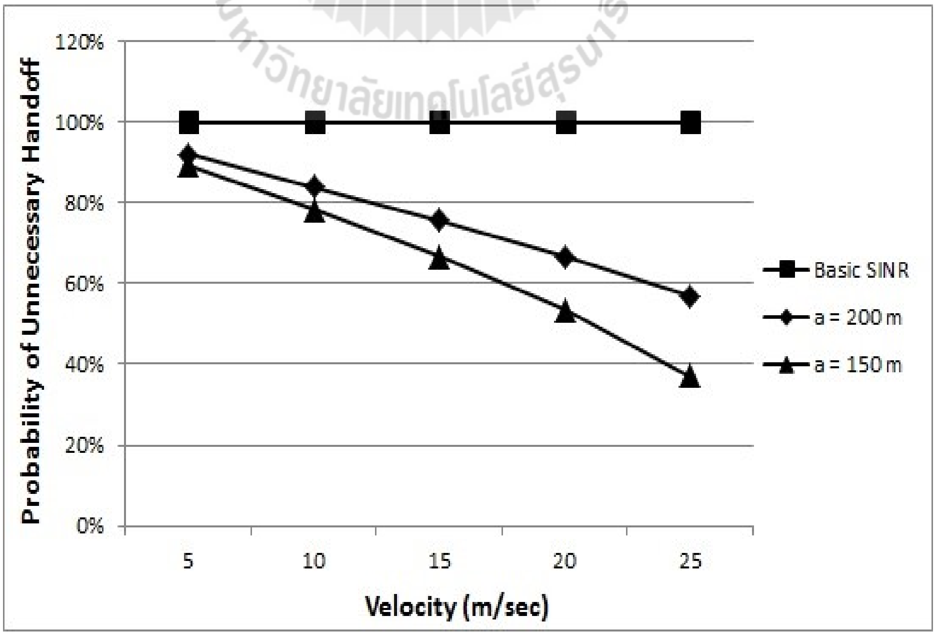


Figure 5.16 Probability of UHO for different user velocity and radius of cells

5.5 Recommendation of The Optimum Threshold

The graphs in Figure 5.17 and 5.18 can be used to recommend the optimum threshold for optimum system performance. These graphs show the trade-off between the percentage of number of handoff reduction per call versus average throughput and the percentage of unnecessary handoffs reduction per call versus average throughput.

Figure 5.17 shows the percentage of number of handoff reduction per call versus average throughput at the worst condition where the noise power is -88 dBm. The percentage of average number of handoff reduction per call is calculated based on the highest average number of handoff per call in basic SINR based VHO algorithm with additional threshold δ_S = 10 dB, which is 7.24 handoff per call.

The degradation of average throughput is acceptable according to the minimum requirement of throughput for transferring multimedia data, such as video streaming. For lowest video quality that has 240p and resolution of 426x240, the video bit rate range is 300–700 Kbps. It means that the lowest average throughput in this study is more than enough. The highest video quality that can be handled by the system is video that has 480p, resolution of 854x480, and the video bitrate range is 500–2,000 Kbps. In this case, δ_V should be set at 10 dB to give minimum average throughput 0.87 Mbps with maximum number of handoff reduction 69.8%.

Figure 5.18 shows the percentage of unnecessary handoffs reduction per call versus average throughput at the worst condition where the noise power is -88 dBm. If the system is required to handle video quality that has 480p, then the optimum recommended threshold is t_{δ} = 10 second. It will give minimum average throughput 1.2 Mbps with maximum unnecessary handoffs reduction 97%.

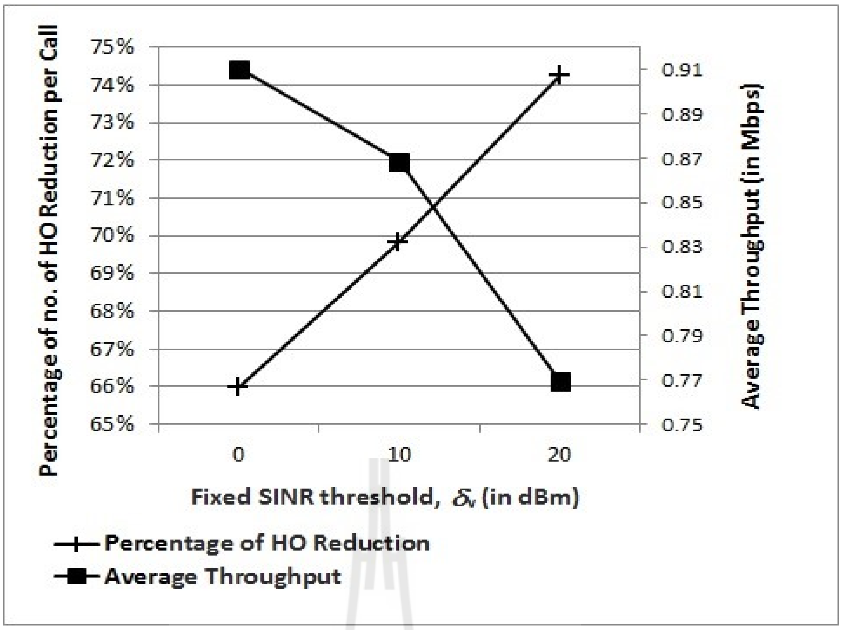


Figure 5.17 Percentage of average number of Handoff Reduction per Call versus Average Throughput

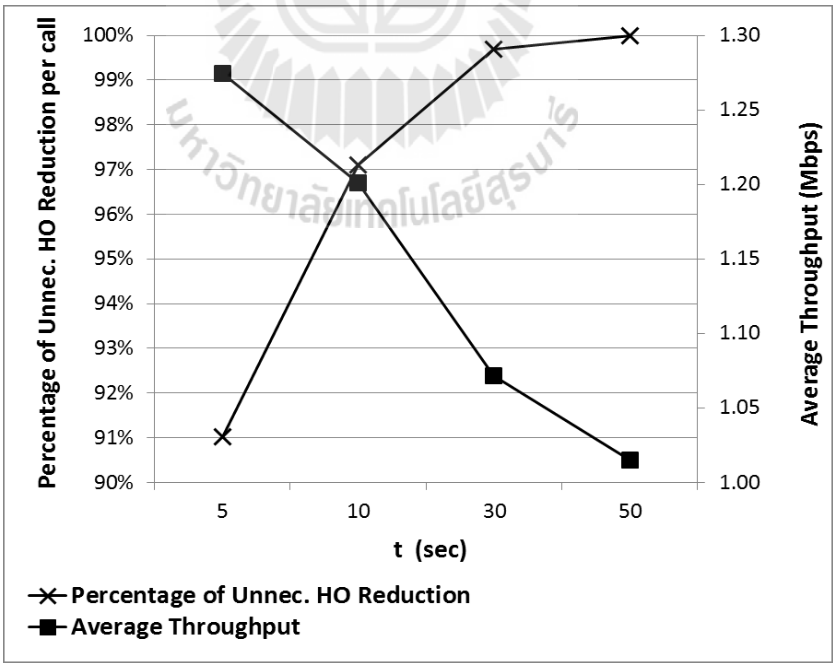


Figure 5.18 Percentage of Unnecessary Handoffs Reduction per Call versus Average Throughput

5.6 Discussion on The Impact of Decreasing UHO

VHO process needs signaling communication between UE and the network. In Hetnet, VHO signaling takes place in both data link and IP layers and needs more signaling overhead (Solouk et al, 2011). When UHO occur during active session, it needs more signaling overhead that consumes more network resources. It leads to increase of packet loss, dropped call probability, and probability of handoff failure. Minimizing UHO as in this proposed algorithm goal will minimize signaling overhead and a chance of having packet loss and dropped call.

In the VHO process, there is a duration in which UE is unable to send or receive any data packets (Hussain et al, 2012). Increase of VHO number leads to larger packet loss and service degradation. In this study, minimizing UHO means minimizing packet loss as well. The proposed algorithm can reduce UHO down to 100% at t_δ = 50 seconds under the condition of having noise power -88 dBm. It means the proposed algorithm can provide no packet loss caused by UHO.

Up to now, many methodologies have been used on VHO, such as policy-enabled schemes, fuzzy logic, neural networks concepts, etc (He *et al*, 2010). Although some of these methods are quite successful, they are not particularly suitable for real-time applications in the real world, since the reliability of them usually depends on complex procedure. The proposed algorithm provide direct and real time SINR comparison and calculation to give the network a chance to directly decide whether UE needs to perform VHO or not. It definitely reduces decision time and complexity of the algorithm compare to any other algorithms aforementioned.

5.7 Chapter Summary

This chapter presents simulation results of the proposed algorithm. It shows that the proposed algorithm has a good indication on the system performance while considering user velocity in the VHO decision. In terms of average throughput, the proposed algorithm gives slightly lower values than the previous studies. However, it gives better performance in terms of average number of handoff per call and dropped call probability. Moreover, the proposed algorithm gives superior performance in terms of UHO and the probability of UHO.

There is always tradeoff between average throughput and average number of handoff and UHO. This study recommends the optimum threshold value based on this tradeoff. Finally, the last section discuss about the impact of decreasing UHO.

CHAPTER VI

CONCLUSION, RECOMMENDATION, AND FUTURE WORK

6.1 Conclusion

A dynamic threshold SINR based VHO algorithm for considering user velocity in the VHO decision has been developed and evaluated in this study. The relation between user velocity and SINR threshold has been formulated and the simulation platform has been set up and validated prior to parameter changing.

Two approaches in implementing the proposed algorithm have been designed. These approaches are to apply the fixed threshold to understand the system behavior and to apply the dynamic threshold to confirm the advantage of the proposed algorithm.

The simulation results have been compared with basic SINR based VHO and combined-SINR based VHO. The simulation results show that the velocity consideration makes the average throughput slightly drops, but gives better performance on the average number of handoff per call and dropped call probability. The proposed algorithm gives significantly better performance on the average number of UHO and probability of UHO.

There is always a tradeoff between average throughput and other performance metrics which are calculated in this study. If the velocity threshold and additional SINR threshold is set lower, then the average throughput becomes higher approaching the ideal value and the other performance metrics also get higher, which should be avoided by the system.

In this study, the dynamic threshold has a certain value where the optimum system performance can be achieved. An optimum setting of fixed threshold has been recommended. An optimum dynamic threshold also has been recommended to give the best performance on the average number of unnecessary handoffs per call with an acceptable average throughput. This value will be recommended in the next section.

6.2 Recommendation

There are two threshold values recommended in this study to achieve the best system performance. The best system performance in this study means the lowest value of the average number of handoff per call, the dropped call rate, the average number of UHO per call, and the probability of UHO, with an acceptable average throughput value. Two threshold values are as follows:

1. In the case where fixed threshold is set in the system, the threshold δ should be set at 10 dB for video streaming with video that has 480p, resolution of 854x480, and the video bitrate range is 500–2,000 Kbps at noise power -88 dBm.
2. In the case where dynamic threshold is set in the system, the optimum recommended threshold is t_{δ} = 10 seconds for video streaming with video that has 480p, resolution of 854x480, and the video bitrate range is 500–2,000 Kbps at noise power -88 dBm.

6.3 Future Works

There are some theoretical and practical issues that need to be addressed for conducting future research. It will improve the accuracy of performance parameters calculation and give better understanding of network behavior. These future works are as follow:

1. On the theoretical side, the capacity of WLAN cells and WCDMA cells that is used in this study should be limited as mentioned in IEEE Std 802.11™-2007 and UMTS WCDMA R99 (Holma dan Toskala, 2004; 3GPP TR 25.942 version 7.0.0 Release 7; ETSI TR 125 942 V7.0.0 (2007-03))
2. On the practical side, the straight line movement of the user is rather impractical and simple. To approach the real situation, user movement should be randomized in direction along the way to the end point.
3. Moreover on the practical side, the configuration of WLAN cells and WCDMA cells in the simulation scenario is too regular. This configuration should be arranged as closed as possible as a real life network. Digital map or 3D (3 Dimension) map can be used to place the cells.

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APPENDIX A

PUBLICATIONS

List of Publications

National Conference Paper

Widjaja, D., and Uthansakul, P. (2015). **Optimum Threshold for Velocity Considered–SINR Based Vertical Handoff Decision in The Heterogeneous Network**. The 41st Congress on Science and Technology of Thailand (STT41). November 2015. Nakhon Ratchasima, Thailand.

International Conference Paper

Widjaja, D., and Uthansakul, P. (2015). **Impact of User Velocity Consideration in SINR Based Vertical Handoff Decision on The Heterogeneous Wireless Network Performance**. 9th South East Asia Technical University Consortium (SEATUC) Symposium. July 2015. (pp. 439-443) Suranaree University of Technology, Nakhon Ratchasima, Thailand.

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BIOGRAPHY

Mr. Damar Widjaja was born on December 22, 1969, in Surakarta, Indonesia. He received his B.Eng. in Electrical Engineering from Gadjah Mada University, Yogyakarta, Indonesia, in 1994, and M.Eng. in Electrical Engineering from University of Indonesia, Jakarta, Indonesia in 2005. Mr. Widjaja is a faculty member at the Electrical Engineering Department, Sanata Dharma University, Yogyakarta, Indonesia. He was admitted to the Ph.D. program in the School of Telecommunication Engineering at Suranaree University of Technology, Nakhon Ratchasima, Thailand under the SUT-Ph.D. Scholarship Program for ASEAN in 2013 and completed the program in 2016. His research interest is in the fields of wireless and mobile communication.