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Performance Modelling and Analysis of Handover and Call Admission Control Algorithm for Next Generation Wireless Networks

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ABSTRACT

The next generation wireless system (NGWS) has been conceived as a ubiquitous wireless environment. It integrates existing heterogeneous access networks, as well as future networks, and will offer high speed data, real-time applications (e.g. Voice over IP, videoconference) and real-time multimedia (e.g. real-time audio and video) support with a certain Quality of Service (QoS) level to mobile users. It is required that the mobile nodes have the capability of selecting services that are offered by each provider and determining the best path through the various networks.

Efficient radio resource management (RRM) is one of the key issues required to support global roaming of the mobile users among different network architectures of the NGWS and a precise call admission control (CAC) scheme satisfies the requirements of high network utilization, cost reduction, minimum handover latency and high-level QoS of all the connections.

This thesis is going to describe an adaptive class-based CAC algorithm, which is expected to prioritize the arriving channel resource requests, based on user's classification and channel allocation policy. The proposed CAC algorithm couples with Fuzzy Logic (FL) and Pre-emptive Resume (PR) theories to manage and improve the performance of the integrated wireless network system. The novel algorithm is assessed using a mathematical analytic method to measure the performance by evaluating the handover dropping probability and the system utilization.

Keywords: Call Admission Control, Fuzzy Logic, Markov Chain Process, Next Generation Wireless System, Pre-emptive Resume.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

2G	Second Generation Wireless Telephone Technology
2.5G	Second and a Half Generation Wireless Telephone Technology
3G	Third Generation Wireless Telephone Technology
3GPP	3rd Generation Partnership Project
AC	Adjustment Channel
AP	Access Point
AQM	Active Queue Management
BS	Base Station
CAC	Call Admission Control
CN	Core Network
DAB	Digital Audio Broadcasting
DCF	Distributed Coordination Function
DCRS	Dynamic Channel Reservation Scheme
DP	Dropping Probability
DSSS	Direct Sequence Spread Spectrum
DTBR	Dual Threshold Bandwidth Reservation
DVB	Digital Video Broadcasting
EDCA	Enhanced Distributed Channel Access
EDGE	Enhanced Data rates for GSM Evolution
FHSS	Frequency Hopping Spread Spectrum
FIFO	First In First Out
FL	Fuzzy Logic
FSS	Fully Shared Scheme

GCS	Guard Channel Scheme
GPRS	General Packet Radio Service
GUIDO	Guard channel based Incremental and Dynamic Optimization
HC	Handover Control
HCCA	HCF Controlled Channel Access
HCF	Hybrid Coordination Function
HDP	High priority handover Dropping Probability
HDTV	High Definition TeleVision
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSUPA	High Speed Uplink Packet Access
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
LC	Load Control
LDP	Low priority handover Dropping Probability
MAC	Medium Access Control
MCP	Markov Chain Process
MDP	Markov Decision Process
MF	Membership Function
NGWS	Next Generation Wireless System
PC	Power Control
PCF	Point Coordination Function
PCS	Personal Communications Service
PR	Pre-emptive Resume

PS	Packet Scheduler
QoS	Quality of Service
RAT	Radio Access Technology
RB	Radio Bearer
RC	Reserved Channel
RM	Resource Manager
RNC	Radio Network Controller
RRM	Radio Resource Management
SA	Sensitivity Analysis
SIR	Signal to Interference Ratio
TD	Tail Drop
TSK	Tskagi Sugeno Kang
UE	User Equipment
UMTS	Universal Mobile Telecommunications System
UTRAN	UMTS Terrestrial Radio Access Network
WAN	Wide Area Network
WCDMA	Wideband Code Division Multiple Access
WG	Working Group
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WMAN	Wireless Metropolitan Area Network
WMN	Wireless Mesh Network
WPAN	Wireless Personal Area Network
WWAN	Wireless Wide Area Network

List of Symbols

K	radio resource capacity
K_U	occupied channel
C_L	lower channel threshold of two-threshold MCP
C_H	higher channel threshold of two-threshold MCP
C_T	channel threshold of one-threshold MCP
λ_1	channel request rate of User A
λ_2	channel request rate of User B
λ_3	channel request rate of User C
λ_{TOTAL}	total channel request rate
λ_H	total channel request rate of Users A and B
ξ_1	acceptance channel request rate of User A
ξ_2	acceptance channel request rate of User B
ξ_3	acceptance channel request rate of User C
$1/\xi$	mean acceptance channel request time
ξ_H	total acceptance channel request rate of Users A and B
η	proportional of channel request rate
x	quantity of occupied channels
P_x	dropping probability of one-dimensional MCP
P_0	steady state probability of one-dimensional MCP
P_A	handover traffic dropping probability of User A
P_B	handover traffic dropping probability of User B
P_{BC}	total dropping probability of Users B and C
P_{TOTAL}	total dropping probability of Users A and B

ΨC	amount of adjustment channels
I	intensity of channel request
T_1	first channel threshold of two-dimensional MCP
T_2	second channel threshold of two-dimensional MCP
S	possible state space of two-dimensional MCP
m	occupied channels by new connection
n	occupied channels by handover traffic
$P_{0,0}$	initial steady state probability of two-dimensional MCP
$P_{m,n}$	joint steady state probability of two-dimensional MCP
U	system utilization

1 INTRODUCTION

1.1 Overview

With the rapid development of wireless mobile communication systems, there has been intense research on today's mobile communication networks and also on development efforts towards a new generation of telecommunication systems. The new system of the next generation network [1] must be able to provide higher Quality-of-Service (QoS), to support a wider range of services and to improve the system capacity. It should offer not only simple mobile voice and data services but also access to Internet Protocol (IP) based services. A common view of a next generation network is that all of the existing radio access technologies, along with any future ones, will coexist in a heterogeneous wireless access network environment. Heterogeneous access networks will dramatically increase the growth in development of a diverse range of high speed multimedia services, such as video on demand, mobile gaming, Web browsing, and e-commerce [2].

No single technology can provide ubiquitous coverage and continuously high QoS, mobile terminals will have to roam among the various access technologies to maintain network connectivity and user satisfaction [2]. Hence, the future generation wireless telecommunication network is expected to provide seamless intersystem roaming across heterogeneous wireless access networks.

Normally, an operator likes to maximizing the radio resource utilization and to accommodate as many users with their varied resource requirements as possible without increasing investment. Hence efficient user roaming and management of the limited radio resources become important for network stability and QoS provisioning. That is to say, the need for effective radio resource management (RRM) has become increasingly vital to the operation of networks.

Call admission control (CAC) is one of the most important components in RRM [2]. Its fundamental purpose is to judge whether radio resource can be assigned to the incoming channel request, according to the current situation of the system. Recently, CAC has been researched extensively as a very important part of RRM [3]. In order to implement the increasing demand for wireless access to packet-based services, and to make network roaming more seamless, there are a variety of CAC algorithms being proposed in [3]-[6].

In this thesis, a class-based CAC algorithm is presented that uses thresholds to classify the different priorities of users and prioritizes channel requests from higher priority users. After introducing the class-based CAC approach, an evolved method is proposed that combines the class-based CAC algorithm with Fuzzy Logic (FL) theory. FL theory gives a good solution to the development of the CAC scheme and is expected to be the most efficacious approach to describing the behaviour of the systems. The reason is that in the case of heterogeneous networks, FL not only provides a platform for handling uncertainty and imprecise knowledge, it also has the ability of deciding which system is the most appropriate for the requested wireless communication.

In addition, the Pre-emptive Resume (PR) theory is added to the class-based CAC algorithm to design a novel CAC algorithm. The algorithm is modelled mathematically by using a two-dimensional Markov chain analysis model. In order to get a comparative performance evaluation of the PR-based CAC and the class-based CAC algorithms, this thesis examines various parameters to measure the performance of the system, such as the dropping probability of handover traffic and the system utilization.

1.2 Aim and Objectives

The research work in this thesis is mainly aimed at investigating a new method for analysing and optimizing the CAC algorithm.

In this thesis, a novel dynamic class-based CAC will be modelled by the coalescence of the FL theory to investigate the system performance. Furthermore, a CAC combined with the PR principle is generated to develop a two-dimensional analysis model to evaluate the performance of the PR-based CAC algorithm.

The item aims to achieve the following research objectives:

- To develop a class-based CAC algorithm combined with FL theory;
- To introduce a one-dimensional MCP model for the performance analysis of the FL-based CAC algorithm;
- To develop a CAC approach coupled with PR theory;
- To build a two-dimensional Markov analytical model for the performance analysis of the PR-based CAC algorithm;
- To assess performances of the FL-based CAC and the PR-based CAC algorithms.

1.3 Contributions

The main contributions of this thesis are listed as follows:

- Present a class-based CAC algorithm, introduce channel threshold method and investigate how the thresholds perform in this algorithm;
- Build a Markov Chain Process (MCP) mathematical model for performance analysis of the class-based CAC algorithm in a heterogeneous wireless network;
- Develop a class-based CAC algorithm combined with FL theory to provide a platform for handling inaccurate parameters, offer dynamic thresholds and optimize the performance of the CAC approach;
- Build a two-dimensional Markov analytical model for the CAC algorithm coupled with PR theory subject to multiple-priority channel request classes;
- Prove that PR theory has an advantage in enhancing the system performance.

1.4 Organisation of the Thesis

After the introduction chapter, the remainder of the thesis is organized as follows:

Chapter 2 briefly presents the structure of the existing wireless telecommunication network, and gives a detailed overview of the key technologies and features of RRM of formal mobile network [3], especially for the two networks used in this thesis that is: the IEEE802.11 [7] based wireless local area network (WLAN) and the Universal Mobile Telecommunications System (UMTS) cellular network. Also, this chapter depicts the basic concepts and functionalities of RRM that are used in UMTS and WLAN, with emphasis on the CAC mechanism. This chapter also presents a detailed literature review of existed CAC algorithms within homogeneous networks.

Chapter 3 describes the motivation for development challenges and main features of the next generation wireless telecommunication system. This chapter specifies the architecture of a heterogeneous network (hybrid UMTS-WLAN network) used within this thesis with emphasis on the importance of analyzing the CAC algorithm for the integrated network. Moreover, a detailed related work of the existing CAC algorithms for the heterogeneous network is involved.

Chapter 4 proposes a class-based CAC algorithm and describes an analytical performance model for the class-based CAC by using Markov Chain Process (MCP) based on the environment of the integrated UMTS-WLAN network. A derived model is then proposed for the class-based CAC algorithm combining with FL theory, which adjusts dynamically the number of guard channels according to the current number of reserved channels and one important QoS parameter--dropping probability (DP). This FL-based CAC optimizes the effects of the threshold and also evaluates the performance of the entire system by analysing the numerical results.

Chapter 5 presents a stochastic analysis model of the CAC algorithm coupling with PR theory within the heterogeneous network. More specifically, this chapter investigates the new algorithm by utilizing a two-dimensional MCP analytical model. Finally, the numerical analysis and results are shown to present the performance comparison of the class-based CAC and the PR-based CAC algorithms.

Chapter 6 gives a summary that draws the conclusions about the work and also discusses ideas for future work.

2 RADIO RESOURCE MANAGEMENT IN WIRELESS NETWORKS

2.1 Introduction

This chapter gives an overview of the background for radio resource management (RRM) within wireless networks and 3rd generation (3G) cellular networks. Section 2.2 discusses the prevalent telecommunication wireless networks, including cellular networks and IEEE802.11/802.16 based wireless networks, etc. Section 2.3 and 2.4 introduce one of the most important elements within any wireless networks: the RRM mechanisms within UMTS and IEEE802.11 wireless networks respectively. In Section 2.5, the CAC algorithm, as the most important RRM mechanism, is described and some related works for the CAC algorithm in a homogeneous network are provided.

2.2 Customary Wireless Telecommunication Networks

Wireless networks are pervasively deployed, in areas such as police department, offices, universities, airports, shopping centers. Conventional wireless network utilizes radio frequency signals and Frequency-Hopping Spread Spectrum (FHSS) / Direct-Sequence Spread Spectrum (DSSS) technologies [8] to ensure a swift way for communication.

Wireless networks provide easy admittance to the network, also can send and share information over the world using satellites and other signals and communicate significant information speedily [7].

A certain series of overlapping types of wireless networks currently exists [9]:

- Wireless Personal Area Networks (WPANs)
- Wireless Local Area Network (WLAN)
- Wireless Mesh Network (WMN)
- Wireless Metropolitan Area Networks (WMAN)
- Wireless Wide Area Networks(WWAN)
- Mobile devices networks

The most common network types found are the IEEE 802.11/16 based WLANs (WLAN and WPAN/mesh networks) and cellular networks (2G/2.5G/3G). WLAN is widely developed because of its simplicity, low cost, flexibility, scalability, high coverage, coexistence and interoperability with other network infrastructures. In the case of cellular networks, the 3rd Generation Partnership Project (3GPP) has been responsible for the third generation (3G) system known as Universal Mobile Telecommunications System (UMTS) since 2000. It consists of a separate packet and circuit switch systems, moving towards a common IP backbone [1].

Radio Resource Management (RRM) is asserted as a vital issue for all the wireless networks, such as General packet radio service (GPRS) /UMTS, Wireless LANs and broadcasting systems, etc. The reason is that, for any communication system, the heart of the problem is possessing an efficient management for the limited radio resource. RRM is the system level control of co-channel interference and other radio transmission characteristics in wireless communication systems [10]. Its responsibility is improving the system spectral efficiency and the utilization of the air interface resources.

Efficient management of radio resources becomes a key factor in enhancing the network performance [11].

2.3 Overview of UMTS Radio Resource Management

Figure 2-1 shows the structure of an UMTS network. The radio access technology is employed by UMTS network is wideband code division multiple access (WCDMA).

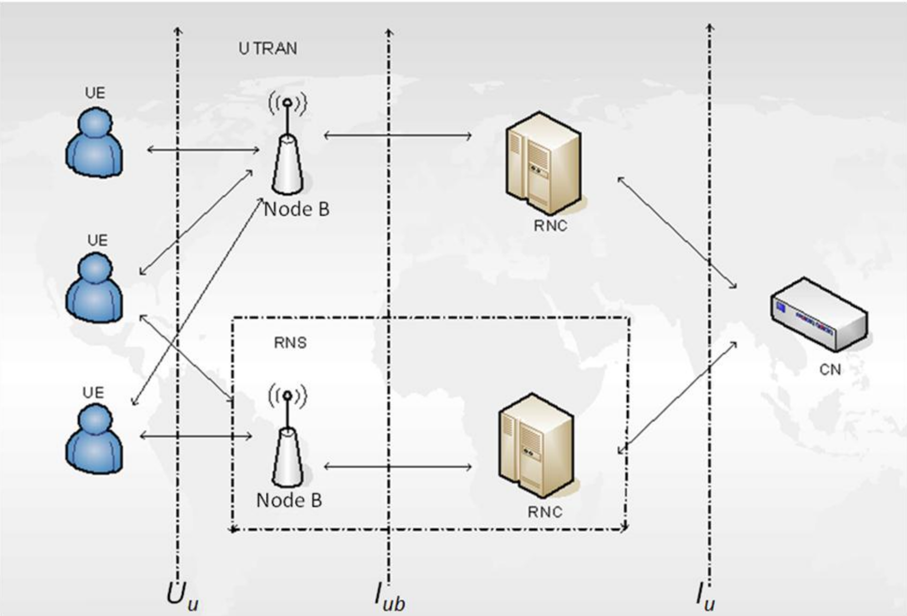

Figure 2-1: UMTS Structure

A complete UMTS network contains three parts: the User Equipment (UE), the Universal Terrestrial Radio Access Network (UTRAN) and the Core Network (CN):

- UE can be any device used to communicate by any user, e.g. a mobile phone, a laptop;
- UTRAN contains multiple Radio Network Controllers (RNCs) and plenty of base stations (Node Bs). UTRAN directly communicates with

user’s handset. a RNC and its corresponding Node Bs form a Radio Network Subsystem (RNS);

- CN is the main part of a telecommunication network; it proves diverse services to users.

The logical interface between UE and UTRAN is U_u; the interface between UTRAN and CN is called I_u. Inside of UTRAN, there is a logical interface between Node B and RNC, with the name of I_{ub}.

RNC is the switching and controlling element of the UTRAN. The RRM of UMTS is typically located centrally in the RNC and carried out by the RNC. The RRM is considered as the control equipment of Node Bs and involves strategies and algorithms for controlling parameters. The objective of the RRM mechanism is to provide the desired QoS level for different applications.

2.3.1 Functionality of UMTS RRM

The functionality of the RNC can be divided into two parts: UTRAN RRM and control functions:

- The RRM is a collection of algorithms used to guarantee the stability of the radio path and the QoS of a radio connection by the efficient sharing and managing of radio resources;
- The UTRAN control functions include all the functions that related to set up, maintenance and release of Radio Bearers (RBs), which exists in interface U_u, serves the radio interface transport and transfers user data between UE and UTRAN.

The basic logical architecture of the RNC is shown below in Figure 2-2:

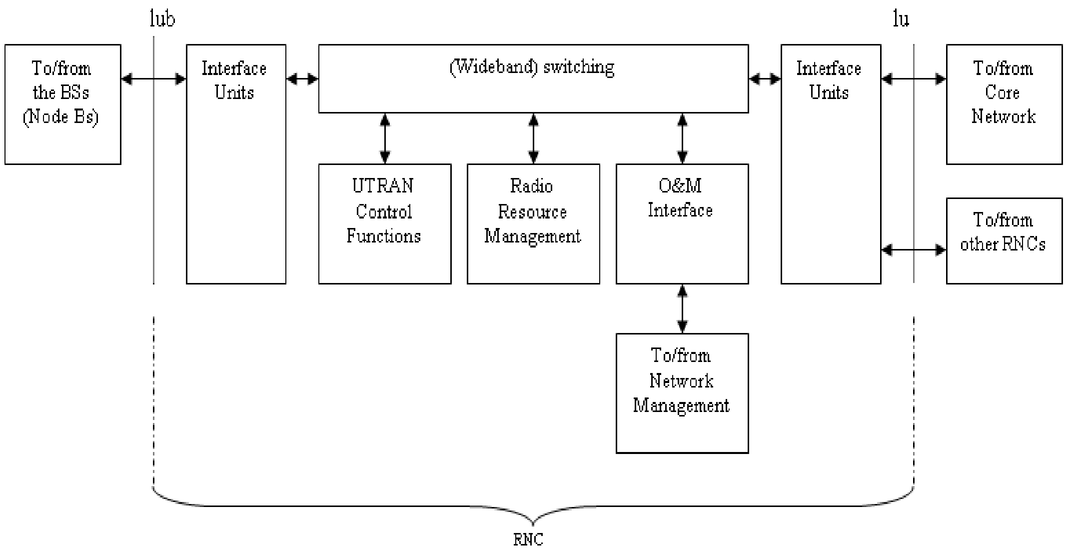

Figure 2-2: Architecture of RNC [12]

2.3.2 RRM Algorithms

RRM strategies and algorithms are responsible for controlling parameters such as transmit power, channel allocation, handover criteria, modulation scheme, error coding scheme, etc. RRM is expected to ensure the target coverage while maximizing and optimizing the radio network capacity and efficiency, and to utilize the limited radio spectrum resources and radio network infrastructure efficiently. To this end, RRM techniques will mainly manage a set of radio parameters, such as the serving cell, maximum bit rate, instantaneous bit rate, transmitted power etc. [13]

The family of the RRM algorithms includes power control, admission control, load control, packet scheduling and handover control algorithms:

- Power Control is the mechanism to control the transmit power in a communication system. It ensures that each user has the minimum transmitting power when reaching the Node B to achieve good performance. It guarantees that the interference levels between different users are kept at a minimum in the air interface whilst still providing the required QoS and maximizing the capacity of the system;

- Admission Control is executed for admitting connections in both uplink and downlink. It is responsible for supervising the fluctuations of the radio resource usage caused by the new user. In order to protect the resource consumption of existing users, admission control usually defines the threshold for interference level or cell load [14]. Once the threshold value crosses the border, admission control will operate to prevent overloading;
- Packet Scheduling is demanded for performing multi-tasking and multi-plexing. It involves three aspects: the throughput, the latency and the waiting time. The aim of operating packet scheduling is to increase the transmitting rate, guarantee the QoS and maximize the system throughput;
- Load Control is a measure mechanism to estimate whether the system is overloaded or stable. Load control mechanism is executed when the congestion happens. Load control decreases the interference level and ensures that the admission control and packets scheduler works well;
- Handover Control is used to handle the mobility of the UEs across cell boundaries and insure seamless roaming.

According to different functions, the RRM algorithms also can be classed into two parts:

- Network based functions: includes Call Admission Control (CAC), Load Control (LC), Packet Scheduler (PS) and Resource Manager (RM);
- Connection based functions: Handover Control (HC) and Power Control (PC).

The RRM functionality can be implemented in many different algorithms, and these impact the overall system efficiency [13]. Simultaneously, the entire system relies on the RRM mechanisms to coordinate and settle the contradictions, which occurs during the system operation. For instance, the communication system is expected to offer a stable QoS, a planned coverage area and a high capacity; whereas, increased capacity induces coverage or/and also a QoS reduction. Under these circumstances, a good RRM implementation will be absolutely essential.

In this thesis, the CAC issue is especially focused. As one of the primary element of the RRM, the effectiveness of the CAC algorithm has the direct effect on the quality and the service provided by the telecommunication network.

2.4 Overview of WLAN Radio Resource Management

The RRM within a WLAN is quite similar to that of a cellular network. The CAC entity is also an essential mechanism of WLAN RRM strategy, which is responsible for authorization, resource availability monitoring, radio resource negotiation and assignment. It is located at access points (AP) of WLAN, according to the standard procedure defined in [15] and required to fulfill the demanded QoS requirements. The objective is to utilize the limited radio spectrum resources and radio network infrastructure as efficiently as possible [10].

The IEEE 802.11 standard specifies two medium access control (MAC) mechanisms:

- The mandatory distributed coordination function (DCF), which is a contention-based access control scheme targeted at delivering classic data services [16];
- The optional point coordination function (PCF), which is a contention-free access control scheme targeted for time-bounded services [17].

However, DCF and PCF cannot guarantee the requested QoS for real-time services of multimedia applications. Therefore, the IEEE 802.11 working group (WG) introduced a compound of DCF and PCF, with the name of the hybrid coordination function (HCF) [16], by combining the functions of both DCF and PCF to enhance QoS support and data transmission.

HCF includes two medium access mechanisms: contention-based channel access, which is referred to as enhanced distributed channel access (EDCA), and controlled channel access, which is defined as HCF controlled channel access (HCCA) [16]. The relationship between EDCA and HCCA is complementary: EDCA provides a better performance in light traffic load; while HCCA portraits strengths under the conditions of heavy traffic. The admission control issue of HCCA is simpler. Vis-à-vis, most of the researches are working on the development of the EDCA mechanism.

The EDCA mechanism has two admission control categories [16]: the measurement-based admission control scheme and the model-based admission control scheme.

In the measurement-based admission control scheme, the threshold-based admission control strategy presents the theory of classifying different types of traffic by using thresholds. The threshold-based admission control strategy is quite easy to be constructed, but it is very difficult to set the threshold values because the system will stop accepting data when radio resource is saturated and resume the data transmission when resources are available. It is hard to get the precise instantaneous QoS metrics.

In the model-based admission control scheme, the Markov chain model-based admission control strategy introduces the analytical model of Markov chain process (MCP) [16].

The measurement-based admission control scheme is operated more based on the practical metrics of wireless systems. On the contrary, the model-based admission control scheme does well in conceptual assumptions and theoretical analysis to optimize the entire system. Thus, it seems that an ideal admission control strategy for WLAN should be a coalition combining these two approaches.

2.5 Call Admission Control Algorithm in UMTS Network

A Call Admission Control (CAC) scheme is a network QoS procedure and implemented between network edges and core to control the traffic entering the network [13]. It is responsible deciding whether to accept or reject a new service request to the system. It aims to ensure the quality of existing services by predicting the load of the cell before new traffic is admitted, thereby deciding if the cell can support the new request or not.

Its goal is to admit a higher number of service requests while at the same time guaranteeing the required QoS for every active connection [14]. Normally, the estimation of CAC is based on Interference or Signal to Interference Ratio (SIR) estimates and threshold comparisons [12].

Generally, the inherent CAC strategies can be divided into two types: wideband power-based admission control strategy and throughput-based admission control strategy.

- Wideband power-based admission control strategy: in uplink direction, when a new user is asking for admission, if the total interference level is lower than the threshold value, then the user will be admitted; adversely, reject the new user. In the downlink direction, CAC is implemented by checking the consumption of transmission power, which includes the original transmission power, the transmission power of the new user and the additional interference power brought by the existing UEs in the system. When the new total downlink transmission power is lower than the maximum value, the new UE will be accepted, otherwise, it is rejected;
- Throughput-based admission control strategy: similar to the wideband power-based admission control strategy, it is based on estimating the load factor. If the present load factor (after the admittance of the new connection) is still lower than the threshold load factor, the system can accept the new user; otherwise, reject it.

On the basis of wideband power- and throughput-based admission control strategies, the author in [18] derived interference-based, capacity-based, handover priority-based and QoS-based admission control strategies from these two essential strategies. Handover priority-based and QoS-based admission control strategies will be treated as the basic theory and further investigated in Chapter 4 and 5.

Handover priority-based strategy considers handover traffic more important than new connection services, and puts bounds to provide more acceptance for handover traffic; QoS-based strategy focuses on different classes of traffic and offers a negotiated QoS.

Most of existed CAC algorithms were conceived primarily concentrating on the improvement for homogeneous cellular or wireless networks [19].

The developing of the CAC algorithm has gone through two stages:

- First Stage: in the earliest literature [20]-[22], the new connection service and the handover traffic are considered as identical. Two representatives for this kind of strategy are Queuing Priority Schemes and Fully Shared Scheme (FSS).

  a) Queuing Priority Scheme of [20] and [21] admits all traffic as long as channels are free. When one kind of service is queued, the other one will be blocked and vice versa.

  b) In [22], similarly to Queuing Priority Schemes, FSS allows handover traffics and new connection request services to share all available radio resource channels.

  These two strategies sacrifice the quality of handover traffic to reduce new connection traffic blocking and increase channel utilization.

- Second Stage: a notion of “reservation” is introduced.

  a) In [23], Dynamic Channel Reservation Scheme (DCRS) assigns reserved channels to handover services; meanwhile it also allows these guard channels to be occupied by new connection services according to the request probability to increased channel utilization [24]. It tries to provide a stable performance and a certain low level of the blocking probability for new connection services.

b) In [25], Dual Threshold Bandwidth Reservation (DTBR) employs two thresholds to dominate new connection request for voice traffic and data traffic that involves both handover and new connection request data traffic [19].This scheme accomplishes the maximum efficiency for handover voice call and maintains the other relative call blocking probability [26].

The CAC approaches for homogeneous networks lay the foundations of exploiting a new CAC algorithm for heterogeneous telecommunication network.

2.6 Summary

This chapter expatiates on the subject of the family of the well-known wireless telecommunication network, especially accentuating the UMTS network and WLAN. The chapter also introduces the radio resource management (RRM), which includes the basic principles, functionalities and algorithms. Among these algorithms, most researchers seem to attach more importance to the issue of the medium admission control scheme. Hence, this chapter specifies the CAC of RRM for both UMTS and WLAN networks. As the primary element of RRM, the CAC algorithm will be the focal point of the work of the next generation wireless networks. Hence, Chapter 3 will not only introduce the next generation telecommunication network but also present the existing CAC algorithms for the next generation system as the background research for the CAC issue.

Following Chapter 3, the evolution of the CAC algorithm for the next generation wireless network will be proposed in Chapter 4 and 5 and its predominance will be presented during the performance investigation.

3 NEXT GENERATION TELECOMMUNICATION SYSTEM

3.1 Introduction

The previous chapter presents a brief overview of RRM concepts in 3G cellular networks and IEEE 802.11 based WLANs. It also reviews the basic concepts and functionalities of the CAC algorithm for each network. All these knowledge can be considered as the background knowledge of operating the next generation system.

Generally, cellular systems offer large coverage area connectivity, but with low bandwidth, limited data traffic and expensive service price. Correspondingly, wireless data networks such as WLAN or Wi-Fi offer broadband access, but only within a limited physical range [27]. Actually, some mobile network operators and internet service providers have launched broadband services for improving the performance of current telecommunication networks:

- High Speed Packet Access (HSPA): it is the improved 3G protocol which contains High Speed Downlink Packet Access (HSDPA) and High Speed Uplink Packet Access (HSUPA) [28]. HSPA is expected to decrease the latency and the production cost compared to WCDMA protocol. HSPA increases peak data rates up to 14 Mbps in the downlink direction and 5.76 Mbps in the uplink direction. Moreover, HSPA enhances the system capacity up to five times more system capacity in the downlink and up to twice as much system capacity in the uplink compared to original WCDMA protocols [28].

- After HSPA, 3GPP released a wireless broadband standard for the WCDMA specification, with the name of the evolved HSPA (also known as: HSPA+). The evolved HSPA provides theoretical data rates up to 84 Mbps in the downlink and 22 Mbps in the uplink (per 5 MHz carrier), but the real speeds will be lower [28].
- Further development for 4G technologies are the Long Term Evolution (LTE) [28] and the WiMAX [28]. In 2009, the ITU-R organization specified the International Mobile Telecommunications Advanced (IMT-Advanced) requirements for 4G standards, setting peak speed requirements for 4G service at 100 Mbit/s for high mobility communication and 1 Gbit/s for low mobility communication [29]. Precisely speaking, current LTE and WiMAX technologies are considered pre-4G because they do not achieve the requested IMT-Advanced speeds of 1 Gbps for stable facility and 100 Mbps for moving device; but they are ambiguously treated as "4G" standards [29].

Hence, it is inevitable that is a tendency to integrate the transmission of multimedia applications and services over various networks into a heterogeneous wireless network [30]. Currently, some companies have already begun to exploit the product that is capable of accessing the hybrid wireless environment. For example, the O2 mobile broadband service allows users to access hotspots although the switch between Wi-Fi and cellular is not seamless; BT has collaborated closely with FON to build BT openzone, which provides BT Total Service that is part of the world's largest Wi-Fi community; Orange Unique service also offers Wi-Fi & cellular systems. It allows people to have one handset that will switch between an Orange wireless router connection and the Orange mobile network [31]. The service will not switch networks in the process of a call. This is preferable to avoid lots of switching pauses which might occur by switching between networks.

With the increasing demand for mobile multimedia service, the next generation wireless networks are expected to eventually combine multiple radio technologies [32], provide high throughput IP-connectivity to users and achieve seamless roaming across heterogeneous radio access technologies (RATs). Obviously, the integrated technology requires a high speed, low cost data services and any-time, anywhere connection. Moreover, another advantage of the increasing tendency to base the core network round a common IP platform makes the cooperation between different service providers simple. The multi-technology terminal allows the user to benefit from various technologies, to choose different service providers and to vary the type of service. In addition, it provides a great flexibility network access for mobile users.

3.2 Challenges

The ideal next generation wireless system will be a fully IP-based integrated system, extend the capacity of the 3G network and 4G will be predominant. It aims to elevate performances to meet the requirements of future high-performance applications like multimedia, full-motion video and wireless teleconferencing. The general idea of constructing the next generation wireless network is to utilize an IP backbone to transmit all the converged information and services (voice, data and video) by encapsulating these into packets. That facilitates use of IP core networks. A wider bandwidth hybrid networks utilizing both WLAN and wide area network (WAN) design meets the subscriber requirements of global mobility and service portability.

The next generation wireless network also can be considered as an evolution of 3G system, thus, it may face various challenges:

- *Packet Transmission Rate*: the next generation wireless network is an all IP packet transmission and is supposed to offer a higher data rate (100 Mbit/s for mobility client and 1 Gbit/s for stationary client), with premium quality and security, and low power;
- *Coverage*: it ought to accomplish seamless connectivity to ensure global roaming across multiple networks, which requires smooth handoff and low-latency data transmission across heterogeneous overlapped networks;
- *Diverse Radio Environment*: it is expected that multiple access technologies will be integrated. It performs convergence and interoperability with existing wireless standards [11];
- *Services*: it is capable of providing high QoS for multimedia applications e.g. multimedia messaging service, high speed data, High-definition television (HDTV) video, mobile TV, etc;
- *Users*: the next generation wireless network has a higher network capacity, enabling more simultaneous users per cell and makes rational use of radio resources to meet the minimal requirements of all the 4G enabled users;
- *Business Benefit*: the feature of the all IP packet transmission could save money and improve security. Besides, the faster services wider

bandwidth and throughput enhance the performance and the reliability of the network.

3.3 Common Architecture of Heterogeneous Network

In the future, wireless communication is going to move towards a universal communication network that uses a very flexible networking infrastructure and dynamically adapts to changing requirements [33].

Nowadays, the evolution of telecommunication system from 3G to the next generation network is developing towards an environment that integrates hybrid wireless networks containing UMTS, WLANs, Worldwide Interoperability for Microwave Access (WiMAX), Personal Area Networking (Bluetooth), Digital Broadcasting (video, audio, DVB, DAB), Home Entertainment Wireless Networking, Multi-Modal Services and satellite networks[19].

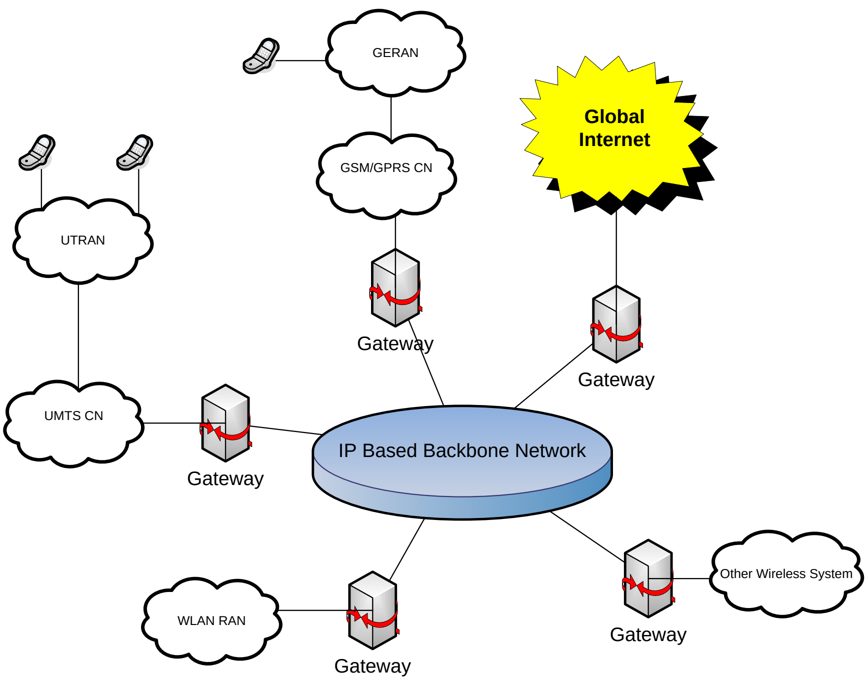

Figure 3-1: Heterogeneous Networks [34]

Hence, the future generation mobile communication system is targeted to support integration and co-existence of multiple radio RATs in a common composite radio environment [35]. Of course, cellular networks still is and will continue to be the primary component in the current and next generation telecommunication networks [19].

3.3.1 Features

Due to wireless access technologies becoming increasingly complex, the existing communication networks have modified into a heterogeneous wireless network comprising converged wireless access technologies and diverse radio interfaces.

The targets of the next generation system are to support intelligent coexistence of diverse RATs, implement joint scheduling and essentially exploit increased system capacity [9].

Hence, the operating pattern of the CAC for the next generation system has been converted from unidirectional model (UE—Specified RAT) to multidirectional model (UE—Multi RAT).

3.3.2 UMTS-WLAN Hybrid Network

Currently, the most prominent achievement for wireless telecom system is the coalescence of the UMTS cellular network and IEEE 802.11 based WLANs. WLANs accomplish a great embedding of hot spots within the coverage of cellular networks, for ubiquitous high-data-rate wireless coverage [36]. In this section, a simple hybrid UMTS-WLAN network is modeled in Figure 3-2 .

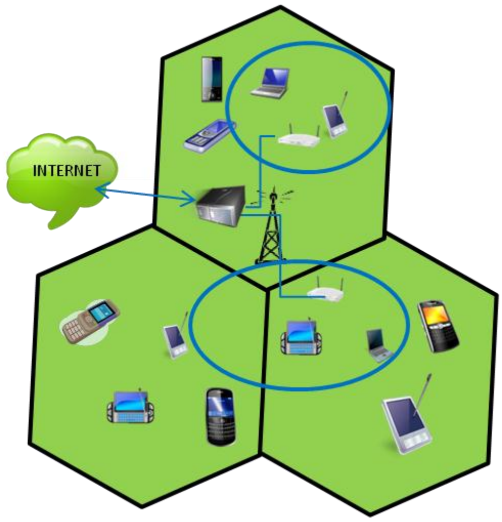

Figure 3-2: Hybrid UMTS-WLAN Network

In the real wireless telecommunication system, the number of customers is erratic because of user's mobility. It makes the assignment of available radio resources become complicated even with resource reuse strategies.

3.3.3 CAC Functional Requirement for UMTS-WLAN Network

Increasing user mobility makes subscribers shift among diverse wireless networks constantly while a service is processing [19]. Thus an ongoing service may have to be handed over to other networks [38]. This results in an admission request to enter the target network to be made for the ongoing service [38]. Meanwhile, new connection requests issued by the intrinsic users are coming into the target network [19].

Both the handover traffic and the new connection will scramble for available radio resource of the target network [13]. However, the limited scarce radio resource and the dynamic large number of user requests may cause the handover traffic being dropped and/or the new connection request being blocked.

It is apparent that an increasing of subscriber mobility leads to the predicament of scarcity limited radio resource allocation and QoS degradation [39]. Hence, QoS provision is an increasingly important task in next generation integrated networks [40].

In order to guarantee the QoS in progress, the target network is required to provide a ubiquitous coverage and ensure good QoS for customers [11]. Efficient management of radio resources becomes a key factor in enhancing the network performance [20]. Hence, it is necessary for the target network to guarantee the seamless transfer, maximize the admission for those handover services and minimize the amount of dropping events [19].

One of the key elements in providing QoS guarantees is an effective CAC policy, which not only ensures that the network meets the QoS requirements for new traffic but also guarantees that the QoS of the existing traffic does not deteriorate [32].

The functionality of CAC is to limit the number of users and controlling their admission requirements to prevent network congestion during the transportation of the traffic within the access and core networks. The CAC algorithm of the next generation wireless network aims to guarantee the seamless transfer, maximize the admission for various services and balance the resource allocation for different services in order to meet the desired QoS requirements [20].

3.3.4 Call Admission Control in Heterogeneous Networks

With the combination of various wireless networks, the CAC mechanism designed for the next generation heterogeneous wireless network is regarded as the most representative conception for access control techniques [19].

The first method known as the Guard Channel Scheme (GCS) [41] reserves a number of channels for general handover traffic to show its priority and implements low dropping probability for handover traffic. However, fixed guard channels cause a high blocking probability of the new connection service and a low resource utilization [42].

The author in [43] proposed a CAC scheme for voice and data traffic in integrated cellular and WLAN networks. This CAC scheme defines voice traffic to have higher priority than data traffic. It transmits voice traffic through the cellular network and data through the WLAN.

Moreover, there are several improved strategies for the CAC algorithm, which are proposed based on the fundamental GCS method. The scheme proposed in [44] improves the GCS scheme by combining it with a First-In-First-Out (FIFO) 1-dimensional stochastic process. The scheme in [45] used a high-order Markov chain to analyze the performance of the CAC and tend to increase the utilization of radio resource. Progressively, an optimal CAC mechanism in [46] is known as the GUard-channel-based Incremental and Dynamic Optimization (GUIDO), which is based on the Markov decision process (MDP) and sensitivity analysis (SA) techniques. With the alteration of traffic conditions, GUIDO is developed for multiple traffic classes to degrade the effort of unnecessary re-computation [46].

Based on all the proposed CAC algorithms being motioned above, it is noticeable that the trend of the developing CAC algorithm for the next generation network accentuates the aspect of “precedence” when studying the CAC algorithm for the heterogeneous network. Therefore, the concept of “precedence” will be taken into account in the following chapters for developing a novel CAC algorithm.

3.4 Summary

This chapter outlines the basic ideology of the next generation telecommunication system and presumable challenges that may be come up against. Furthermore, this chapter sketches the major structure of the heterogeneous network, which can be considered as the background environment for investigating new CAC algorithms. As one of the most important and indispensable issues in RRM, the research of developing a novel CAC algorithm is going to be detailed discussed in the next chapter.

4 THE EVOLUTION OF CALL ADMISSION CONTROL ALGORITHM FOR THE NEXT GENERATION WIRELESS NETWORKS

4.1 Introduction

This chapter presents two CAC schemes for the next generation telecommunication networks. Firstly, Section 4.2 is going to present a class-based CAC algorithm based on existing strategies for the integrated UMTS-WLAN network; and then, in Section 4.3, an evolution version of the CAC algorithm will be derived from the class-based approach by combining Fuzzy Logic theory. Both of these two schemes sort users into different classes and operate a one-dimensional MCP analysis method to analyze the system performance [40].

4.2 Class-Based Call Admission Control Algorithm

In this section, a CAC algorithm based resource allocation policy for heterogeneous network is presented, taking into account user classes [47] and channel allocation.

In a heterogeneous network, owing to the coexistence of multiple-RATs and user mobility, an ongoing service may have to be handed over to other networks [35]. In order to guarantee the quality for service in progress, the target network is required to provide a ubiquitous coverage and ensure good QoS for customers [38].

4.2.1 Analytical Model

As been mentioned in Chapter 3, a common style of hybrid network comprised of a UMTS cellular network and a WLAN network [48]. The simplest model for integrated network embraces two WLAN networks and a single UMTS cell, which is shown in Figure 4-1. The APs of the two WLANs embed into UMTS cell; and the UMTS network wreathes the whole coverage area of two WLANs.

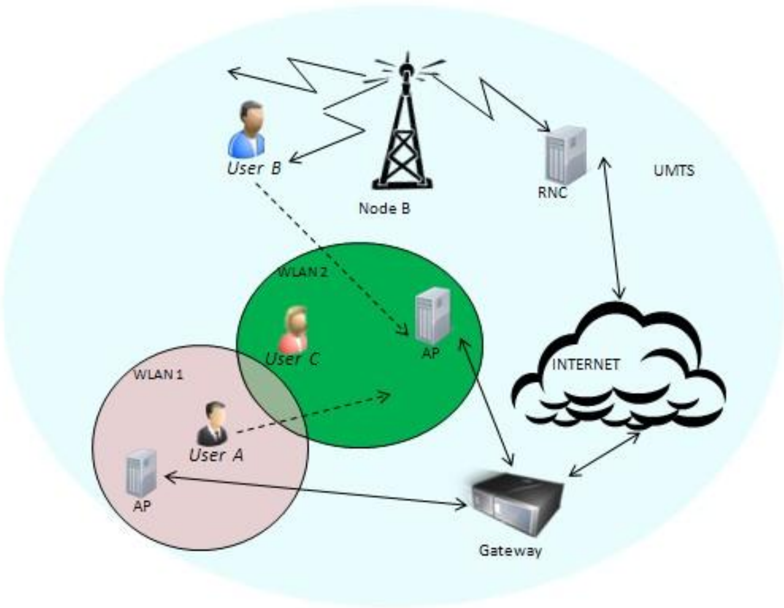

Figure 4-1: Integrated UMTS-WLAN Network [19]

The handover procedure takes place when user switches between UMTS and WLANs; meanwhile, new connection requests are originated by the destination wireless network [19]. Thus, two categories of services emerge: the handover traffic and the new connection. From the user's point of view, comparing two services, subscribers prefer to give higher priority to handover traffic [49]. The reason is that handover may bring service break off, and it is more annoying to have a call abruptly terminated in the duration of the connection than being blocked occasionally on a new connection attempt [50].

In this integrated network, three classes of users are defined: Users A, B and C:

- User A initially allocates in and connected with WLAN 1. It is going to enter and establish a new connection with WLAN 2. If the destination WLAN 2 does not have available resource, then User A's connection will be terminated;
- User B initially connects with the UMTS network and moves into WLAN 2's coverage area. Therefore it tries to ask for radio resource from WLAN 2. If the resource request is rejected, User B also can continue to use the UMTS network for the ongoing service;
- User C is assumed as a stable node within WLAN 2 coverage area and does not shift among dissimilar RATs. This class of user will establish a new connection within WLAN 2 only.

Users A and B generate handover traffic. User C sets up new connection services. Generally speaking, customers prefer to give a higher priority to handover traffic of existing connections rather than new connections [40]. It is more annoying to have a call abruptly terminated in the duration of the connection than being blocked occasionally on a new connection attempt [49].

On the other hand, User A should bear a higher precedence than User B. The reason is that User A is transferring an ongoing service to another wireless network via a hard handover [47] as it is moving out the coverage of its initial network WLAN 1 which expects to release the radio resource as soon as possible. This phenomenon might lead to a continuous service disruption; while User B has the capability of keeping a continuous serving from the UMTS network, even if WLAN 2 rejects to permit the channel request from User B [40]. Thus, User A is claiming precedence over User B for avoiding service termination and has the highest priority, User B has the intermediate priority and User C is treated as the lowest priority.

Using this environment, the next section is going to investigate a class-based CAC by utilizing a MCP model, which reflects the priority of every arrival admission request using a mathematical analytic method and analyzes the system performance by evaluating the traffic dropping probability.

4.2.2 Performance Analysis

Assuming the amount of the entire radio channel in WLAN 2 is equal to K; the amount of occupied channel is given by K_U. This CAC algorithm stipulates two channel thresholds: C_L and C_H ($C_L < C_H$).

The thresholds C_H and C_L, in Figure 4-2, act as the arbitrators, who are in charge of the admission request of Users B and C.

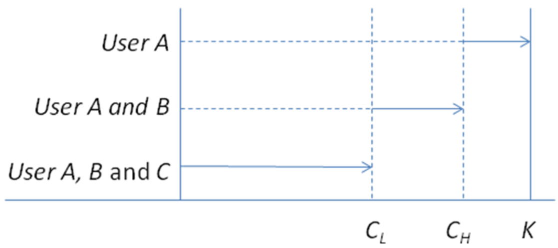

Figure 4-2: Channel Allocation Diagram for Two-Threshold Scheme

On an arrival of a new channel request, may be issued by User A, B or C, four circumstances may happen:

1) If the total resource of the target network is already occupied, any request from any user will be rejected by WLAN 2;

2) If K_U < C_L, WLAN 2 will admit any channel request, no matter which kind of user initiates the request;

3) If $C_L \le K_U < C_H$, WLAN 2 will just permit the radio resource demand which are originated by Users A and B;

4) If $C_H \le K_U < C$, WLAN 2 will only accept the resource request from User A; thus rejecting any requests from Users B and C.

The resource request rates of Users A, B and C are defined as λ_1, λ_2 and λ_3 respectively, which act in accordance with Poisson arrival process. Assuming that ξ_1, ξ_2 and ξ_3 represent the acceptance channel request rates of Users A, B and C, and $1/\xi$ is the mean acceptance request time which obey a negative exponential distribution.

According to this theory, this hierarchy can be annotated in a one-dimensional Markov chain, which is described in Figure 4-3:

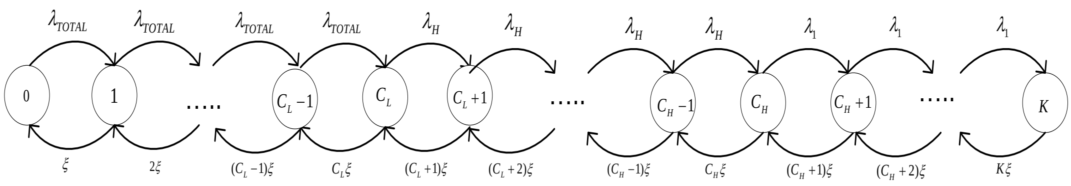

Figure 4-3: State Transition Diagram [19]

where $\lambda_{TOTAL}=\lambda_1+\lambda_2+\lambda_3$, $\lambda_H=\lambda_1+\lambda_2$.

The Markov chain visualizes the performance in the form of steady-state probability P_x, so called dropping probability. The formula for each state is list:

$$P_x = P_0 \frac{(\lambda_1+\lambda_2+\lambda_3)^x}{x!\xi^x} \text{, where } 0 < x \le C_L \tag{4-1}$$

$$P_x = P_0 \frac{(\lambda_1+\lambda_2+\lambda_3)^{C_L} \cdot (\lambda_1+\lambda_2)^{x-C_L}}{x!\xi^x} \text{, where } C_L < x \le C_H \tag{4-2}$$

$$P_x = P_0 \frac{(\lambda_1+\lambda_2+\lambda_3)^{C_L} \cdot (\lambda_1+\lambda_2)^{C_H-C_L} \cdot \lambda_1^{x-C_H}}{x!\xi^x}$$, where $C_H < x \le K$ (4-3)

P_0 is the steady-state probability of the system being idle [50]. x stands for the quantity of occupied channels and xth state transition [19]. On the basis of normalization equation $\sum_{x=0}^{K} P_x = 1$ and the steady state probability equation, the expression of P_0 can be obtained:

$$P_0 = [\sum_{x=0}^{C_L} \frac{(\lambda_1+\lambda_2+\lambda_3)^x}{x!\xi^x} + \sum_{x=C_L+1}^{C_H} \frac{(\lambda_1+\lambda_2+\lambda_3)^{C_L} \cdot (\lambda_1+\lambda_2)^{x-C_L}}{x!\xi^x} + \sum_{x=C_H+1}^{K} \frac{(\lambda_1+\lambda_2+\lambda_3)^{C_L} \cdot (\lambda_1+\lambda_2)^{C_H-C_L} \cdot \lambda_1^{x-C_H}}{x!\xi^x}]^{-1} \quad (4\text{-}4)$$

When the entire resource is already taken up, the channel requests from User A will be declined. Hence, the dropping probability of User A's handover traffic can be gained from steady state probability equation P_x, when x is equal to K:

$$P_A = P_0 \frac{(\lambda_1+\lambda_2+\lambda_3)^{C_L} \cdot (\lambda_1+\lambda_2)^{C_H-C_L} \cdot \lambda_1^{K-C_H}}{K!\xi^K} \quad (4\text{-}5)$$

As being specified, as long as the used channels are equal to or greater than C_H, resource requests of Users B and C are firmly refused. Thus, the total dropping probability of Users B and C is denoted as:

$$P_{BC} = \sum_{x=C_H+1}^{K} P_x = \sum_{x=C_H+1}^{K} P_0 \frac{(\lambda_1+\lambda_2+\lambda_3)^{C_L} \cdot (\lambda_1+\lambda_2)^{C_H-C_L} \cdot \lambda_1^{x-C_H}}{x!\xi^x} \quad (4\text{-}6)$$

Let η be the proportional of the channel request rate of User B to that of User C, hence, the handover traffic dropping probability of User B can be written as:

$$P_B = \eta \cdot P_{BC} \quad (4\text{-}7)$$

Therefore, the total handover dropping likelihood P_{TOTAL} is the sum of P_A and P_B. Normally, the system utilization is profiled as the ratio of the used channel to the whole channel capacity [51]; therefore the resource utilization of the class-based CAC scheme is characteristic of:

$$U = \frac{\sum_{x=1}^{K} xP_x}{K} \quad (4\text{-}8)$$

where U is the utilization of the whole system.

In order to examine the performance of the proposed two-threshold class-based CAC algorithm, a one-threshold CAC approach is used for comparison. The one-threshold CAC approach is the Guard Channel Scheme (GCS), which is mentioned in Section 3.3.4.

The one-threshold CAC approach is considered as a special case of the two-threshold CAC approach. In the two-threshold scheme, let C_L move to the value of C_H, defines the new threshold for as C_T, shown in Figure 4-4, and then, Users B and C have the same priority.

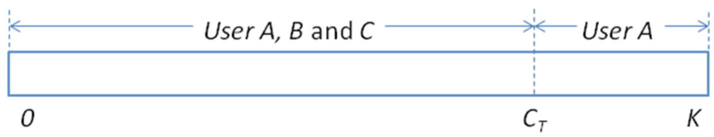

Figure 4-4: Channel Allocation Diagram for One-Threshold Scheme

In this case, all other parameters have same definition as in the proposed two-threshold class-based algorithm, once a new channel request arrives,

- If the used channels are less than C_T, any channel request from any user will be accepted;
- If the amount of used resource is equal to or greater than C_T, the system will only admit channel requests from User A, even though

Users B and C also send new channel requests. In other words, as User A has higher precedence than of the other users, the handover traffic from User A will be accepted as long as there is an available channel;

- If all available channels K are occupied, the one-threshold system will drop any channel request, even from User A.

The steady state probability P_x of the one-threshold scheme is defined as:

$$P_x = P_0 \frac{(\lambda_1 + \lambda_2 + \lambda_3)^x}{x!\xi^x}, \text{ where } 0 < x \leq C_T \tag{4-9}$$

$$P_x = P_0 \frac{(\lambda_1 + \lambda_2 + \lambda_3)^{C_T} \cdot \lambda_1^{x-C_T}}{x!\xi^x}, \text{ where } C_T < x \leq K \tag{4-10}$$

Basing on the normalization equation $\sum_{x=0}^{K} P_x = 1$, the expression of P_0 is obtained:

$$P_0 = [\sum_{x=0}^{C_T} \frac{(\lambda_1 + \lambda_2 + \lambda_3)^x}{x!\xi^x} + \sum_{x=C_T+1}^{K} \frac{(\lambda_1 + \lambda_2 + \lambda_3)^{C_T} \cdot \lambda_1^{x-C_T}}{x!\xi^x}]^{-1} \tag{4-11}$$

The dropping probability of User A in the one-threshold scheme is $P_{A,}$ traffic is dropped when all of radio channels are full, and thus, P_A is given by:

$$P_A = P_0 \frac{(\lambda_1 + \lambda_2 + \lambda_3)^{C_T} \cdot \lambda_1^{K-C_T}}{K!\xi^K} \tag{4-12}$$

Due to the constraint of the threshold C_T, Users B and C's channel requests will be rejected, since the existing connections occupy C_T or more channels. So, the dropping probability P_B of User B's handover traffic is defined as:

$$P_B = \eta \sum_{x=C_T+1}^{K} P_0 \frac{(\lambda_1 + \lambda_2 + \lambda_3)^{C_T} \cdot \lambda_1^{x-C_T}}{x!\xi^x} \tag{4-13}$$

The entire handover traffic dropping probability of the one-threshold scheme is the summation of P_A and P_B. The utilization formula of this scheme has the same function as equation 4-8.

4.2.3 Numerical Results

Based on the mathematical analysis of Markov chain model, this section presents the analytical results and the performance comparison of the CAC algorithms with one-threshold and two-threshold by using MATLAB software.

Assuming parameters of this analytical model are set as: *K=50 channels*, λ_1= *0.25~0.9 channels/s*, λ_2 = *0.25~0.9 channels/s*, λ_3= *0.8~2.0 channels/s*, $1/\xi=1/\xi_1=1/\xi_2=1/\xi_3=150s$.

In Section 4.2.2, the class-base CAC algorithms with one-threshold and two-threshold are presented. In order to embody the performance brought by "threshold", this thesis will exhibit the CAC algorithm without any threshold: it is the original radio resource sharing, which allows any classes of user to share the entire available resource equally.

Figure 4-5 plots the dropping probability curves of the CAC algorithms without any threshold and with one-threshold. The horizontal axis stands for the channel request rate, while the vertical axis represents the dropping probability of handover traffic.

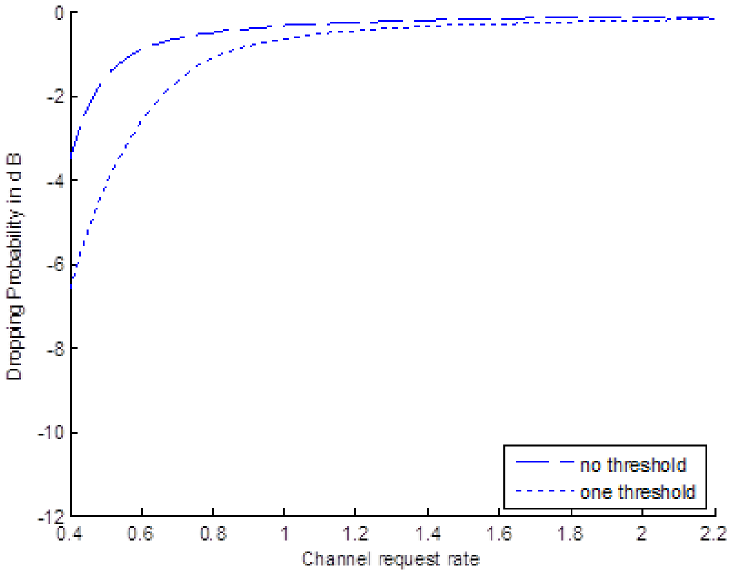

Figure 4-5: Dropping Probabilities of No-Threshold and One-Threshold Schemes [19]

It is straightforward that the increasing channel request rate gives an increase in dropping probability. The CAC without threshold allows handover traffic and new connection to share the available channel equally; the CAC algorithm with one-threshold will terminate the admission of the new connection and force User C's channel requests to wait until the resource is released, when the available channels reach the critical value. Hence, the whole handover traffic dropping probability of the CAC algorithm without threshold is higher than that of one threshold method.

Figure 4-6 shows User A's handover traffic dropping likelihoods within the one-threshold and the two-threshold scheme versus the channel request rate.

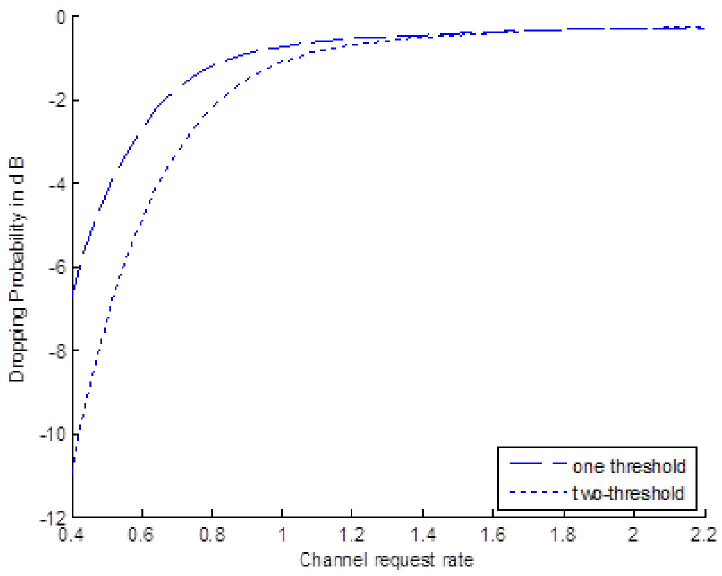

Figure 4-6: User A's Dropping Probabilities in One-Threshold and Two-Threshold Schemes [19]

It appears that the two-threshold scheme generates a lower handover dropping probability than the one-threshold scheme. The two-threshold class-based CAC algorithm not only restricts the channel requests from Users B and C by using the thresholds C_H and C_L, but also offers dual guard and more radio resource assignment for User A.

From the view of handover service, the numerical results of these two figures summarize that the two-channel threshold scheme performs much better than the one threshold and the no threshold schemes in the matter of cutting down the handover services dropping probability and improving the quality of handover services.

4.3 Fuzzy Logic-Based Call Admission Control Algorithm

The CAC algorithm presented in Section 4.2 assigns and controls radio resource channels based on the differentiation of the user's priority, and analyses the performance in a mathematical way for the integrated UMTS-WLAN environment.

Nevertheless, the CAC of the real mobile communication system is based on diversified real-time measurements, such as dynamic QoS requirements and varying channel conditions, etc. If the position of the threshold is fixed, that might lead to radio resource waste, so the ability to dynamically adjust the thresholds could be an important addition.

It is difficult to address all the technical challenges of CAC, especially the inaccurate appraisal and the incomplete statistical representation of the input traffic. Fuzzy Logic (FL) provides an approximate, but effective means of describing the behaviour of the systems that are too complex and not easy to tackle mathematically [49].

In the last few years, several FL-CAC algorithms have been presented for homogeneous networks. The author in [49] specifies the performances of the FL-based CAC for WCDMA system; the FL channel allocation method for Personal Communications Service (PCS) is described in [52]; a FL-AC scheme for data and voice services are developed for GPRS-EGPRS network in [53]; In [54], a FL-CAC is introduced for UMTS cellular networks based on the measurements of the pilot signal power. Furthermore, a FL partition-based CAC is proposed for Mobile WiMAX in [55].

Even the work mentioned above are related to homogeneous networks, but the application of FL becomes highly skillful to heterogeneous networks. Therefore, in this section, under the integrated environment of Figure 4-1, a class-based CAC algorithm combined with a FL policy will be implemented for the heterogeneous network.

The aims of using FL are to offer dynamic thresholds and to keep a low dropping probability. FL theory has the ability to cope with imprecise problems and provides a platform for handling uncertainty. This section will show an evolved class-based CAC algorithm associated with FL theory, which is named as FL-based CAC algorithm.

4.3.1 Fundamental Concept of Fuzzy Logic System

A fuzzy system is basically formed from four parts, in Figure 4-7:

- Fuzzifier
- Inference Engine
- Fuzzy Rule Base
- Defuzzifier

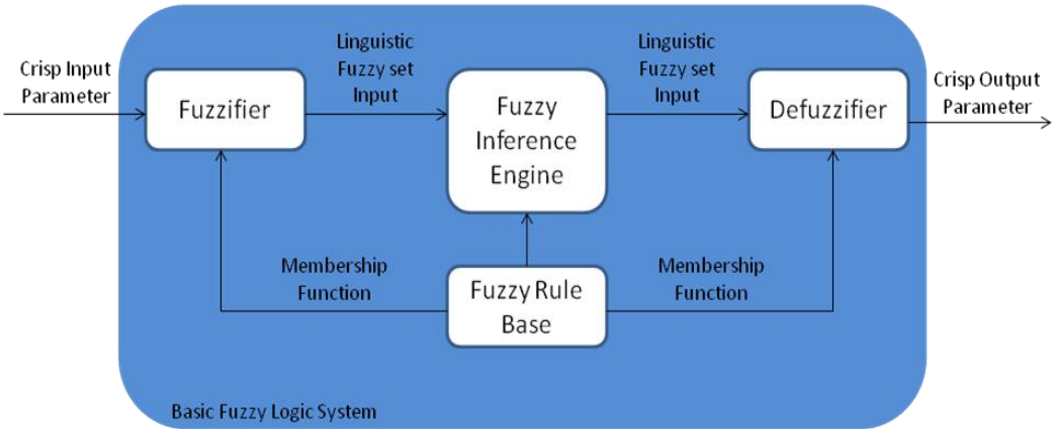

Figure 4-7: Fuzzy Logic System

The Fuzzifier converts the instantaneous input values into a fuzzy set in linguistic language, which is characterized by the Membership Function (MF). Then the Inference Engine applies the Fuzzy Rule Base (IF-THEN Rule) on the input fuzzy set and gets the decision off the output fuzzy set, which is also pictured by the MF. Finally, the Defuzzifier converts the output set into the usable non fuzzy control values.

The Fuzzy Inference Engine and the Fuzzy Rule Base are decision mechanisms. The Fuzzy Rule Base is formed by a series of IF-THEN rules. It is used to describe the logical relationship between the input fuzzy set and the output fuzzy set.

There are three common models for the Inference Engine: Mamdani model, Tskagi-Sugeno-Kang (TSK) model and Tsukamoto model [49]. All of them follow the same input structure and IF-THEN Rule. The main difference among those models is that the output MFs: the output MFs of Mamdani model, TSK model and Tsukamoto model are a fuzzy set, a linear crisp function and a constant respectively. In this thesis, the Mamdani model is used to profile the characteristic of the FL system.

4.3.2 Analytical Model

The novel dynamic CAC with a FL mechanism is an expansion in terms of previous class–based CAC algorithm. The aim of using FL theory is to optimize the quantity of the channel thresholds so as to assign radio resource efficiently and guarantee the QoS requirement [56]. This new algorithm is operated according to the instantaneous handover services dropping probabilities of Users A and B and the amount of reserved channels that are defined by C_L, C_H and K.

4.3.2.1 Membership Function

The Membership function (MF) is the basic principle of FL theory and describes the character of a FL system. It usually takes on a value between *0* and *1*, where *1* is for full membership and *0* for the null-membership, while values in between give the degree of membership [52].

To choose the type and number of membership functions, it is necessary to take into account both computational efficiency and adaption complexity of the fuzzy inference system [49]. The most common MFs are the triangular MF, the trapezoidal MF, the bell MF and the Gaussian MF [49]:

- The triangular function and the trapezoidal function are linearly distributed. From the MF curves of these two functions, it is easy to tell that the triangular function and the trapezoidal function reflect a more precise and transparent tendency of the object;
- The Gaussian function follows a Gaussian distribution and is a better reflection of the propagation model;
- The bell function follows a Normal distribution. It has a better transitional property and provides a more ambiguous performance.

The Gaussian function (Gaussian distribution) and the bell function (Normal distribution) more like human’s brain and suit to the cases with more fuzzification; while, the triangular function and the trapezoidal function adapt to the instances with the requirement of providing accurate results, the triangular function even gives more accurate result than the trapezoidal function.

The FL will help the class-based CAC algorithm to choose an optimal exact amount of channels. Thus, in this thesis, the triangular MF is applied.

Besides, another advantage of the triangular MF is easy to calculate and fast processing.

The FL controller estimates whether the channel assessment is optimal or not, and then executes the radio resource adjustment. The expected functionality of the novel dynamic CAC is described as: once a new channel request arrives, the FL-based CAC algorithm will dynamically tune the channel threshold in the target network based on the existing handover dropping probability [56] and decide whether to accept or deny the arriving resource request to assist the performance of the entire system.

The FL controller defines three input parameters:

- The handover traffic dropping probability of the highest priority user (User A), P_A;
- The handover traffic dropping probability of the intermediate priority user (User B), P_B;
- The number of reserved channels, which is guarded by thresholds (C_L and C_H).

It also defines one output parameter—the adjustment channels for C_L (or C_H), which is defined as the amount of channels to be added to or minus from C_L (or C_H).

The MFs for the parameters are defined as follows:

- INPUT 1: In order to simplify the calculation, the new algorithm defines the High priority handover Dropping Probabilities (HDP) and the Low priority handover Dropping Probabilities (LDP) to have the same value of *0.01*. Hence, both the HDP and the LDP are considered as having the same MF, which is shown in Figure 4-8, and use the same linguistic set: L(DP) = {Z(Zero), VL(Very Low), L(Low), M(Medium), H(High)} [56];

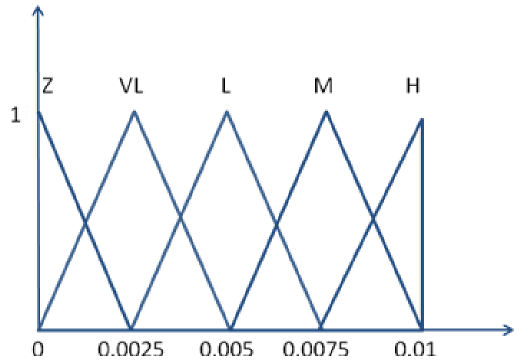

Figure 4-8: MF for Handover Dropping Probability [56]

- INPUT 2: The amount of reserved channels is declares as *ΨC*, which is profiled in Figure 4-9. The fuzzy set for reserved channel (RC) is set as: L(RC) = {VS(Very Small), S(Small), M(Medium), B(Big), VB(Very Big)} [56];

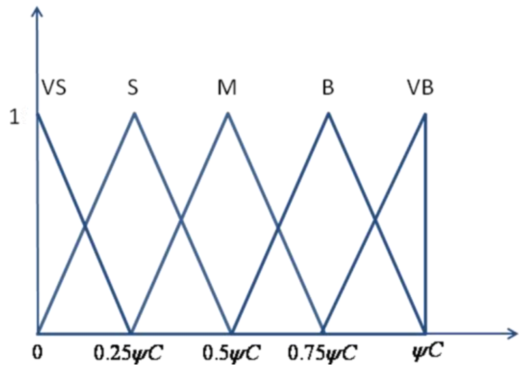

Figure 4-9: MF for the Quantity of Reserved Channels [56]

- OUTPUT: As the output of the FL system, the MF definition of the adjustment channels (ACs) for each threshold is deployed in Figure 4-10 and its range varies from -*ΨC* to *ΨC*. L(AC) = {NB(Negative Big), NLB(Negative Little Big), NM(Negative Medium), NS(Negative Small), NVS(Negative Very Small), Z(Zero), PVS(Positive Very Small), PS(Positive Small), PM(Positive Medium), PLB(Positive Little Big), PB(Positive Big)} [56].

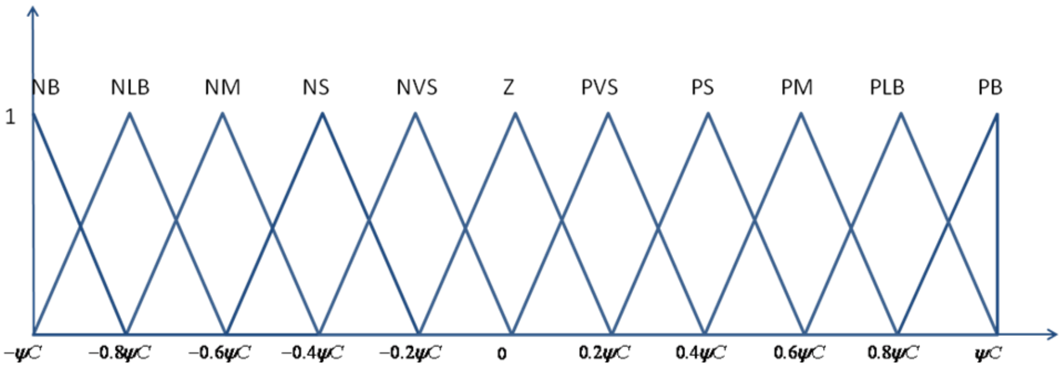

Figure 4-10: MF for the Number of Adjustment Channels [56]

For the sake of evaluating the number of the adjustment channels for two thresholds, the value of *ΨC* is different when analyzing C_L and C_H respectively. When calculating the adjustment channels for C_L, the value of *ΨC is* defined as C_H-C_L, and for the purposes of calculating the adjustment channels for C_H the amount of *ΨC* is configured as *K*-C_H.

FL theory is expected to provide real-time measurements and tune the channel thresholds C_L and C_H dynamically. Hence, in accordance with the basic concept and the class-based two-threshold CAC algorithm, Figure 4-7 will be converted as follows:

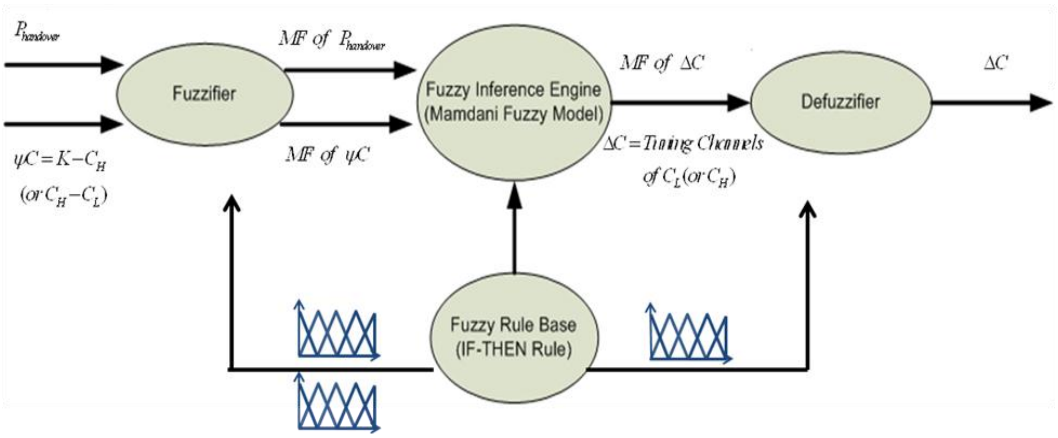

Figure 4-11: Fuzzy Logic System for Adjustment Channel

4.3.2.2 Fuzzy Rule Base

The Fuzzy Rule Base, also called IF-THEN Rule, describes a conditional statement. A FL system uses linguistic variables to map the input fuzzy variables to the output fuzzy variable, which is achieved under conditions prescribed by IF-THEN Rule [56]. The FL controller calculates the amount of AC according to the values of DP and RC. In this thesis, DP and RC all have 5 MFs, hence, a series of 25 IF-THEN roles is generated to manage 25 different combinations as presented in Table 1.

Table 1: IF-THEN Rule [56]

Rule No.	Handover Dropping Probability	Reserved Channel	Adjustment Channels
1	Zero	Very Small	Zero
2	Zero	Small	Negative Very Small
3	Zero	Medium	Negative Small
4	Zero	Big	Negative Medium
5	Zero	Very Big	Negative Big
6	Very Low	Very Small	Zero
7	Very Low	Small	Zero
8	Very Low	Medium	Negative Very Small
9	Very Low	Big	Negative Small
10	Very Low	Very Big	Negative Medium
11	Low	Very Small	Positive Small
12	Low	Small	Positive Very Small
13	Low	Medium	Negative Very Small
14	Low	Big	Negative Small
15	Low	Very Big	Negative Medium
16	Medium	Very Small	Positive Medium
17	Medium	Small	Positive Small
18	Medium	Medium	Positive Very Small
19	Medium	Big	Zero
20	Medium	Very Big	Negative Very Small
21	High	Very Small	Positive Big
22	High	Small	Positive Medium
23	High	Medium	Positive Small
24	High	Big	Positive Very Small
25	High	Very Big	Zero

4.3.3 Numerical Results

This section presents the results of comparing the results of the class-based CAC with and without Fuzzy Logic: the FL-based CAC algorithm and the class-based CAC algorithm.

4.3.3.1 Tuning Channels

According to the FL concept, MF and Fuzzy Rule Base, a grid is plotted to reveal the relationship between two inputs and one output.

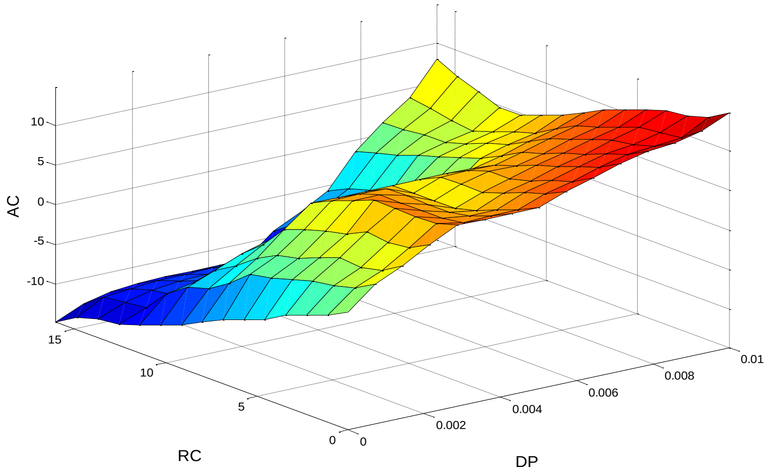

Figure 4-12: Adjustment Channels [56]

There are three element vectors in Figure 4-12: the horizontal two variables depict DP and RC inputs , while the vertical variable represents the AC output [56]. The output surface specifies the number of sample points on which to evaluate the membership functions in the input or output range [57]. This figure shows an output surface and clarifies the optimal amount of adjustment channels for channel thresholds.

4.3.3.2 Performance Comparison

After calculating the adjustment channels by the FL controller, with the purpose of evaluating the performance of the FL-based CAC algorithm, this section shows the simulation curves of handover dropping probabilities of diverse users with different priorities in the class-based CAC and the FL-based CAC algorithms respectively. The same assumptions are used for both algorithms: *K=50 channels*, *0.25* $\leq\lambda_1\leq$ 0.*9 channels/s*, *0.25* $\leq\lambda_2\leq$ *0.9 channels/s*, *0.8* $\leq\lambda_3\leq$ *2.0 channels/s*, and $1/\xi=1/\xi_1=1/\xi_2=1/\xi_3=150s$.

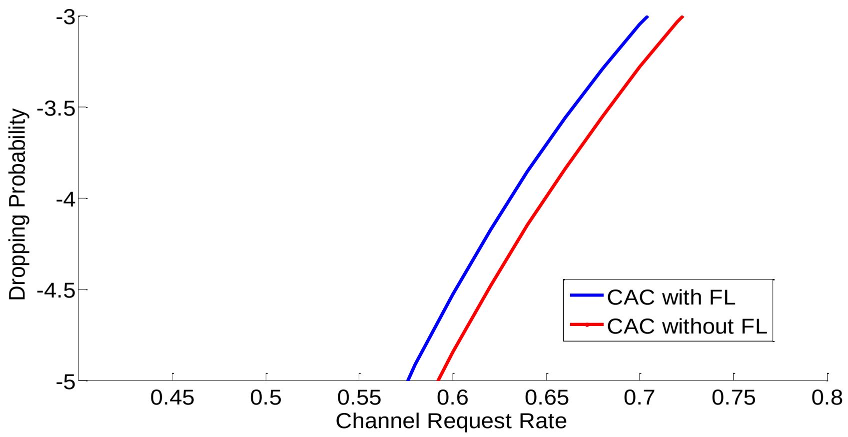

Figure 4-13: P_A in Class-Based and FL-Based Schemes [56]

Figure 4-13 reveals that with the increasing of channel request rate, the dropping probability of the highest priority handover service is increasing in both the class-based CAC and the FL-based CAC algorithms. However, even using adjustment channels, the handover dropping likelihood of User A in the FL-based CAC algorithm has similar characteristic as P_A in the class-based algorithm.

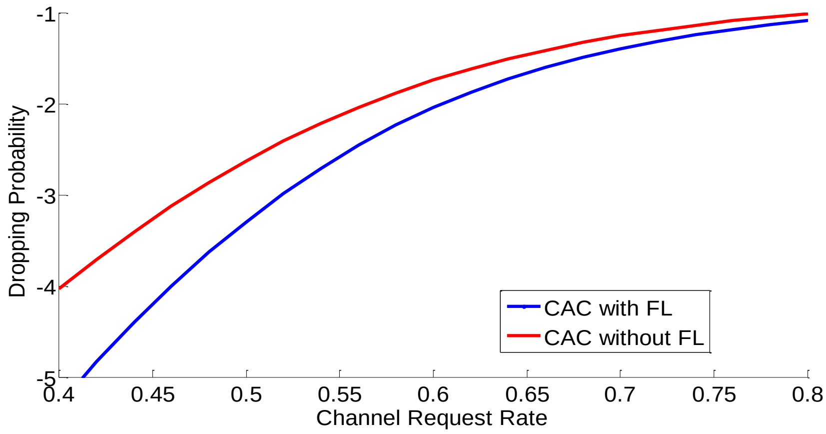

Figure 4-14: P_B in Class-Based and FL-Based Schemes [56]

Figure 4-14 illustrates that the handover traffic dropping probability of User B in the class-based CAC and the FL-based CAC algorithms. The simulation result verifies that the FL-based CAC algorithm brings a lower handover dropping probability for User B. The FL-based CAC algorithm dynamically modulates an optimum value for thresholds to meet the QoS requirement and gives a lower handover dropping probability at lower channel request rates [56].

Looking at the numerical results of two figures above, the thresholds altered by the FL mechanism performs a much better measurement to dynamically adjust the thresholds and provides a lower handover dropping probability, especially for User B. Therefore, the intelligent FL-CAC algorithm minimizes the entire handover dropping probability and guarantees the quality of transferred traffic during its lifetime successfully [56].

4.4 Summary

This chapter has presented a class-based CAC algorithm. It classifies users into different classes (the highest priority, intermediate priority and the lowest priority) and uses one-dimensional Markov chain with two-threshold analytical model to reflect the diverse precedence. Through comparing the numerical results with the CAC approach with one-threshold and without threshold, it is demonstrated that the class-based CAC with two-threshold scheme provides a better performance than the other two schemes.

An improvement to the class-based CAC is also carried out to consummate the thresholds of the class-based CAC algorithm by using FL theory. FL dynamically adjusts the thresholds for the class-based CAC algorithm to enhance the performance of the system.

5 CALL ADMISSION CONTROL ALGORITHM WITH PRE-EMPTIVE RESUME PRIORITY METHOD

5.1 Introduction

In the last chapter, a class-based one-dimensional MCP analytic method is use to model the performance of the system. Once the amount of occupied channels reaches the channel threshold, which is the notification as the incipient stages of congestion, the system will start to abandon coming radio channel requests randomly. The channel request will be accepted while the congestion is eliminated. This may lead to channel request delays and drops, system stability degradation and bandwidth fairness in the presence of persistent congestion [58]. :

In order to meet the QoS requirements, choosing an adaptive scheduling mechanism will be an important and promising scheme for congestion control and QoS guarantee in communication networks [59].

This chapter is going to develop another improved CAC algorithm coupling with Preemptive Resume (PR) policy in a two-dimensional Markov analytical model to differentiate multiple priority classes of user and investigate the performance for heterogeneous wireless network.

Within the context of this chapter, the hybrid UMTS-WLAN network which is described in Chapter 4 is the network that is being used as the basis for the simulations. The new CAC algorithm is still based on the user’s classification and channel allocation policy as well. The two-dimensional MCP mathematical analytic method is introduced to appraise the dropping likelihood of handover traffic for reflecting the system performance.

5.2 Pre-Emptive Resume Policy

The Pre-emptive Resume (PR) theory [59] is borrowed heavily from queue management principle.

- The basic principle of the queue management is Tail Drop (TD) management strategy. TD starts out to drop arrival packets/requests, when the queue is full.
- After TD stage, an Active Queue Management (AQM) [58] is introduced as a notable improvement of TD. AQM initiates packets/requests discard before the queue is full. AQM sets up a specific value as a congestion signal and runs probabilistically dropping. It maintains the marginal value for the queue, once the content reaches the marginal value, the system will reduce the number of arriving requests of the system.
- Pre-emptive is one type of priority discipline, which is ordinarily employed for amending the performance of existing AQM schemes. PR policy assumes that a packet/request with higher priority has a privilege to replace a packet/request with lower priority from the service channel. Since the priority unit interrupts service of a non-priority unit, the non-priority unit on its re-entry may resume service from the point where it was pre-empted [60]. The resume rule ensures that the service time of the non-priority unit is less than the amount of re-entry time.

5.3 Performance Analysis

A retrospection of the integrated network contains one UMTS cell and two overlapped WLANs (WLAN 1 and WLAN 2) being described in Figure 4-1. There are three classes of users: Users A, B and C. Users A and B generate handover traffic; User C issues new connections. User A has the highest priority, User B has intermediated priority and User C has the lowest priority.

According to the different priorities, the PR principle serves the channel requests from Users A and/or B pre-empting User C's channel request that has being served. The processing of pre-empted channel request from User C will be resumed after accomplishing the request from Users A and/or B.

λ_1, λ_2 and λ_3 stand for the arriving channel request rates of Users A, B and C; λ_{TOTAL} represents the total arriving channel request rate; λ_H is the total channel request rate of handover traffic. The acceptance rates of Users A, B and C, are ξ_1, ξ_2 and ξ_3. $1/\xi$ is denoted as the mean acceptance time of channel request with a negative exponential distribution.

The entire channel capability of WLAN 2 is still equal to K units; each channel request will occupy one unit. The number of used channels is defined as K_U. T_1 and T_2, are assumed as two channel thresholds for User C's new connection and User B's handover traffic respectively. As long as there is free channel, User A's channel request will be served; once the available channels equal to or less than $K- T_2$, User B's channel request will be denied; while the amount of idle channel is equal to or less than $K- T_1$, the channel requests from User C will be rejected. The model of PR policy is described in Figure 5-1.

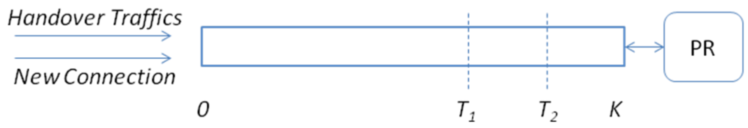

Figure 5-1: Preemptive Resume Scheme

Hence, according to the theory, a corresponding two-dimensional Markov state diagram is constructed in Figure 5-2.

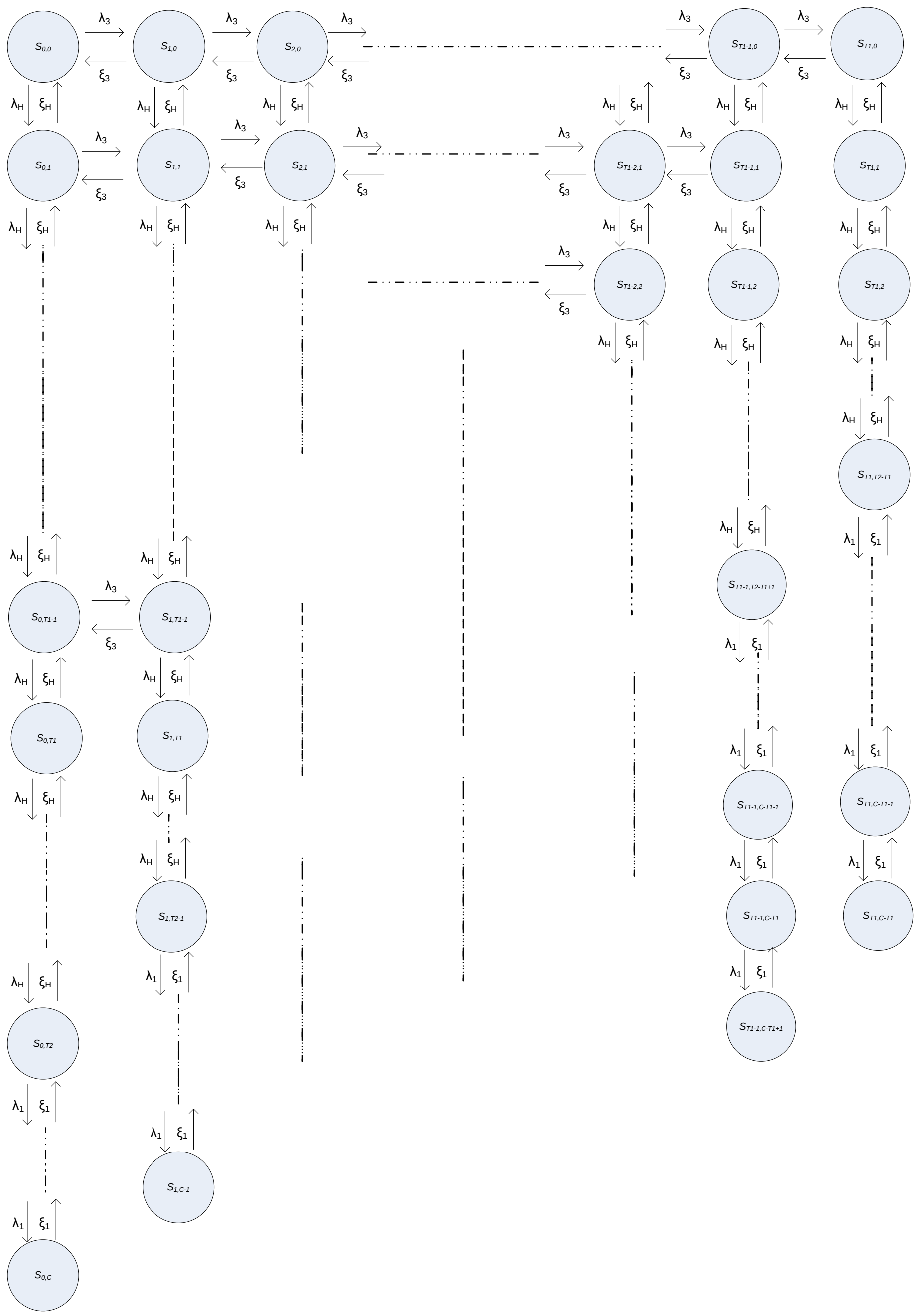

Figure 5-2: Two-Dimensional Markov Chain Model

The two-dimensional MCP system is modeled for the PR-based CAC algorithm to analyze the performance of this new algorithm.

Defining the intensity of channel request as:

$$I = \frac{\lambda_H}{\xi_H} + \frac{\lambda_3}{\xi_3} \qquad (5\text{-}1)$$

where λ_H and ξ_H symbolize the average channel request rate and the mean rate of acceptance channel request of handover traffic (including Users A and B).

In accordance with the above PR theoretic, the possible state space is depicted with two-dimensional Markov chain should be:

$$S = \{(m,n) \mid 0<T_1<T_2<K,\ 0< m+n \le K\} \qquad (5\text{-}2)$$

Each state *(m, n)* shows the amount of occupied channels by diverse users: the value of *m* represents the channel number occupied by new connection and *n* specifies the quantity of used channel by (high/low priority) handover traffic [40]. Let *S (m,n;m',n')* stand for the transition rate from state *(m,n)* to state *(m',n')*.

- The transition of state (*m,n*) to state(*m,n+1)*, ($0 \le m+n < T_1$), means the channel request rate of handover traffic from Users A and B, all of the channel requests are accepted by the system; the transition from state (*m,n*) to state (*m,n-1)*, ($0 \le m+n < T_1$), implies the system acceptance rate of channel request for Users A and B;
- The transition shifts from state (*m,n*) to state (*m+1,n)*, ($0 \le m+n < T_1$). This is to do with the channel request rate from User C, λ_3, as long as the total occupied channels (*m+n)* are less than T_1, User C's requests will be admitted; when the transition migrates out of state (*m,n*)

toward to state (*m-1,n)*, (*0 ≤ m+n <*T_1), the system acceptance rate of User C's is ξ_3;

- When the amount of entire used channels (*m+n)* is greater than T_1, User C's channel requests are denied, only channel requests from handover traffic can be served; thus, the transition only transfers from state (*m,n*) to state (*m,n+1)*, ($T_1 \le m+n < T_2$), meaning that system just takes into account channel requests of Users A and B;
- With the increasing amount of seized channels, the instantaneous (*m+n)* is rising up to T_2, when the state (*m,n*) converts to state (*m,n+1)*, ($T_2 \le m+n < K$), the system merely absorbs User A's request and abandons any channel requests from Users B and C.

Hence, the representation of each feasible state *S (m,n;m',n')* is given by:

$$\begin{cases} S(m,n;m,n+1)=\lambda_H, & (0<m\le T_1, m+n<T_1) \\ S(m,n;m,n-1)=n\xi_H, & (0<m\le T_1, m+n<T_1) \\ S(m,n;m+1,n)=\lambda_3, & (0<m\le T_1, m+n<T_1) \\ S(m,n;m-1,n)=m\xi_3, & (0<m\le T_1, m+n<T_1) \\ S(m,n;m,n+1)=\lambda_H, & (0<m\le T_1, T_1\le m+n<T_2) \\ S(m,n;m,n-1)=n\xi_H, & (0<m\le T_1, T_1\le m+n<T_2) \\ S(m,n;m,n+1)=\lambda_1, & (0<m\le T_1, T_2\le m+n<K) \\ S(m,n;m,n-1)=n\xi_1, & (0<m\le T_1, T_2\le m+n<K) \end{cases} \quad (5\text{-}3)$$

There are *m* channel requests for the new connection and *n* channel requests for the handover traffic. According to the principle of detailed balance equation, which describes the probability associated with a Markov chain in and out of states or set of states [61], the equation of state probability is given for every state *S* by:

$$P_{m,n}=\begin{cases}\dfrac{P_{0,0}}{m!n!}\cdot\left(\dfrac{\lambda_3}{\xi_3}\right)^m\cdot\left(\dfrac{\lambda_H}{\xi_H}\right)^n, \\ \qquad where\ \ 0\le m\le T_1, m+n\le T_1 \\ \dfrac{P_{0,0}}{m!n!}\cdot\left(\dfrac{\lambda_3}{\xi_3}\right)^m\cdot\left(\dfrac{\lambda_H}{\xi_H}\right)^{T_1-m}\cdot\left(\dfrac{\lambda_H}{\xi_H}\right)^{m+n-T_1}, \\ \qquad where\ \ 0\le m\le T_1, T_1\le m+n\le T_2 \\ \dfrac{P_{0,0}}{m!n!}\cdot\left(\dfrac{\lambda_3}{\xi_3}\right)^m\cdot\left(\dfrac{\lambda_H}{\xi_H}\right)^{T_1-m}\cdot\left(\dfrac{\lambda_H}{\xi_H}\right)^{T_2-T_1}\cdot\left(\dfrac{\lambda_1}{\xi_1}\right)^{m+n-T_2}, \\ \qquad where\ \ 0\le m\le T_1, T_2\le m+n\le K\end{cases} \tag{5-4}$$

where $P_{m,n}$ is the joint steady state probability; T_1 and T_2 are two thresholds for this algorithm. $P_{0,0}$ is the initial steady state probability of the system. According to the normalization equation $\Sigma_{m,n}P_{m,n}=1$, the expression of $P_{0,0}$ is obtained:

$$\begin{aligned}P_{0,0}=[\ &\sum_{m=0}^{T_1}\frac{1}{m!}\left(\frac{\lambda_3}{\xi_3}\right)^m\cdot\sum_{n=0}^{T_1-m}\frac{1}{n!}\left(\frac{\lambda_H}{\xi_H}\right)^n \\ &+\sum_{m=0}^{T_1}\frac{1}{m!}\left(\frac{\lambda_3}{\xi_3}\right)^m\left(\frac{\lambda_H}{\xi_H}\right)^{T_1-m}\cdot\sum_{n=T_1-m+1}^{T_2-m}\frac{1}{n!}\left(\frac{\lambda_H}{\xi_H}\right)^{m+n-T_1} \\ &+\sum_{m=0}^{T_1}\frac{1}{m!}\left(\frac{\lambda_3}{\xi_3}\right)^m\left(\frac{\lambda_H}{\xi_H}\right)^{T_1-m}\left(\frac{\lambda_H}{\xi_H}\right)^{T_2-T_1}\cdot\sum_{n=T_2-m+1}^{K-m}\frac{1}{n!}\left(\frac{\lambda_1}{\xi_1}\right)^{m+n-T_2}\ ]^{-1}\end{aligned} \tag{5-5}$$

In this proposed algorithm, the performance evaluation parameters are set up the handover traffic dropping probability, the new connection blocking probability and the system utilization.

The system will drop the channel request from handover traffic with the highest priority of User A once there are no free channels. Thus dropping probability P_A is depicted as formula:

$$P_A=\sum_{m=0}^{T_1}\frac{P_{0,0}}{m!(K-m)!}\cdot\left(\frac{\lambda_3}{\xi_3}\right)^m\cdot\left(\frac{\lambda_H}{\xi_H}\right)^{T_1-m}\cdot\left(\frac{\lambda_H}{\xi_H}\right)^{T_2-T_1}\cdot\left(\frac{\lambda_1}{\xi_1}\right)^{K-T_2} \tag{5-6}$$

While the number of occupied channels is up to T_2, User B's handover traffic are not going to be served, the channel requests will be rejected and the dropping probability can be calculated. Hence the equation of the dropping probability of User B is gained:

$$P_B = \sum_{m=0}^{T_1} \frac{P_{0,0}}{m!(T_2-m)!} \cdot \left(\frac{\lambda_3}{\xi_3}\right)^m \cdot \left(\frac{\lambda_H}{\xi_H}\right)^{T_1-m} \cdot \left(\frac{\nu_H}{\xi_H}\right)^{T_2-T_1} +$$

$$\sum_{m=0}^{T_1} \frac{P_{0,0}}{m!} \left(\frac{\lambda_3}{\xi_3}\right)^m \left(\frac{\lambda_H}{\xi_H}\right)^{T_1-m} \left(\frac{\lambda_H}{\xi_H}\right)^{T_2-T_1} \cdot \sum_{n=T_2-m+1}^{K-m} \frac{1}{n!} \left(\frac{\lambda_1}{\xi_1}\right)^{m+n-T_2} \quad (5\text{-}7)$$

The total dropping probability of handover traffic, denoted by P_{TOTAL}, includes the dropping probabilities of the highest handover traffic and the intermediate priority handover traffic. Since P_A and P_B are mutually exclusive, P_{TOTAL} is written as:

$$P_{TOTAL} = P_A + P_B \quad (5\text{-}8)$$

In communication networks, the network throughput reflects the performance of a system. Both the channel utilization (in percentage) and the packet drop rate are treated as less ambiguous terms of throughput. Thus, the system utilization U will be discussed, that is defined as the ratio of the used channels to the whole channel capacity [10], the equation of U is:

$$U = \frac{\sum_{m,n} mnP_{m,n}}{K} \quad (5\text{-}9)$$

Equation 5-9 has two parameters should be considered: m and n. Hence, the expanding formula of Equation 5-9 is:

$$U = \frac{1}{K} \cdot [\sum_{m=0}^{T_1} \sum_{n=0}^{K} (m+n) \cdot P_{m,n}] \quad (5\text{-}10)$$

5.4 Numerical Results

This section is derived from the class-based CAC algorithm with PR policy using the two-dimension scheme analytical expressions. The dropping probability is still the key measurement of evaluating the performance of the entire system in order to meliorate the system QoS. The measured parameters contain the User A's handover traffic dropping probability (P_A), the User B's handover traffic dropping likelihood (P_B), the total handover traffic dropping rate of the system (P_{TOTAL}) and the system utilization (U).

For analyzing the performance of the revised analytic model, a brief investigation for the examined parameters of the PR-based CAC algorithm is carried out. The results are compared with those for the primal class-based CAC algorithm that is introduced in Chapter 4.

The following assumptions are used throughout this section:

- $K=100$ *channels*,
- $0.2< \lambda_1<1.5$ *channels/s*,
- $0.5< \lambda_2< 3$ *channels/s*,
- $0.8< \lambda_3<2.0$ *channels/s*,
- $1/\xi=1/\xi_1=1/\xi_2 =1/\xi_3=50s$.

5.4.1 Numerical Results of P_A and P_B

Figure 5-3 plots the dropping likelihood curves for the handover traffic and demonstrates the handover traffic dropping probability of Users A and B in the class-based CAC and the PR-based CAC algorithms, respectively.

The horizontal axis stands for the channel request rate and the vertical axis represents the dropping probability for the diverse handover traffic with different priorities. The red curves show the dropping probability of Users A and B in the class-based approach; while the blue ones present P_A and P_B in the PR-based approach. With the channel request rate rising, the dropping probabilities of two algorithms are increasing.

The tendencies of the P_A in both algorithms and the P_B in the PR-based approach have a prominent variation; relatively, compared to the virtually flat curve for the P_B of the class-based CAC algorithm.

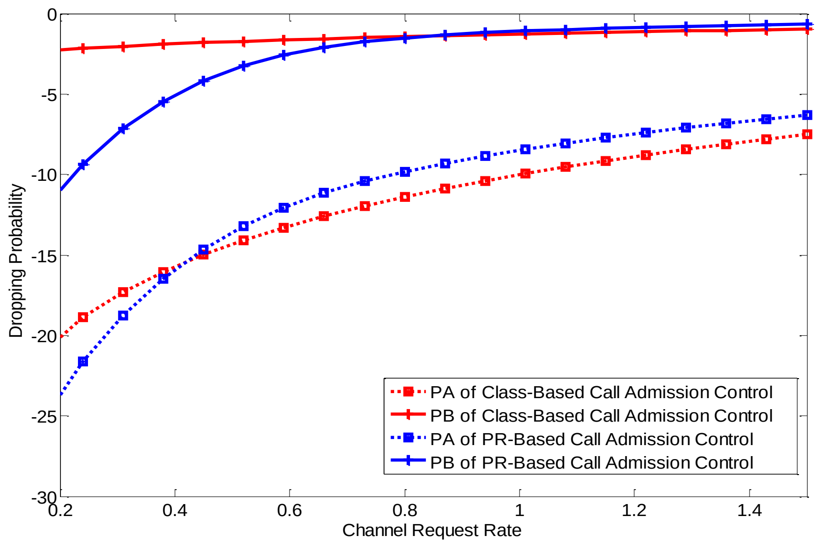

Figure 5-3: Dropping Probability of Handover Traffic

This figure shows that the P_A s of both algorithms have a similar trend. In the interval channel request rate = [0.2 0.4], the dropping percentage of arrival channel requests of the PR-based CAC algorithm is lower than that in the class-based CAC algorithm; when the channel request rate is greater than *0.4channel/s*, the dropped channel request percentage of the PR-based CAC algorithm is higher than the class-based CAC algorithm. The P_B of the PR approach is considerably less than that for the class-based approach at the initial phase. The PR principle gives full scope to the degradation of traffic dropping and show a low dropping probability compared with the class-based CAC algorithm at low channel request rates. However, when the amount of free channel become less and less as the channel request rate increases, the PR-based CAC algorithm has almost the same dropping percentage of channel requests as that of the class-based CAC algorithm.

Hence, the PR-based CAC algorithm provides a similar P_A to the class-based CAC algorithm; whereas, it generates a much lower P_B, at low channel request rates, contrasting to the original class-based CAC approach.

5.4.2 Numerical Results of Total Handover Traffic

After discussing the dropping probabilities of the different categories of handover traffic, the total handover traffic dropping probability (P_{TOTAL}) for the class-based and the PR-based CAC algorithms are shown in Figure 5-4.

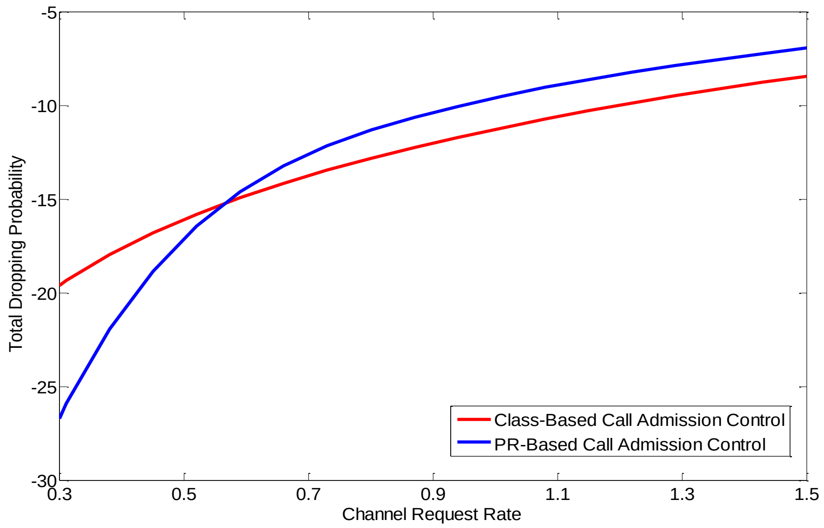

Figure 5-4: Total Handover Dropping Probability

The blue curve shows the total dropping probability of the PR-based CAC algorithm; and red curve represents P_{TOTAL} of the class-based CAC algorithm. As would be expected from Figure 5-4, the total handover traffic dropping probability of the PR-based approach is much lower than P_{TOTAL} of the class-based approach in the interval [0.3 0.6], which implies that P_B is influential at these lower channel request rates. While, the value of the channel request rate varies from *0.6channel/s* to *1.5channel/s*, P_A tends to dominate the characteristic of the total handover dropping ratio, and the total handover dropping probability of the PR-based approach is slightly higher than the P_{TOTAL} of the class-based approach.

5.4.3 Numerical Results of Utilization

Besides the handover dropping probability, in the telecommunication system, the performance of a system can be measured in terms of the percentage of the successful message delivery over a communication channel as well. Hence, the utilization, which is elaborated in Equation 5-10, is another measurement of appraising the performance of a system.

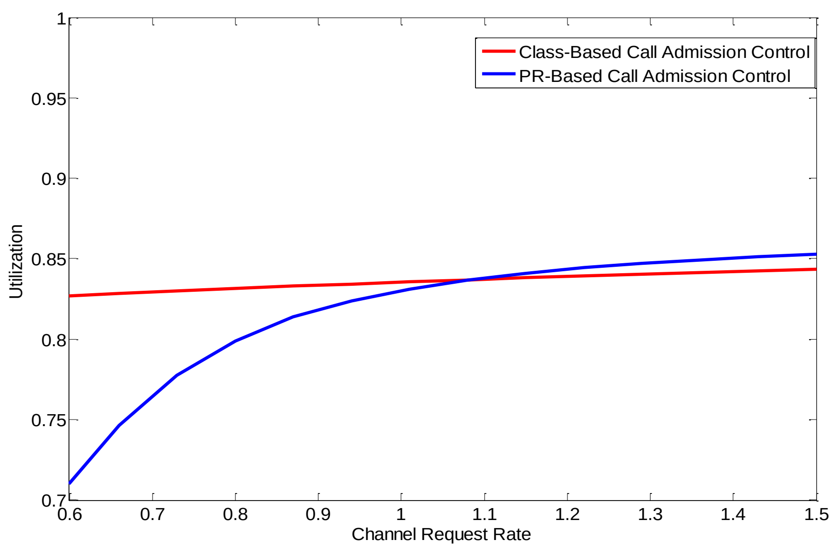

Figure 5-5: Utilization of Two Algorithms

Figure 5-5 illustrates that the overall channel utilization of the PR-based scheme is lower than that of the class-based scheme at channel request rates less than *1.1 channels/s*; however, above this rate the PR-based algorithm generates a higher channel utilization. Thus it is possible to enhance the entire utilization, which can be considered as part of future work.

5.5 Summary

In this chapter, an evolved CAC algorithm combing with the PR theory has been developed and validated for evaluating the performance measures with two-dimension Markov chain channel thresholds subject to heterogeneous telecommunication wireless network [59].

After analyzing the mathematical model, the PR-based CAC algorithm is compared to the class-based CAC algorithm using the following parameters: the handover traffic dropping probability of User A (P_A), the handover traffic dropping likelihood of User B (P_B), the total handover traffic dropping rate (P_{TOTAL}) and the system utilization (U).

From the numerical results of Figure 5-3, Figure 5-4 and Figure 5-5, it can be seen that the PR-based CAC algorithm produces an advantage over the class-based CAC algorithm; the PR theory reduces the handover services dropping probability, guarantees and protects the QoS of the handover traffic and improves the performance of the whole system particularly at lower channel request rates.

6 CONCLUSIONS AND FUTURE WORK

6.1 Conclusions

This thesis starts with the introduction of the fundamental RRM concept in both UMTS and WLAN networks, especially in the concept of CAC within RRM. It also describes a prevalent hybrid UMTS-WLAN network that is a proposed version of the next generation wireless system. Due to the limited radio spectrum and multimedia traffic characteristics, this type of network requires the design of an efficient and practical CAC algorithm.

This thesis demonstrated a class-based CAC algorithm for the hybrid UMTS-WLAN network. The new algorithm operates a one-dimensional Markov chain to prioritize the channel requests by using channel thresholds in accordance with distinct user classes and evaluates the system performance according to the dropping probability of handover traffic. The one-dimensional MCP analysis model shows that the proposed CAC approach with two thresholds effectively decreases the dropping probability of handover traffic, minimizes the dropping likelihood of the user with the highest priority and guarantees the quality of transferred traffic during its lifetime [19].

The thesis investigated an intelligent class-based CAC algorithm using FL theory. Considering the mobility information of the new user, already existing users and service requests, the fuzzy approach seems to be an adaptive solution, which can overcome measurement errors, mobility and traffic model uncertainty, and avoid the requirements of complex mathematical relations among various design parameters [62]. Hence, this thesis proposes a feasible

FL-based CAC algorithm with two-threshold issue. This FL-based CAC algorithm dynamically modulates an optimum value for thresholds to meet the requirement of the QoS and keep the whole handover traffic to a low level [56]. The mathematical results verify that, compared with the pure class-based CAC algorithm, the FL-based CAC gives a similar dropping probability of the higher priority handover traffic and a lower dropping probability of the lower priority handover traffic. Generally speaking, the FL-base CAC algorithm provides a lower dropping probability for the total handover traffic contrasting to the dropping probability for the total handover traffic in the class-based CAC algorithm.

Finally, this thesis utilized a two-dimensional MCP model to resolve a class-based CAC algorithm combined with Pre-emptive Resume theory (PR-based CAC). This novel algorithm still sorts users into distinct classifications. However, the PR theory allows a channel request from a user with higher priority to pre-empt the channel request from a user with lower priority, which is being currently being served. The pre-empted channel request from the user with lower priority will be resumed after the channel request from the user with higher priority is completed. This algorithm assesses the system performance by comparing the dropping probability of the handover traffic and the system utilization. This approach increases the admission probability of the handover traffic, minimizes the dropping probability of the total handover traffic, improves the system utilization and guarantees the QoS for handed over traffic.

6.2 Future Work

There are several potential issues that require further investigation. The ideas for further development are briefly outlined below:

- The present work in this thesis show that the channel requests from users are classified into different classes according to the user's moving trend. This thesis roughly defines the priority per user. Actually, each user may have the diverse QoS classes of services such as conversation, streaming, interactive and background services. These different classes of services from different user should be considered discriminatively by the proposed future CAC algorithm. This would involve defining the priority level based on both the user's type (as in this thesis) and also the class of service requested. This would develop a more comprehensive CAC algorithm with more precedence for the next generation heterogeneous telecommunication network.
- In order to motivate the potential of the entire radio resource, the system should fulfill subscriber's requirement of QoS and fast access to the wireless network. Thus, the concept of capacity planning mechanism should be adopted. The capacity planning is such a process that manages the system performance and forecasts the system congestion. The target of applying capacity planning mechanism is to measure the capacity of the system, provide the effective use of available resources and improve the channel utilization of the integrated next generation wireless networks.

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