Modified Limited Data Rate Usage Algorithm using Markovian Decision Process Model

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Declaration

I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institute of tertiary education. Information derived from the published and unpublished work of others has been acknowledged in the text and a list of references is given.

Rupam Deb Date:

Dedicated to my parents for all their love and inspiration

The thesis titled **"Modified Limited Data Rate Usage Algorithm using Markovian Decision Process Model"** submitted by Rupam Deb, Student ID: 0409052012P and Session April 2009, to the Department of Computer Science and Engineering, Bangladesh University of Engineering and Technology (BUET), has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Master of Science in Computer Science and Engineering and approved as to its style and contents. Examination held on May, 2012.

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Abstract

The dual mode hand-held devices to connect both the wireless local area network (WLAN) and the cellular network, i.e., the universal mobile telecommunication system (UMTS), are becoming popular. Users want to make trade-off between the use of high cost low speed UMTS covering wide area and that of WLAN providing low cost high speed services within limited area on demand basis. The switching from one network to another is referred as the vertical handover (VHO). VHO from UMTS to WLAN is not challenging in terms of switching time as the UMTS still works within the communication range of WLAN. However, VHO from WLAN to UMTS poses strict time constraints as the signal of the previous network become weaker quickly. Many connections drop in the process depending on the velocity of the mobile devices as the procedures do not complete within the time obtained. The success rate of VHO from WLAN to UMTS can be improved significantly by incorporating delaying handoff, i.e., extending the time span in the previous network using limited data rate usage (LDU) method. Unfortunately, the existing LDU method modelled through Markovian decision process did not consider the basic and important assumption that a call can be returned back to its previous state within its transitional time of the VHO process. In this thesis, we have modified the LDU method and model it using Markovian decision process incorporating the abovementioned assumption. Simulation results prove the effectiveness of our proposed modified LDU method in terms of handoff dropping probability and call blocking probability.

Abbreviations

1D	1-dimensional
2D	2-dimensional
B3G	Beyond 3rd generation
RF	Radio frequency
BS	Base station
MU	Mobile unit
MSC	Mobile switching centre
QoS	Quality-of-service
WLAN	Wireless local area network
UMTS	Universal mobile telecommunications system
LDU	Limited data rate usage
RSSI	Received signal strength indication
MN	Mobile node
NIC	Network interface card
IP-PBX	Internet protocol private branch eXchange
HHO	Horizontal handover
VHO	Vertical handover
WLAN-AP	Wireless access point
RTS	Real time services
NRTS	Non real time services
RA	Router advertisement
CoA	Care of address
HA	Home agent
FA	Foreign agent
ARP	Address resolution protocol
MO	Mobile out

MI	Mobile in
MIHF	Media independent handover function
MPLS	Multiprotocol label switching
DCP	Designated crossover point
IP	Internet protocol
PoD	point of departure
TN-STL	stand-alone trigger node
QCS	QoS server in customer's network
QNS	QoS server in provider's network
MIES	Media independent event service
MICS	Media Independent command service
3G	Third generation
DM	Dual mode
pdf	Probability density function
PSTN	Public switched telephone network
UML	Unified modelling language
TCP	Transmission control protocol

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Chapter 1

Introduction

The term "wireless" has become a generic and all-encompassing word used to describe communications in which electromagnetic waves or radio frequency (RF), rather than some form of wire, carries a signal over part or the entire communication path. Wireless technologies continue to evolve to address the insatiable demand for faster response times, lager bandwidth, and reliable transmission. As the industry moves toward the development of past third generation (3G) systems, engineers have frenzied all the affordable physical layer technologies discovered to date. This has necessitated more intelligent and optimized utilization of available wireless resources. The colossal growth in computing facilities and wireless communication infrastructure has empowered people of diverse careers to enjoy the freedom of controlling and performing the majority of their daily activities, including entertainment, using mobile electronic device anywhere and anytime.

Wireless operations permits services, such as long range communications, that are impossible or impractical to implement with the use of wires. The term is commonly used in the telecommunications industry to refer to telecommunications systems (e.g. radio transmitters and receivers, remote controls, computer networks, network terminals, etc.) which use some form of energy (e.g. RF, infrared light, laser light, visible light, acoustic energy, etc.) to transfer information without the use of wires. Information is transferred in this manner over both the short and the long distances. Our life has become much easier with the use of wireless networking.

A cellular network divides a geographical region into a number of adjoined cells as shown in Figure 1.1. The coverage area of a cell is guided by the target transmission capacity and thus controlled by the power-level of the radio waves used. Mobile devices i.e. mobile units (MU) within a cell communicate with other devices, internal or external to the cell, via a control centre i.e. base station (BS) which uses a dedicated frequency spectrum as the physical layer of communication with the units. The hierarchy of the network evolves by placing a mobile switching centre (MSC) to control a number of adjacent BSs, connected with it using high

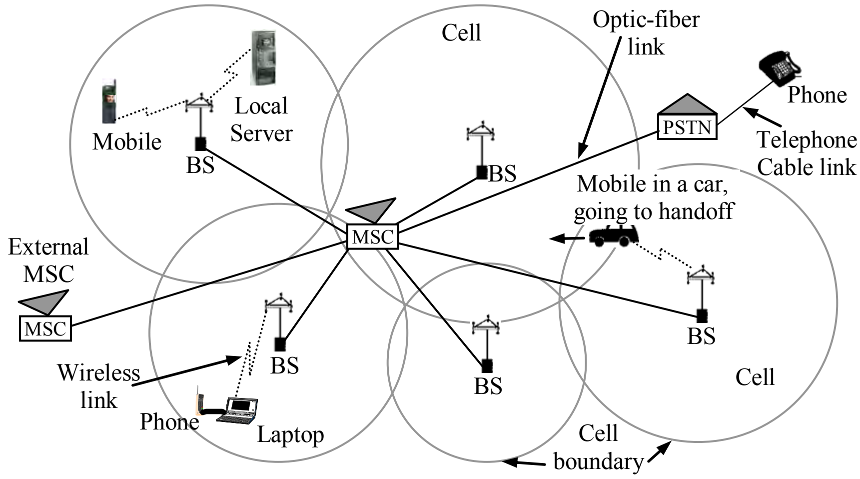

Figure 1.1: A typical cellular network organisation and hierarchy.

speed optical fiber links, act as a gateway to the external networks. To maximize the use of the limited radio frequency spectrum available for the entire network, an elegant bandwidth reuse principle is used where the available frequency spectrum is divided into a predefined number of smaller spectrums that are distributed to the cells so that no two adjacent cells use the same. When an MU is admitted by the BS to initiate a service, a satisfactory level of resources is allocated to it as per the quality-of-service (QoS) requirement. Continuation of the service at this QoS level, however, cannot be guaranteed when the MU migrates, i.e. hands off, into a neighbouring cell with insufficient resources to offer. This service continuation uncertainly problem has been greatly compounded with the increase in handoff rate due to the smaller sized cells required by the next generation cellular networks to support higher transmission rates of multimedia applications. Resource management, therefore, still remains the key area of research for efficient and effective implementation of cellular networks.

A cellular network is a radio network distributed over land areas called cells, each served by at least one fixed-location transceiver known as cell site or base station. When joined together these cells provide radio coverage over a wide geographic area. This enables a large number of portable transceivers (e.g., mobile phones, pagers, etc.) to communicate with each other and with fixed transceivers and telephones anywhere in the network, via base stations, even if some of the transceivers are moving through more than one cell during transmission.

In a cellular radio system, a land area to be supplied with radio service is divided into regular shaped cells, which can be hexagonal, square, circular or some other irregular shapes, although hexagonal cells are conventional. Each of these cells is assigned multiple frequencies which have corresponding radio base stations. The group of frequencies can be reused in other cells, provided that the same frequencies are not reused in adjacent neighbouring cells as that would cause co-channel interference. The increased capacity in a cellular network, compared with a network with a single transmitter, comes from the fact that the same radio frequency can be reused in a different area for a completely different transmission. If there is a single plain transmitter, only one transmission can be used on any given frequency.

Cellular networks offer a number of advantages such as larger coverage area, and reduced interference from other signals etc. There also certain drawbacks associated with the use of cellular networks such as higher charging rate for mobile devices and low bandwidth provisioning etc.

A wireless LAN (or WLAN, for wireless local area network, sometimes referred to as LAWN, for local area wireless network) is one in which a mobile user can connect to a local area network (LAN) through a wireless (radio) connection. The IEEE 802.11 group of standards specify the technologies for wireless LANs which use the Ethernet protocol and carrier sense multiple access with collision avoidance (CSMA/CA) for path sharing and include an encryption method, the wired equivalent privacy (WEP) algorithm.

A wireless local area network (WLAN) links two or more devices using some wireless distribution method (typically spread-spectrum or OFDM radio) and usually providing a connection through an access point to the wider internet. This gives users the mobility to move around within a local coverage area and still be connected to the network. Wireless LANs have become popular in the home due to ease of installation and the increasing popularity of laptop computers. Public businesses such as coffee shops and malls have begun to offer wireless access to their customers; often for free. Large wireless network projects are being put up in many major cities: New York City for instance, has begun a pilot program to provide city workers in all five region of the city with wireless internet access.

Wireless networks continue to develop, usage has grown in 2010. Cellular phones are the part of everyday wireless networks, allowing easy personal communications. Inter-continental network systems use radio satellites to communicate across the world. Emergency services such as the police utilize wireless networks to communicate effectively. Individuals and businesses use wireless networks to send and share data rapidly, whether it be in a small office building or across the world. Another use for wireless networks is a cost effective means to connect to the Internet, in regions where the telecommunications infrastructure is both poor and lacking in resources, typically in rural areas and developing countries.

A wireless network is more vulnerable, because anyone can intercept and sometimes divert a network broadcasting signal when point to point connections are used. Many wireless networks use WEP security systems. These have been found to be still vulnerable to intrusion. Though WEP does block some intruders, the security problems have caused some business to continue using wired networks until a more suitable security system can be introduced. The uses of suitable firewalls overcome some security problems in wireless networks that are vulnerable to attempt unauthorized access. Wireless networking enables you to move from one place to another without having to miss any information i.e. flexible enough. Easy collaboration, using wireless you can easily share files and information with others. For example, you can collaborate on a presentation with colleagues during a traffic jam. People choose the WLAN for its lower charging rate and high bandwidth provisioning.

The dual-mode hand-held devices to connect WLAN and cellular network now become commercially available. This allows the devices to access high-speed WLAN coverage when it is available and to communicate via the cellular network in other situations. The cellular coverage is typically much more wide spread than WLAN. High-bandwidth allocation for wireless will make possible a relatively low-cost wiring of classrooms in the United States. A similar frequency allocation has been made in Europe. Hospitals and businesses are also expected to install wireless LAN systems where existing LANs are not already in place. Using technology from the Symbionics Networks, Ltd., a wireless LAN adapter can be made to fit on a Personal Computer Memory Card Industry Association (PCMCIA) card for a laptop or notebook computer. The dual-mode handheld devices such as cell phone, laptop, notebook, PDA are common in to-day market. Dual-mode cell phones are forecast to grow 198 percent worldwide between 2006 and 2010 [40]. The dual-mode cell phone market reached nearly $27 billion in 2007 and is forecast more than triple by 2012 [38].

When the MU is moving away from the area covered by one cell and entering the area covered by another cell the call is transferred to the second cell in order to avoid call termination when the MU gets outside the range of the first cell, a handover or handoff is conducted [31]. When a MU moves away from a BS, the signal level degrades and there is a need to switch communications to another BS. Handover is the mechanism by which an ongoing connection between a MU and a correspondent terminal or host (CH) is transferred from one point of access to the fixed network to another. Handover may be horizontal handover (HHO) or vertical handover (VHO). In HHO, the users use the same network access technology and mobility performs on the same layers. Here, the on-going calls are to be maintain and although the change of IP address because of the mobile node movement [39]. In VHO, the user can move between different network access technologies. Here, the mobility performs between the different layers. In VHO, the mobile node moves across the different heterogeneous networks and not only changes the IP address but also change the network interface, QoS characteristics etc [39].

Vertical handover or vertical handoff refers to a network node changing the type of connectivity it uses to access a supporting infrastructure, usually to support node mobility. For example, a suitably equipped laptop might be able to use both a high speed WLAN and cellular technology for internet access. WLAN connections generally provide higher speeds, while cellular technologies generally provide more ubiquitous coverage. Thus the laptop user might want to use a WLAN connection whenever one is available and to use fall over to cellular connection when the WLAN is unavailable. Vertical handover refers to automatic fall over from one technology to another in order to maintain communication. This is different from a “horizontal handover” between different wireless access points that use the same technology in that a vertical handover involves changing the data link technology used to access the network.

In a homogeneous cellular system, a handover occurs when the connection is transferred between two base stations using the same access technology: the signal strength is the common metric used to predict the connection loss and to find the best neighbouring cell to associate. The notion of vertical handover was introduced with the development of different wireless technologies and the coexistence of their network deployment including GSM, GPRS, and UMTS as cellular networks and WiFi, WiMAX as broadband access networks. Thus, a mobile station able to operate on several technologies should roam freely from one interface to another, being able to maintain its network connection and the QoS required by higher layer applications. As wireless technologies become an integral part of daily life, we are witnessing the need for a system that can put access to wireless network services in a different perspective. Mobile users and applications are putting pressure on operators to improve the seamless handover of devices and services, a pressure that will continue into the future. Handovers must be executed regardless of the network access technology or administrative domain. Operators may have to integrate several technologies seamlessly in order to deliver unlimited content to users in a world where networks of 4G and beyond are about to become widespread. Strong business competition for subscribers, along with the wide-scale and ever increasing availability of local wireless networks (such as IEEE 802.11 and its related technologies) will give nomadic and mobile users the opportunity, and systems the power, to make better handover decisions. The vertical handover is a very important capability in the future wireless communication era, where an integrated network grouping multiple technologies will try to offer a global broadband access to mobile users.

We develop a WLAN-to-Cellular handover algorithm using Markovian decision process model by considering the following motivated works as mentioned below:

i) In traditional handovers, such as a handover between cellular networks, the handover decision is based mainly on RSS (Relative Signal Strength) in the border region of two cells, and may also be based on call drop rate, etc. for resource management reasons. In vertical handover, the situation is more complex. Two different kinds of wireless networks normally have incomparable signal strength metrics, for example, WLAN compared to UMTS. In, WLAN and UMTS networks both can cover an area at the same time. The handover metrics in this situation should include RSS, user preference, network conditions, application types, cost etc.

ii) During Cellular-to-WLAN handover, due to the better bandwidth provisioning in WLAN than cellular network the MUs don’t face problems like handover from WLAN-to-Cellular network. To provide for full interoperability, real-time seamless handover between the handset interfaces is very important. Since the cellular coverage is typically much more widespread than that of WLAN, WLAN-to-Cellular handover usually poses more strict time constraints than handover in the Cellular-to-WLAN direction.

iii) Seamless WLAN-to-Cellular network handover can often be very difficult to achieve. A particularly bad scenario may occur when mobile users exit from indoor WLAN coverage to outdoors during active voice connection. During VHO, a call switches its connectivity from one network to another, so it is very tough to successfully done the WLAN-to-Cellular network handover.

Addressing the above mentioned issues and with the aim of getting a best VHO method, the contribution of this thesis listed below:

i) In the conventional method, the switching decision is taken as soon as the signal strength goes below a certain limit. Smadi *et al.* [33] proved that the handoff rate can be improved significantly by incorporating delaying handoff i.e., extending the time span in the previous network, using limited data rate usage (LDU) method through modeling both LDU based and the conventional method with Markovian decision process. The LDU algorithm exploits this critical switching time and delayed the hand-off initiation up to a limit a call can be continued with its previous network. In some cases, it is observed the mobile devices come back to its previous network after hand off decision is initiated. Unfortunately, the Markovian decision process model designed in [33] incorporated the LDU usage time but did not consider the fact that a call can come back to its previous network from the critical boundary point. In our thesis, we have modified the Markovian decision process models for both LDU and conventional methods by incorporating a probability for coming back to the previous network from the state of implementing hand offs.

ii) To model both the conventional and LDU based VHO decision algorithm by incorporating the assumption that a call can be returned back to its previous state from its LDU period, using Markovian decision process model.

iii) To provide a smooth and seamless connectivity while switching from one network to another.

iv) To increase the value of the successful VHO rate while maintaining the service blocking rate at the same level that achieved in LDU algorithm.

The rest of the thesis is organized as follows: Chapter 2 contains the basic and details concept of the vertical handover.

Chapter 3 describes the related research work and existing algorithms for vertical handover.

Chapter 4 contains the proposed modified conventional LDU method and defines where the modifications are essential. The simulation results are also presented here.

Chapter 5 provides the proposed modified LDU method with simulation results.

Finally, Chapter 6 concludes and gives direction to future research.

Chapter 2

Vertical Handover

Vertical handover or vertical handoff refers to a network node changing the type of connectivity it uses to access a supporting infrastructure, usually to support node mobility. For example: a suitably equipped laptop might be able to use both a high speed wireless LAN and a cellular technology for Internet access. Wireless LAN connections generally provide higher speeds, while cellular technologies generally provide more ubiquitous coverage. Thus the laptop user might want to use a wireless LAN connection whenever one is available, and to 'fall over' to a cellular connection when the wireless LAN is unavailable. Vertical handovers refer to the automatic fall over from one technology to another in order to maintain communication. Vertical handover is happened when a mobile node moves across heterogeneous access networks. Horizontal handover roaming refers to the technical ability to handover either from one access point to another within the same technology. Differently from horizontal handover, the used access technology changes as well as IP address, because the mobile nodes moves different access network which uses different access technology. In this case, the main concern of vertical handover is to maintain on-going service although not only the change of IP addresses but also the change of network interfaces, QoS characteristics, and etc.

2.1 Introduction

Many laptop users have dual technology in their laptops to connect to the Internet; a laptop may use wireless LAN (WLAN) or cellular network connection technologies. WLAN provides higher bandwidth at very low rates. A cellular network is not as reliable, is often costly, and available bandwidth is dependent on network traffic. The WLAN is configured by default on the laptop. However, upon WLAN failure, the cellular network is available to keep the user connected to the Internet. The movement from one type of technology to the other is the vertical handover, which keeps a user‟s machine connected to the Internet and provides uninterrupted communication.

In traditional handovers, such as a handover between cellular networks, the handover decision is based mainly on relative signal strength (RSS) in the border region of two cells, and may also be based on call drop rate, etc. for resource management reasons. In vertical handover, the situation is more complex. Two different kinds of wireless networks normally have incomparable signal strength metrics, for example, WLAN compared to UMTS. In, WLAN and UMTS networks both cover an area at the same time. The handover metrics in this situation should include RSS, user preference, network conditions, application types, cost etc. For a vertical handover to occur, the following must be considered:

I. A vertical handover supported device must contain a dual card to connect the two different wireless networks.

II. With vertical handover, two wireless technologies are compared by means of handover-metrics. The wireless technology with the better handover metric is preferred.

III. User requirements and preferences, relative-signal strength, overall network conditions and costs are major factors for the handover decision.

In Wireless LAN, mobile node (MN) is the most essential component. Through wireless medium the MN communicate with other MN and to AP which is associated with wired network. MN may be PC or Note book that is equipped with wireless network interface card (NIC) [16]. In Wireless and wired network, the AP is a transceiver that can transmit, store and receive the data. AP also works as bridge between wired and wireless networks. In the wired network the AP is connected with the server that offers the service to MN. In wireless networks the AP acts as base station (BS), that combines the wireless network with wired network [16].

2.2 Vertical Handover

The vertical handover from WLANs to the cellular network is referred to as upward vertical handover and the vertical handover from the cellular network to WLANs is referred to as downward vertical handover. The vertical handover can also be hard or soft. Hard vertical handover is when the old connection is broken before the new connection is made and soft vertical handover is when the new connection is made before the old connection is broken [20]. Unless explicitly stated otherwise, in our thesis, the term vertical handover refers to soft vertical handover and it is upward.

A vertical handover scenario is shown in Figure 2.1. While in WLAN coverage, a dual mode mobile station (MS) makes voice connections through an internet protocol private branch eXchange (IP-PBX), which anchors the call. The initial call in this example consists of the concatenation of call legs 1 and 2. Later, when the handset roams out of WLAN coverage, the vertical handover (VHO) is triggered, and call leg 1 is replaced in real time by cellular call leg 3. In such cases, the IP-PBX anchoring is normally done through a conference bridge at the anchor node, so that soft handover is possible using Session Initiation Protocol signaling [34]. In Fig. 1, call leg 2 does not change and is held for the duration of the call, and insulates the called node from any handover activity.

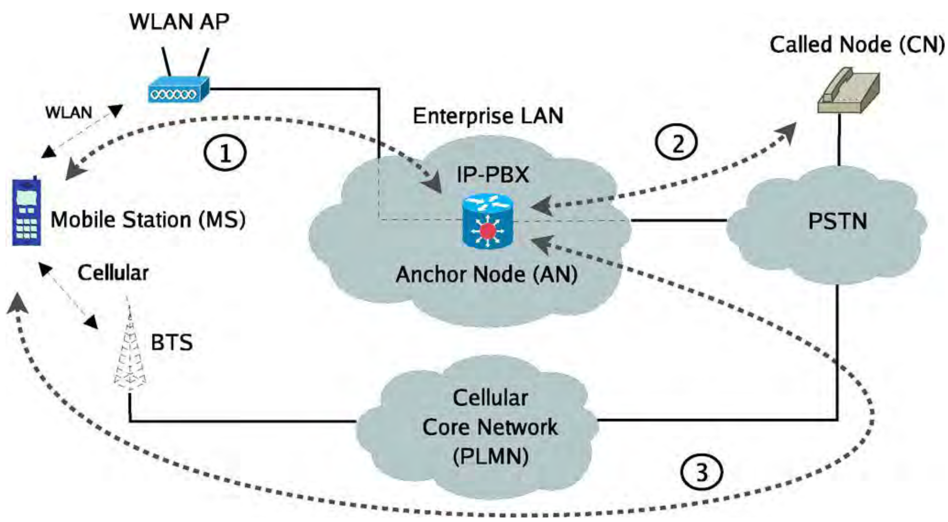

Figure 2.1: Vertical handover scenario.

2.3 Vertical Handover features

Figure 2-2 shows the Technical feature of Vertical handover. It describes three main categories.

I. Mobility Engineering
II. Resource Management
III. Service Management

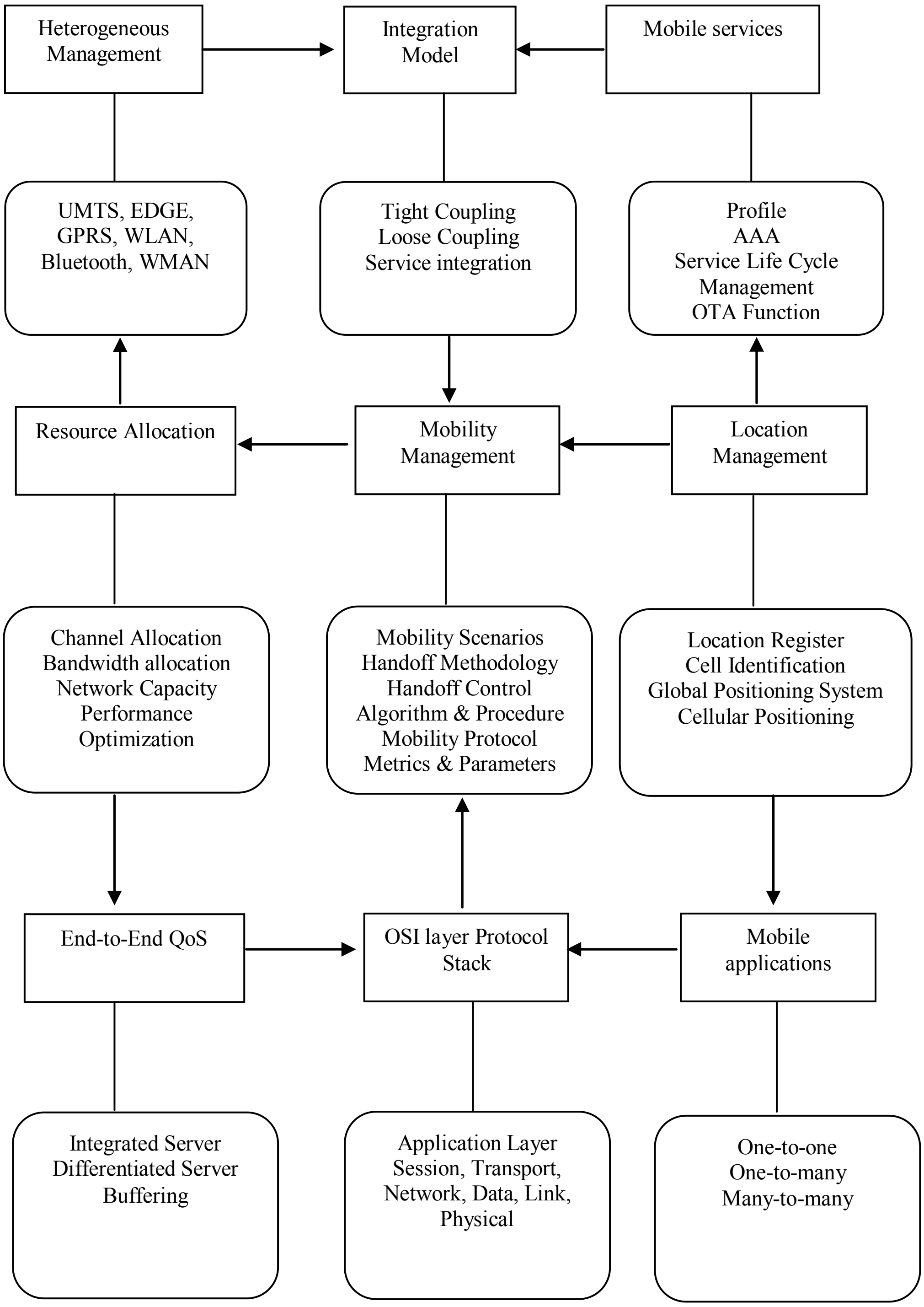

Figure 2.2: Vertical handover architecture.

Resource management consists of two main parts i.e. direct and indirect resource allocation in heterogeneous wireless networks. Direct resource allocation referred to as channel and bandwidth allocation where as indirect resource allocation referred to as network capacity and performance optimization via different ways. QoS directly based on resource allocation whereas end-to-end QoS needs other managements such as packet‟s priority in router using header compression on wireless network and packet‟s buffering in routers and terminal. Mobility Engineering composes heterogeneous networks and services. Mobility engineering offers different services such as mobility management, design and implementation of multiple protocols [41, 42] middleware solution in OSI protocol stack layer. Service management offers the interactive mobile applications, location management, mobile services and service life cycle via "OTA" functions. OTA function is used for upgrading and downloading the services.

2.3.1 WLAN vs. UMTS (Cellular network)

The quantitative comparison of Wireless LAN Access Pinot (AP) and UMTS Base Station (BS) per Coverage area, cost and data rate is shown below:

UMTS Cellular Network Base Station (BS)

- Coverage unlimited
- Data rate 9.62 – 300 Kbps
- Cost – High

Wireless LAN Access Point (AP)

- Coverage limited
- Data rate 1 – 11 Mbps
- Cost - Low

2.3.2 Limitations of Vertical Handover

There are some limitations of vertical handover, e.g. it handles all the connections in same manner. When all TCP/IP connection automatically transfers from one interface to another, in this situation only one wireless interface (the best one) is used at that moment. The term used „the best one‟ normally concern with end user specific application. In most cases it use different techniques for multiple connections and it may also suitable for finer grained approach („this approach refers to sequential instruction for stream execution in parallel on asynchronous multiprocessor"). The second limitation of vertical handover is that vertical handover need the same network interface. All the wireless interfaces must be used as part of the same Mobile IP and DNS infrastructure because mobile nodes and peers must be able to reach the Mobile IP and DNS server. Because of these two limitations [26, 5, 15] vertical handover cannot bring together the ad-hoc technologies, such as ad-hoc 802.11b, IrDA and Bluetooth.

The cellular coverage is typically much more widespread than that of WLAN; WLAN-to-Cellular handover usually poses more strict time constraints than handover in Cellular-to-WLAN direction. There are two types of traffic: 1. real time services (RTS) and 2. Non Real Time Services (NRTS). In real time services disruption of ongoing mobile"s session must be reduced. During the delay sensitive that is real time services handover operation should be faster as it is possible, because in this case we have to minimize the delay during the handover process. In case of non real time services the transmitted data is more important than that of delay, therefore connection to WALN Access Point (AP) coverage area should be maintained as long as possible.

2.3.3 Handover Delay in Vertical Handover

Between the heterogeneous wireless networks the handover process can be set apart into handover execution and handover decision process. In handover decision process both the mobile node and network decides that when the handover process will be occur. After taken handover decision, the handover execution process continues. The handover decision process involves supplementary network information such as replica address detection time in Mobile IPv6, when handover decision and detection process overlaps. The handover delay can be alienated in to three main mechanisms [5, 15].

2.3.3.1 Discover Time (t_d)

In this process via link layer beacon, the mobile terminal perceive that it is in the under the range of new wireless network from where it get the router Advertisement (RA) of new access router. Through the RA and triggered-based router solicitation from access router in the visited network, the mobile terminal (MT) detects the coverage on new network.

2.3.3.2 Address Configuration Period (t_c)

In this period the MT receive the Router Advertisement (RA) and updates its routing table and assign the new care of address (CoA) to all its interfaces. This new CoA based on new access router accessible form RA.

2.3.3.3 Network Registration Period (t_r)

In this period the binding updates are transmit to home agent (HA) as well as correspondent node and collect the acknowledgement from correspondent node. As binding acknowledgement from correspondent node is elective, so we consider the situation when mobile node accept packet from correspondent.

2.4 Vertical Handover between WLAN and Cellular network

Handover is the mechanism by which ongoing connection between MS is transferred from one point of access point to another point while maintaining the connectivity. When MS moves away from WLAN-AP to Base station of UMTS, the signal level degrades and there is a need to switch communications to another point of attachment that gives access to the existing IEEE 802.11 WLAN network or UMTS network. Handover mechanism in an overlay network and underlay WLAN network could be performed so that the users attached to the UMTS just occasionally check for the availability of the underlay WLAN network. A good handover algorithm is needed to make the decision when to make handover in order to avoid an unnecessary handover, i.e. false handover occur. The handover procedure or mechanism is based on RSS metrics. It means that the handover initiation or the handover triggering is sensitive to these signals [27, 28].

An MS moving from the WLAN network coverage may suddenly experience severe degradation of service and will have to perform handover very fast to maintain the higher layer connection. The following stages occur when an MS moves away from the coverage of WLAN within the UMTS coverage:

I. The signals received from the access point in WLAN network is initially strong and the MS is connected to the WLAN network, which is also the home network of the MS and the HA [A home agent is a router on a mobile node‟s home network which tunnels datagrams for delivery to the mobile node when it is away from home. It maintains current location (IP address) information for the mobile node. It is used with one or more foreign agents] in this network.

II. The signals from the access point become weaker when the mobile moves away. The mobile scans the air for another access point. If no access point is available, or if the signal strengths from the available access point are not strong enough, the handover algorithm uses this information along with other possible information to make a decision on handling over to the higher overlay UMTS network. Connections procedures are initiated to active the UMTS PCMCIA card.

III. The handover algorithm in the MS decides to dissociate from the WLAN and associate with the UMTS network.

IV. The FA [A foreign agent is a router that stores information about mobile nodes visiting its network. Foreign agents also advertise care-of-addresses which are used by Mobile IP] is activated and used by the MS dual PCMCIA card and the mobile IP protocol, and the MS gets a CoA due to visiting the UMTS network as a foreign network.

V. The HA in the WLAN is informed about the new IP address through a mobile IP registration, and it does proxy address resolution protocol (ARP) and interprets the datagram. The HA encapsulates the datagram and tunnels any packets arriving for the MS to the FA of the UMTS networks. At the end of the delivery, the MS will deencapsulated and get the datagram.

2.5 Problems in Vertical Handover

Wireless network is the major medium of communication between the people in today‟s tremendously growing world of Telecommunication. The demand of this type of communication is increasing day by day, therefore to handle this demand more wireless networks have to establish to obtain the high data rate requirement. In case of VHO due to symmetric nature RSS is not compatible with VHO. Mobile out (MO) means when MN goes WLAN to UMTS network and mobile in (MI) means when MN goes UMTS network to WLAN. When Mobile Terminal discovers the WLAN coverage area its starts the MI process because MI decision depends upon the availability of preferred network. Now if more than one

Wireless LAN access point (AP"s) are present in the coverage area then the MT establishes the connection with the AP from which it receives the strongest Received Signal Strength (RSS).

Now in MO scenario the Mobile Terminal MT performs only one handoff at the end of Wireless LAN, where network is expected to unavailable. So according to scenario discuss the above the VHO faces the following problems [2].

I. To minimize the number of surplus handover processes to reduce the network load.

II. To maximized the underlay network resources.

III. To assure the required degree of quality of services (QoS)

IV. To reduce the congestion of the network in case of MI.

V. To prefer the handover in case of MO in the underlay network.

2.6 VHO Limitations Due to WLAN Deployment

There are two approaches for WLAN-Cellular interworking: tight coupling and loose coupling. In loosely coupled architecture WLAN connect to the cellular network through an external Internet Protocol network. In our thesis, vertical handover architecture is based on loosely coupled architecture. An example of the VHO timing is shown in Figure 2.3. The figure shows the smoothed (IEEE 802.11 b/g) WLAN link quality [received signal strength indication (RSSI) in decibels below 1 mW] as a function of time when the MS is moving out of WLAN coverage at a constant speed. At $t = t_{tp}$, we assume that the smoothed RSSI has dropped below a trigger threshold S_{tp}, and the VHO is triggered. At $t = t_{11}$, the WLAN link has then dropped to a value S_{11}, which is insufficient to reliably carry the connection. We define a successful seamless VHO as that in which the triggering and establishment of the cellular call leg is completed before the WLAN link is lost, i.e.

$$P_{success} = P\{t_{margin} > t_{vho}\} \tag{2.1}$$

Where, t_{vho} is the time required to perform the VHO and $t_{margin} = t_{11} - t_{tp}$ is the time difference between the VHO trigger and the time at which the WLAN link is lost [33].

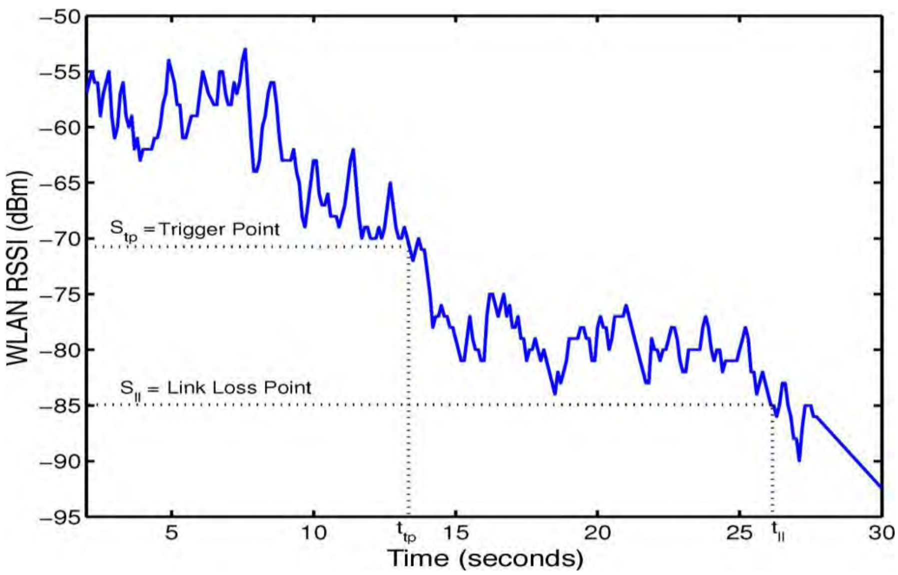

Figure 2.3: Illustrate t_{margin}.

In a loosely coupled system, the user has no control over cellular establishment latency: thus, to improve $P_{success}$, one must increase t_{margin} by

Option-1: Triggering the handover earlier

Option-2: Holding the Link to lower RSSI values

This may be done by using a higher signal strength triggering threshold S_{tp} for option-1. Unfortunately; there are strict limitations to this approach, which are dictated by the nature of the WLAN deployment. WLAN coverage is normally deployed based on target minimum guaranteed signal strength S_{margin}. This means that, throughout the coverage area of interest, the link quality will exceed $S_{\min}$ with a high probability. Due to the automatic data rate adjustment in IEEE 802.11, this value of $S_{\min}$ translates into a minimum link data rate for which the system was designed. When access points (APs) are sparsely deployed, then the value of Smin will tend to be low, resulting in low average link data rates. Conversely, when APs are densely deployed, $S_{\min}$ will tend to be higher, resulting in higher data rates and higher network capacity. When a VHO is to be triggered, the RSSI trigger threshold S_{tp} must be strictly less than $S_{\min}$, i.e. $S_{tp} < S_{\min}$; otherwise, the false handover rate may be unacceptable.

False handover occurs when VHO is unnecessarily triggered, resulting in a cellular call leg while WLAN coverage is still sufficient. Obviously, if S_{tp} exceeds $S_{\min}$, then this threshold may frequently be crossed while the MS is inside the WLAN hotspot and the false handover rate may be unacceptable.

The other way (using option-2) to improve $P_{success}$ is to allow the MS to hold the WLAN link as long as possible. When this is done in IEEE 802.11, the link will be rate adjusted to lower bit rates as the link quality drops. However, allowing stations to drop to low bit rates can have a negative impact on system capacity and is particularly undesirable in high-capacity Wi-Fi networks, such as those deployed for carrying real-time voice. This is done by having the AP advertise restricted IEEE 802.11 basic service set rates and requiring MSs to hand over rather than to drop below the set limits. These mechanisms create an artificially higher value of S_{11} than that dictated by minimum WLAN bit rates, which reduces the time available to perform VHO and leads to increased failure rates.

2.7 Summary and Comments

The motivation inter-technology (vertical handover) for the hybrid mobile data networks arises from the fact that no one technology or service can provide ubiquitous coverage, and it will be necessary for a mobile terminal to employ various points of attachment to maintain connectivity to the network at all times. From section 2.6 it is clear that it is very difficult to successfully complete the vertical handover unless the WLAN deployment has carefully been engineered. So for a seamless vertical handover, we have to find a solution which gives the system enough time by which time the vertical handover can done successfully. However, this is very difficult task given the time constraints in a loosely coupled WLAN-Cellular architecture.

Chapter 3

Literature Review

Seamless wireless local area network (WLAN)-to-cellular handover can often be very difficult to achieve. A particularly bad scenario may occur when mobile users exit from indoor WLAN coverage to outdoors during active voice connections. The dual mode hand-held devices to connect WLAN and universal mobile telecommunications system (UMTS) are becoming popular to meet the challenges of bringing in both the cellular networks covering wide area and WLAN providing low cost high speed services within limited area. To achieve this target, many vertical handover (VHO) algorithms have been proposed that determine the appropriate time at which swapping of networks is performed. Some methods proposed explicit trigger mode to assist early detection of a vertical handover. Some methods are developed utilizing advantages of handoff detection and triggering through link layer mechanisms. This chapter provides a comprehensive overview of various methods, presented in literature, to explain the mechanisms for handover management between WLAN-to-cellular networks.

3.1 Introduction

Wireless devices are becoming increasingly multimodal, containing both wireless local area network and wireless cellular interfaces. This allows the device to access high speed WLAN coverage when it is available and to communicate via the cellular network in other situations. To provide for full interoperability, real time seamless handover between the two handset interfaces is very important. Since the cellular coverage is typically much more widespread than that of WLAN, WLAN-to-cellular handover usually poses more strict time constraints than handover in the cellular-to-WLAN direction.

The main problem of the vertical handover is that to early determination or detection of VHO. If we early detect the transitioning time then the handset enough time to connect to the cellular network before loosing its WLAN link. For early detection of vertical handover

(VHO), the media independent handover (MIH) function [19] in existing fast vertical handover hierarchical Mobile IPv6 (FVH-HMIPv6) provides information for the mobile terminals (MT) to allow seamless handover between different networks described in section 3.3.

During the vertical handover, one of the key issues is to reduce the disruption to ongoing mobile‟s session. Therefore the challenge with which the service providers are confronted is to find a solution with less cost subject to constrained handover latency. The handover cost estimation using designated crossover point (DCP) [20] rerouting method between UMTS/WLAN described in section 3.4. One of the most important factors in vertical handover is handoff delay. The experimental handoff delay using layer-2 triggering method is compared with theoretical estimation. The handoff delay in heterogeneous networks is explained in section 3.5.

This is very difficult to successfully complete the vertical handover unless the WLAN deployment has carefully been planning. Smadi *et al.* [35] proved that the Vertical handoff rate can be improved significantly by incorporating delaying handoff i.e., extending the time span in the previous network, using limited data rate usage (LDU) method. The LDU algorithm improves the vertical handover performance without adversely affecting the WLAN capacity is explained in section 3.6. Our thesis is based on LDU algorithm. The LDU algorithm is designed using two dimensional Markovian decision process model. The Markovian decision process model is explained in section 3.2. An explicit trigger node [26] exposes to assist early detect the vertical handover which is an extension of LDU [26] method describe in section 3.7.

The rest of the chapter is organised as follows: Section 3.2 presents markovian decision process model. The related review of existing vertical handover method: Vertical handover using MIH function is presented in Section 3.3, Section 3.4 presents DCP rerouting method. Utilizing link layer mechanism vertical handover is presented in Section 3.5. Limited data rate usage method is presented in section 3.6, trigger node assisted WLAN to cellular vertical handover method is presented in Section 3.7. Finally, a summary and some concluding remarks are presented in Section 3.8.

3.2 Markovian Decision Process

A Markov chain, named after Andrey Markov, is a mathematical system that undergoes transitions from one state to another, between a finite or countable number of possible states. It is a random process characterized as memoryless: the next state depends only on the current state and not on the sequence of events that preceded it. This specific kind of "memorylessness" is called the Markov property. Markov chains have many applications as statistical models of real-world processes. Formally, a Markov chain is a discrete (discrete-time) random process with the Markov property. Often, the term "Markov chain" is used to mean a Markov process which has a discrete (finite or countable) state-space. The Markovian decision process model has following properties:

I. All states of the Markov process communicate with each other i.e., it is possible to go from each state, possibly in more than one step, to every other states.

II. The Markov process does not drift away to infinity.

A Markov decision process is a Markov chain in which state transitions depend on the current state and an action vector that is applied to the system. Typically, a Markov decision process is used to compute a policy of actions that will maximize some utility with respect to expected rewards. Usually a Markov chain is defined for a discrete set of times. In Discrete-time Markov Decision Process, decisions are made at discrete time epoch. However, for Continuous-time Markov Decision Process, decisions can be made at any time when decision maker wants. Different than Discrete-time Markov Decision Process, Continuous-time Markov Decision Process could better model the decision making process when the interested system has continuous dynamics.

A Markov system (or Markov process or Markov chain) is a system that can be in one of several (numbered) states, and can pass from one state to another each time step according to fixed probabilities. Markov processes are used to model a variety of important random systems, including communication systems, transportation networks, image segmentation and analysis, biological systems and DNA science analysis, random atomic motion and diffusion in physics, social mobility, population studies, epidemiology, animal and insect migration, queuing systems, resource management, dams, financial engineering, actuarial science, and decision systems [13].

If a Markov system is in state i, there is a fixed probability, P_{ij}, of it going into state j the next time step, and P_{ij} is called a transition probability. In an abstract setting, consider a system moving through time that has n possible states that is a random process. Such a process is considered to be a first-order Markov process if the state at the next time period is only reliant on the current state of the system. For a first-order Markov process, we can assign a transitional probability, P_{ij} for all i, j in $\{1,\cdots\cdots,n\}$ where P_{ij} represents the probability that if a system is currently in state i that it will be in state j at the next time period.

A random process, $x(t)$, is said to be a Markov process if for any time instants, $t_1 < t_2 \cdots\cdots < t_n$, the random process satisfies

$$\begin{aligned} & p\left(x(t_n) \le x_n \middle| x(t_{n-1}) = x_{n-1}, x(t_{n-2}) = x_{n-2}, \ldots, x(t_1) = x_1\right) \\ & = p\left(x(t_n) \le x_n \middle| x(t_{n-1}) = x_{n-1}\right) \end{aligned} \qquad (2.1)$$

In this equation, we interpret t_{n-1} as the present time so that t_n represents some point in the future and $t_1, t_2 \cdots\cdots, t_{n-2}$ represent various points in the past. The Markovian property then states that given the present, the future is independent of the past. Or, in other words, the future of the random process depends only on where it is now and not on how it got there.

A Markov system can be illustrated by means of a state transition diagram, which is a diagram showing all the states and transition probabilities. The matrix P whose ijth entry is P_{ij} is called the transition matrix associated with the system.

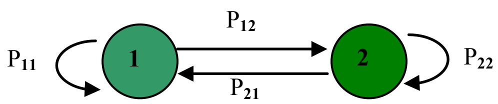

Figure 3.1: Transition matrix probability.

In Figure 3.2, the entries in each row add up to 1. Thus, for instance, a 2×2 transition matrix P would be set up like Figure 3.2 using Transition matrix probability shown in Figure 3.1.

To state

1 **2**

From state **1** **2**

$$\begin{bmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{bmatrix}$$

Figure 3.2: 2×2 transition matrix.

An absorbing state is a state from which there is a zero probability of exiting. An absorbing Markov system is a Markov system that contains at least one absorbing state, and is such that it is possible to get from each non-absorbing state to some absorbing state in one or more time-steps. A Markov process is called a regular Markov process if some power of the corresponding transition matrix has only positive elements. It can be shown that every regular Markov process eventually converges to a certain state vector, called the steady-state vector that is independent of the initial state vector. When a system reaches the steady-state vector, it is considered to be equilibrium.

The equilibrium of Markov processes is an alluring quality of certain real life models, such as population statistics after multiple generations. A Markov random field (also called a Markov network) may be considered to be a generalization of a Markov chain in multiple dimensions. In a Markov chain, state depends only on the previous state in time, whereas in a Markov random field, each state depends on its neighbours in any of multiple directions. A Markov random field may be visualized as a field or graph of random variables, where the distribution of each random variable depends on the neighbouring variables with which it is connected. More specifically, the joint distribution for any random variable in the graph can be computed as the product of the "clique potentials" of all the cliques in the graph that contain that random variable. Modeling a problem as a Markov random field is useful because it implies that the joint distributions at each vertex in the graph may be computed in this manner.

3.3 Media Independent Handover Function

To provide general solutions for the vertical handover in heterogeneous access networks, the IEEE 802.21 standards group has dealt with a new standardization issue called the media independent handover function (MIHF) [17, 5, 1], which enables transparent service continuity while a mobile device switches between heterogeneous access network technologies. The MIHF is to provide abstracted services to upper layers by means of a unified interface and thus to enhance user"s experience of mobile devices by supporting handover between heterogeneous wireless networks. So, it can be stated that the MIHF is very useful facilities for vertical handovers in heterogeneous wireless access networks.

MIH, also known as IEEE 802.21 can be utilized to optimize the handover process for mSCTP [7]. MIH can improve mSCTP seamless handover between homogenous and heterogeneous networks by providing layer-2 trigger information. This information can help mSCTP to perform interface switching during the handoff process with a minimum delay and complexity [9]. However MIH only provides information to allow handover between different networks, it does not perform any handovers by itself. This information is very important to take decision for vertical handover.

The services provided by MIHF help the upper layers in maintaining service continuity, service adaptation to varying quality of service, battery life conservation and network discovery and link selection. The MIHF can help the upper layers to implement effective procedures to couple services across heterogeneous network interfaces. Upper layers utilize the service provided by the MIHF across different entities to query and reserve resource required for a handover operation between heterogeneous access networks. Therefore, the MIHF can be very useful facilities for vertical handovers in heterogeneous wireless networks.

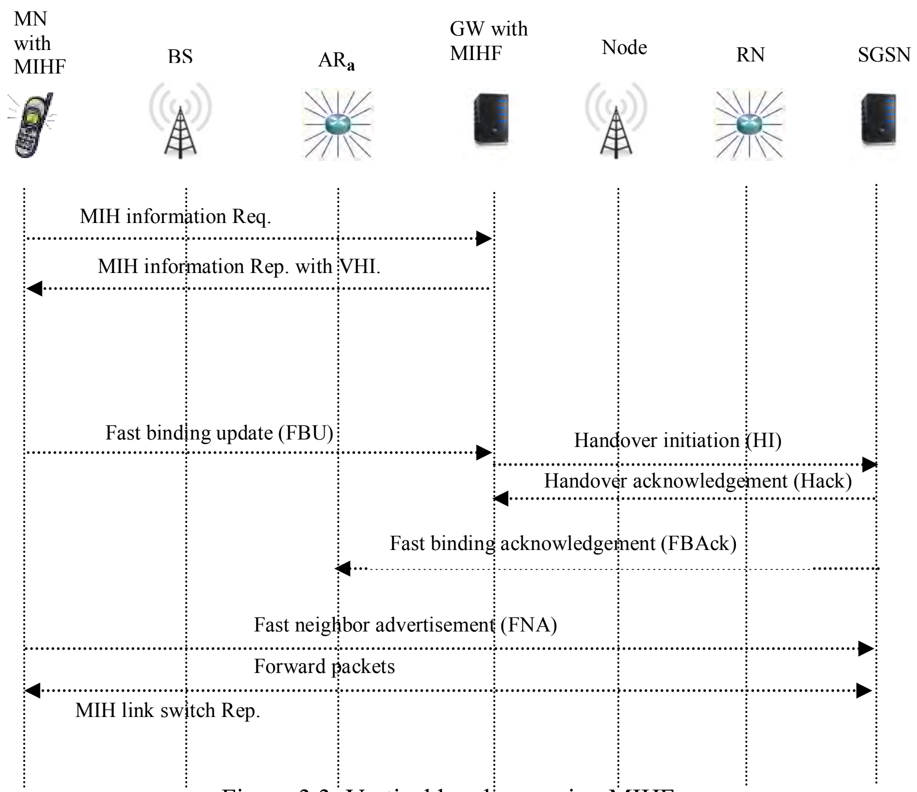

Figure 3.3: Vertical handover using MIHF.

The MIHF defines three different services: Media Independent Event Service (MIES), Media Independent Command Service (MICS) and Media Independent Information Service (MIIS). MIES indicates changes in state and transmission behaviour of the physical, data link and logical link layers or predict state changes of these layers. The common events of MIES are “MIH link up”, “MIH link down”, “MIH link going down” etc. MICS enables upper layers to control the physical, data link and logical link layers. MICS commands like this: “MIH scan”, “MIH configure”, “MIH switch” etc. MIIS provides a framework and corresponding schemes by which the MIHF entity can discover and obtain network information existing within geographic area. MIIS provides access to both static and dynamic information.

When the mobile node (MN) connected link becomes weak, the MIHF MIES will be informed by the MAC layer of the MN and produce “MIH Link Going Down” message. By receiving this message the MN selects the 3G network to handover to. After selecting the 3G network, the MN can utilize MIHF MICS and generate a link switch command using “MIH Link Switch” request. Then, the MN sends a fast binding update (FBU) message to the old MAP (oMAP) via its current access router (AR_a). After receiving FBU, the oMAP in WirelessMAN in IEEE (IEEE 802.16e) network sends a handover initiation (HI) message to new MAP (nMAP) to establish new network. This handover procedure is shown in Figure 3.11. Interface switchover can be optimized by using MIH. However, mSCTP still needs some additional components to perform location management. In this method, the “MIH information” request and reply messages must be done much before the layer-2 trigger i.e. MIH link going down. In this method, the time is needed for discover MAC address is fully eliminated.

3.4 Designated Crossover Point Rerouting Method

The designated crossover point (DCP) rerouting policy estimated the cost for vertical handover by placing the agents, referred as DCP only on the edge routers in the customers‟ premises to support vertical handovers. For each mobile terminal there is one DCP in the path of the communication (UMTS or WLAN) to deroute the signaling message and data traffic between the wireless networks for handling the mobility caused by vertical handovers. In this architecture, agents referred to as DCP [18, 11, 8, 37] places only on the edge routers in the customers‟ premises to support vertical handovers. The method is improving the cost of the vertical handover based on Mobile IP between UMTS and WLAN in the loose interworking scenario for real time services.

When a vertical handover happens, the mobile changes its association of the network and COA. As a result, the QCS(QoS server in customer‟s network)-QNS(QoS server in provider‟s network) negotiation for the resource reservation over IP backbone to the „CE of mobile" is mandatory and thus induces a high latency of vertical handover and serious interruption of real time services. To relieve from the problem, two approaches are possible:

I. Delaying the vertical handover, i.e. enabling the vertical handover after the new path is determined.

II. Multicast the streams to the base stations where the mobile currently and possibly visits.

The efficiencies of the both approaches depend on the location to join and old new paths. By simply joining the old and new paths at the crossover router, the latency of the vertical handover can be removed. However, within the IP end-to-end QoS architecture more considerations are needed to be taken. Possible crossover points to perform the join operation under the reference IP end-to-end QoS architecture. From Figure 3.4, the call continues with the network 10.3.0.0 and 10.1.0.0. If the mobile moves from the network 10.1.0.0 to the network 10.2.0.0, the crossover router point maybe (a), (b) or (c). Now which point is optimal one?

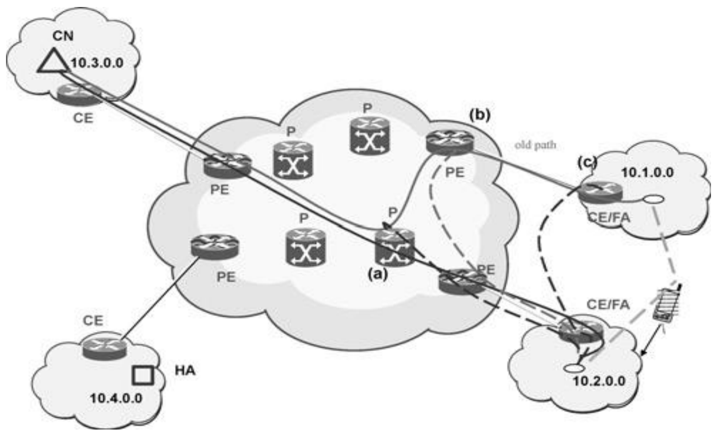

Figure 3.4: Possible crossover points for placing DCP.

From the first sight, placing the crossover point at (a) induces best routing efficiency. Secondly for the router point at (b) or (c), the new path should be derouted. To set crossover point, some important points have to think: such as longer delay, scalability, multiple reservations etc. For case (a), the optimal point depends on the core networks (CNs). For case (b), the customer edge router (old CE)/ foreign agent (FA) may connect to two PEs where the question arise multihoming. For above reasoning crossover point at (c) is the good option. For choosing point (c) just move the DCP to the „CE of mobile", i.e. DCP rerouting. DCP reroute use the address of „CE of mobile" as new CoA.

But when joining old and new paths, some drawbacks are induced. The latency for the QCS-QNS negotiation: Such as real time service is interrupted. This method works well in small network but DCP maintaining pre-allocated pipes or multiple reservations of routers generates longer delay in large scale network. If we all-time think join the old and new paths: for the macro flow communications it creates a bottleneck situation. This method clearly increased cost overhead when the UMTS and WLAN cells are increased.

3.5 Handover Through Link Layer Triggering

Mobile systems require seamless connectivity to reduce service disruptions. Each mobile node is assigned an IP address, in the same way as any other nodes, known as the mobile node"s home address. When visiting a foreign network a mobile node acquires a CoA, which is a globally-routable address, through the IPv6 address auto-configuration mechanism. The association of a mobile node"s home address with a care-of-address is known as binding. It does not place any request on intermediate nodes and routers of the internet: it only requires the presence in visited networks of a router sending Router Advertisement packets. Here, the link layer mechanism [3, 15] is used to vertical handoff between different network technologies. This method explained the handover delay such as: detecting lower layer events, handoff execution delay using layer-2 triggering method and compared with theoretical estimation.

This method describes the relationship between link layer (L2) and network layer (L3) handoffs and shows that the contribution of L2 handoff to the overall delay can be predominant, especially when there are more users in the same cell. The method is based on open source implementation of mobile IPv6 for linux (MIPL). MIPL supports seamless vertical handover between the network interfaces available in a mobile node: the interfaces are found by using the standard IPv6 address auto configuration. In MIPL, it is assumed that both old and new interfaces are available during the vertical handover. Vertical handovers can be classified as:

I. Forced handovers: triggered by physical events regarding network interfaces availability.

II. User handovers: triggered by user policies and preferences.

Detection and triggering are more important for the first kind of handover. In the second case, most of the times, both interfaces available before starting the handovers. The efficiency of this method is fully dependent on the presence of different network interfaces how to configure a mobile node to transparently migrate among different network environments at each different level.

The basic idea of lower layer triggering is to monitor the status of the interface in order to trigger the handoff without waiting the network layer triggering based on Router Advertisements (RAs). The architecture is shown in Figure 3.5 that monitors the interfaces to different interfaces to different technologies with the aim of hiding the details of the low level interaction with the device drivers.

The *Event_Handler* running in user-space that reads the description of which policy it should enforce for the priorities of the network interfaces. It manages events read from an *Event Queue*, where events are inserted by modules (handlers) in charge of monitoring all the network interfaces. The *Event_Handler* response to events can be either to trigger a vertical or horizontal handoff (that is, a change of interface or link) or to configure an idle interface to manage a possible handoff.

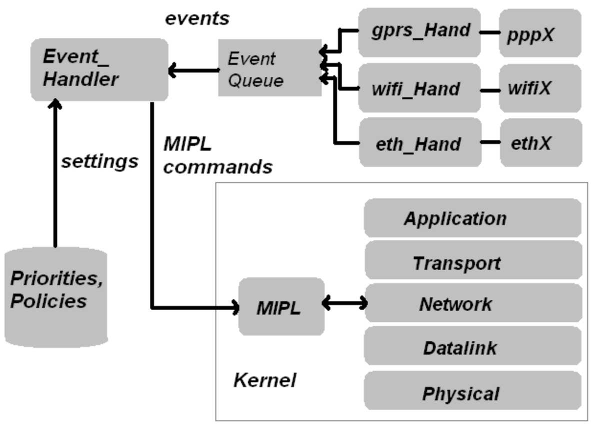

Figure 3.5: lower layer triggering architecture.

The *Event_Handler* algorithm is shown in Figure 3.6 Events regard either link availability or failure or link quality. The efficiency of lower layer triggering depends on fast signaling to the *Event_Handler* from the network interface handlers: i.e. get information about the interfaces status.

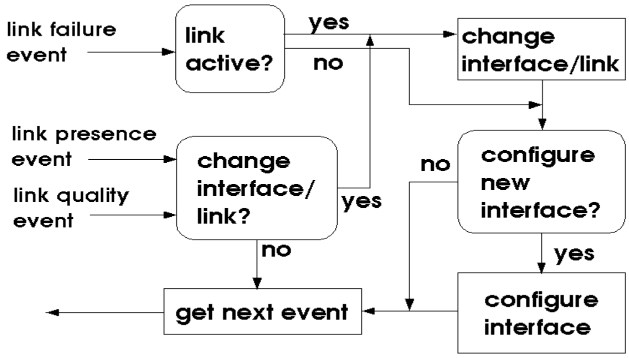

Figure 3.6: Event_handler algorithm.

This solution is highly dependent on the number of clients of the visited WLAN. There is still an open debate in the IETF community about the employment of lower layer information at the network layer. The most important performances factor such as: success probability and call blocking probability of vertical handover did not explained with improvements of handover delay.

3.6 Performance parameters

A new call is blocked when a corresponding request is rejected. This results in a call not being initiated. A handover is blocked when a vertical handover request is rejected. This results to an abnormally terminated existing call. An outgoing call is dropped when an unsuccessful vertical handover occurs. Admitting more new services causes the frequent disruption to the ongoing services in a congested network and may result in their termination. From the users‟ perspective, being blocked to initiate a new service due to resource constraints is undesirable. However, dropping an ongoing service, while roaming across cells, is far less desirable, if not unacceptable. A cellular network must therefore implement a resource reservation strategy to ensure higher priority for handoff services. Reserving resources decreases the call dropping probability (CDP) at the expense of increased call blocking probability (CBP) and reduced bandwidth utilization, defined as the ratio of the total bandwidth in use and the total bandwidth available. To evaluate the vertical handover method, we have to calculate the performance parameters. These performance parameters give the clear identification: is the vertical handover method performed better or not? These performance parameters are explained below.

3.6.1 Call dropping probability (CDP)

This is the most important parameter for choose the best vertical handover method. The formula is:

$$CDP = \frac{number\,of\,calls\,dropped\,during\,handoff}{total\,number\,of\,calls\,in\,network}$$

The call dropping occurs for the various reasons such as- 1) the mobile unit needs to rate adjust with other channels which is not available in the system. 2) The mobile unit wants to switch to another data rate which is not given by the system.

3.6.2 Call blocking probability (CBP)

This is also an important term for calculating the performance of vertical handover methods. The formula is:

$$CBP = \frac{number\,of\,new\,calls\,blocked\,in\,network}{total\,number\,of\,calls\,in\,network}$$

The call blocking occurs for some reasons such as- 1) Maximum number of calls already running in the wireless access point or cell. 2) All channels in wireless access point or cell in a network are consumed by running calls.

3.7 Limited Data Rate Usage Method

The European Telecommunications Standards Institute has specified two WLAN-Cellular interworking: 1. loose coupling and 2. tight coupling [8]. Loosely coupled architectures connect the WLAN to the Cellular network through an external Internet Protocol (IP) network, such as that found in a corporate enterprise. In tight coupling, the WLAN is integrated into the service provider"s Cellular network, and an interworking gateway (GW) provides adaptation between the two systems. The LDU method is designed for loosely coupled architecture. In chapter 2, it was shown that a successful seamless WLAN-to-Cellular handover as that in which the triggering and establishment of the cellular call leg is completed before the WLAN link is lost [33, 25, 4, 6, 12, 29, 43, 44, 30]. The most important performance factor of vertical handover is the handoff dropping rate which is clearly explained in LDU algorithm. No other vertical handover method clearly discussed it before.

The mobile station (MS) must be allowed to hold the link long enough while the Cellular call leg is being established. From Figure 3.7 and Figure 3.8, it shown that an MS needs to maintain the WLAN link to RSSI values with corresponding data rates close to the noise floor to accomplish a successful vertical handover. This is described in section 2.6. Since many modern high-capacities WLAN installations may restrict WLAN access point (AP)-MS data rates, so that high capacity operation can be ensured. In Limited Data rate Usage (LDU) algorithm [33] accomplished the vertical handover (VHO) in the presence of high-capacity WLAN installations.

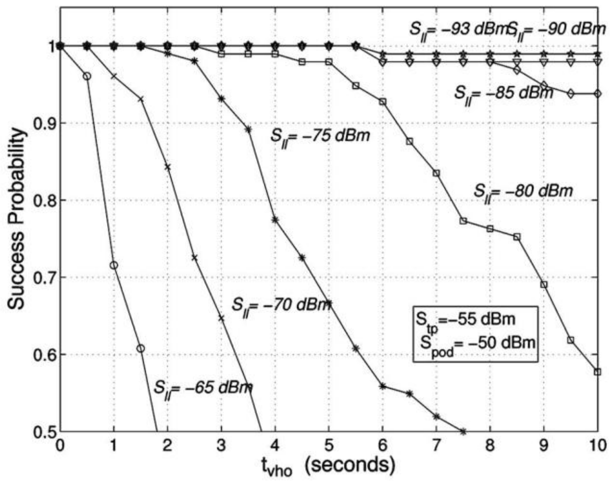

Figure 3.7: $P_{success}$ as a function of t_{vho} for S_{pod}=-50 dBM.

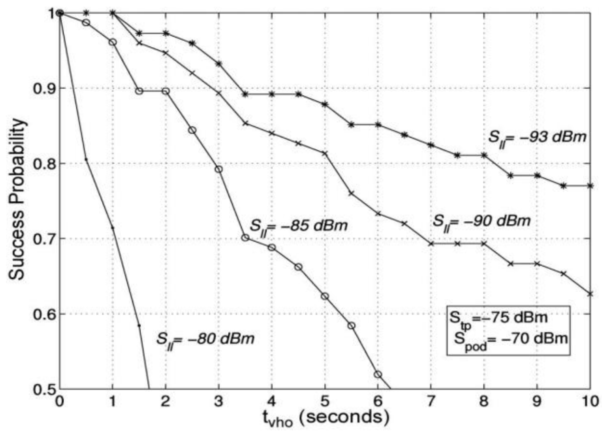

Figure 3.8: $P_{success}$ as a function of t_{vho} for S_{pod}=-70 dBM.

In a conventional system, the AP will terminate an MS‟s association if the link quality drops below S_{11} (WLAN link loss point). In LDU, however, the AP-MS link quality is permitted to drop to a value of as low as $S_{disassocite}$ ($\leq S_{11}$) for up to a time period denoted by T_{Ldu}. In LDU, a timer is kept in the WLAN-AP for each associated MS $MS_i.Timer$. If the MS_i‟s link quality $MS_i.RSSI$ drops below S_{11}, the timer begins running until it reaches a value of T_{Ldu}. If the link recovers before the timer reaches T_{Ldu}, then the timer is reset and the process continues. However, if the link quality remains below S_{11} for this time period or if the link quality ever drops below $S_{disassocite}$, then the MS_i is disassociated and vertical handover done. The algorithm is shown in Figure 3.9.

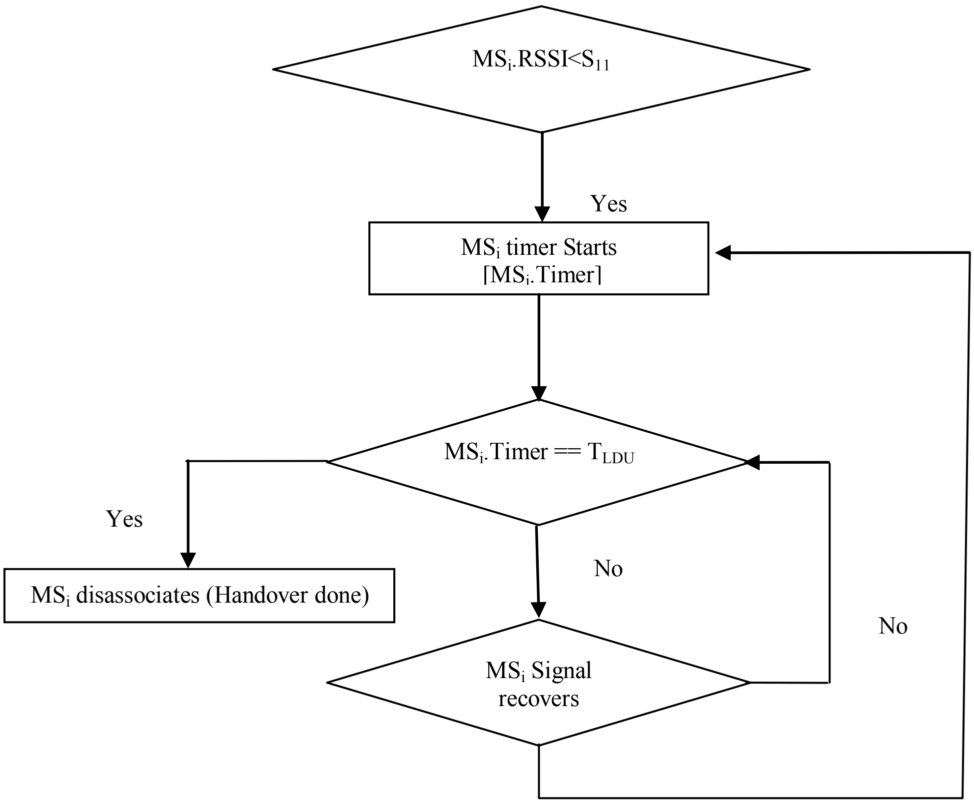

Figure 3.9: Limited Data rate Usage algorithm.

The intent behind the LDU algorithm is to permit MSs to hold the WLAN link at values less that S_{11} for a limited period of time, so that VHO can successfully be accomplished.

Enforcing a fixed time period prevents stations from indefinitely holding the link at low data rates, which might adversely affect the capacity of the AP. The value of T_{Ldu} must be greater than the time needed for VHO with a high probability. At first, we explain conventional vertical handover method then LDU algorithm. The vertical handover method both conventional and LDU algorithm is described using two dimension markovain decision process model.

The AP is discretized such that a new call consumes a single "channel" at the highest data rate. The AP is assumed to handle at most N concurrent calls at this data rate. This assumption is used for new voice connections that are made inside the indoor WLAN coverage area. When a WLAN is installed for high-capacity VoIP, the AP density is usually high so that the highest bit rate can be used for each link inside the nominal coverage area, i.e. a high $S_{\min}$. An AP that is not implementing the LDU algorithm will restrict the advertised data rates to maintain capacity, whereas an AP that is implementing the LDU algorithm will allow stations that are associated with the AP at high data rates to maintain the link when an active session starts to experience lower data rates.

To model this behaviour, we consider a simple example where the conventional or non-LDU WLAN-AP is assumed to advertise two data rates, i.e. R_1 and R_2. An LDU AP is assumed to advertise a third data rate R_3, but this is only permitted for MS"s that have initiated a VHO. The VHO is triggered when the MS link drops from R_1 to R_2. If the MS cannot maintain the data rate at R_2 before the call has completed or the VHO has succeeded, then the call is forcefully terminated. In contrast, the LDU AP allows the MS to rate adjust down to R_3 and to maintain the link until either the call is completed or the VHO has succeeded.

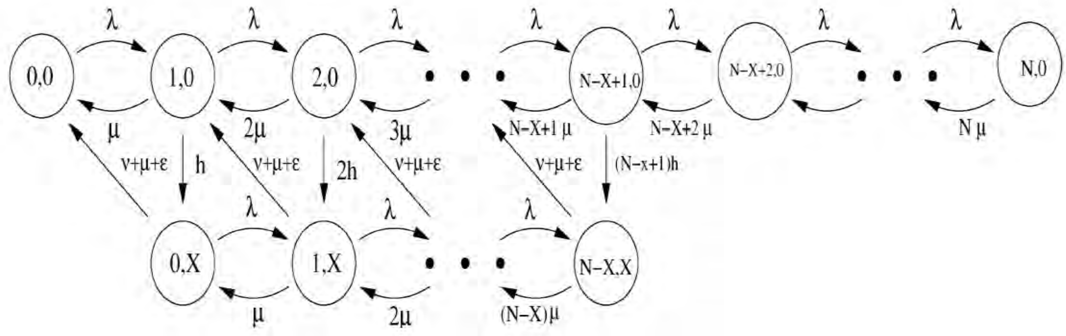

Figure 3.10: Markov process for the conventional method.

The design of two dimension markovian decision model is shown in Figure 3.10 describing the non-LDU AP. New calls arrive according to a poisson process with mean arrival rate λ. A given call may be completed after an exponentially distributed time $1/\mu$. An active call may also initiate a VHO at a rate of h. Immediately after initiating the VHO, the MS starts to consume X channels, instead of one channel, which it consumed at R_1. A call that has shifted to a lower data rates can be successfully finishing the VHO with rate v, or be dropped with rate ε if it requires rate adjustment to R_1. Compared with new calls arrivals VHO events are assumed to be rare: for that reason only a single VHO event can be outstanding at any given time.

The new call blocking probability is found by summing over the probabilities of being in states $S(N,0)$ and $S(N-X,X)$ since no more new calls can be admitted to the system. Handover dropping occurs for the following two events:

I. When the MS operating at data rate R_2 needs to switch to R_3 data rate, which is not supported by the conventional or non-LDU AP

II. When the MS is experiencing R_1 data rate and needs to rate adjust to R_2 data rate but there are no available channels.

The handover dropping probability is

$$B'_{handover} = \left(\left(\sum_{i=n-x+2}^{n} \Pr\{s(i,0)\} h \right) + \left(\sum_{i=0}^{n-x} \Pr\{s(i,x)\} \varepsilon \right) \right) \bigg/ \left(\sum_{i=0}^{n} \Pr\{s(i,0)\} h \right) \qquad (2.2)$$

From Figure 3-6, it is shown that if any calls from the state $n-x+2$ to state n (calls are operating at R_1 data rate) want to initiate vertical handover i.e. to adjust second data rate R_2 this call is dropped. Secondly, when a call from state 0 to state $n-x$ (calls are operating at R_2 data rate) needs to switch to third data rate R_3 but this third data rate is not supported by conventional vertical handover method this call is dropped. In this markovian decision process model, the first row is operating call at R_1 data rate consuming one channel and second row is operating call at R_2 data rate consuming X channels.

The LDU method exposes the third data rate R_3 and Markovian process is modified to describe an AP using LDU. An additional row is added to allow MSs to rate adjust to data rate R_3. So, an MS that is experiencing second data rate R_2 and needs to rate adjust third data rate is allowed to operate at R_3 data rate and the call starts to consume Y channels instead of X channels it consumed at R_2 data rate. Therefore, an MS can operate at any of three available

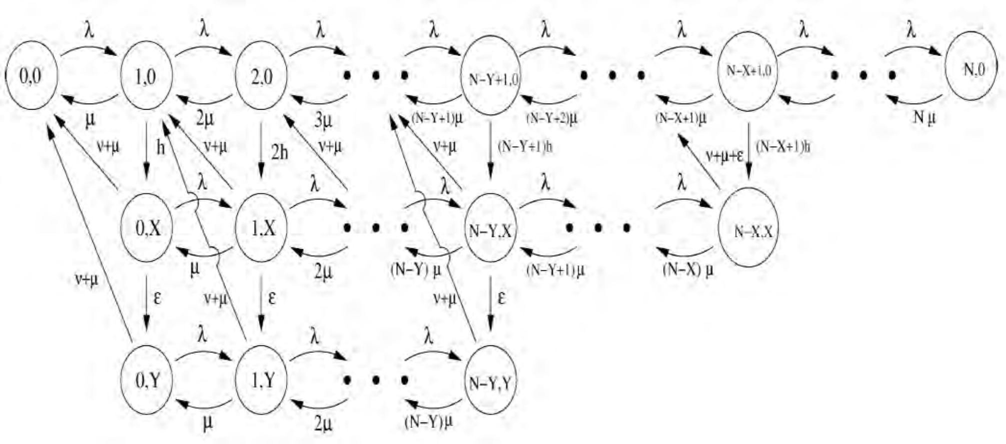

Figure 3.11: Markovian decision process model for limited data rate usage method.

data rates R_1, R_2 and R_3. The new call blocking probability is found by summing over the probabilities of being in states $S(N,0)$, $S(N-X,X)$ and $S(N-Y,Y)$ since no more new calls can be admitted to the system.

The handover dropping probability for LDU method is

$$B_{handover}^{LDU}=\left(\left(\sum_{i=n-x+2}^{n}\Pr\{s(i,0)\}ih\right)+\left(\sum_{i=n-y+1}^{n-x}\Pr\{s(i,x)\}\varepsilon\right)\right)\Big/\left(\sum_{i=0}^{n}\Pr\{s(i,0)\}ih\right) \tag{2.3}$$

From Figure 3.11, it is shown that if any calls from the state $n-x+2$ to state n (calls are operating at R_1 data rate) want to initiate vertical handover i.e. to adjust second data rate R_2 consuming X channels but no available channels this call is dropped. Secondly, when a call from state $n-y+1$ to state $n-x$ (calls are operating at R_2 data rate) needs to switch to third data rate R_3 but no available channels to adjust third data rate this call is also dropped. However, the good scenario is that for the state 0 to state $n-y$ no vertical handover dropping is occurred. In this markovian decision process model the first row is operating call at R_1 data rate consuming one channel; second row is operating call at R_2 data rate consuming X channels and third row is operating call at R_3 data rate consuming Y channels. In both markovian models the state is described by:

$$s(i,j) \quad \begin{array}{l} i = number\ of\ new\ calls\ operating\ at\ data\ rate\ R_1 \\ if\ j = 0,\ there\ is\ no\ call\ actively\ handover \\ j \neq 0,\ there\ is\ a\ single\ call\ initiate\ handover \end{array}$$

3.8 Trigger Node Assisted WLAN to Cellular Vertical Handover

To provide successful VHO the WLAN link has to be maintained until the cellular connection is established. This method extends the LDU method by exposing an explicit trigger node [24, 25, 4, 19] to assist early detection of vertical handover which will give the handset enough time to connect to cellular network before loosing its WLAN link. A trigger node is a very simple IEEE 802.11 device that merely transmits beacons and is placed at the building exits. It transmits beacons at the PoDs (signal strength at point of departure point) of the WLAN deployment. When a MS gets close to the PoD, it senses the transmissions from the trigger node (TN) and initiates a VHO. In this method, two algorithms are proposed with which the MS initiates a VHO.

The boundary AP (BAP) has the strongest signal at the vicinity of the PoD. The first triggering algorithm uses both the RSSI from the trigger node, S_{tn} , and the RSSI from the BAP, S_{bap} , to initiate a VHO and is called TN-COM. A VHO is triggered by the MS whenever the RSSI from the TN is sensed to be stronger than that from the BAP and it is below a certain threshold, S_{tn}^{tp}. The following inequality formally states the triggering condition.

$$S_{bap} < S_{tn} < S_{tn}^{tp}$$

Using the trigger node in this method it is possible to initiate VHO close to the PoD regardless of the value of $S_{\min}$. However, if the signal at the PoD is not sufficiently large to sustain a call during its VHO then the call will lose its WLAN before VHO is completed. The TN-COM algorithm is a good choice if the deployment has a low $S_{\min}$ but the RSSI at the PoD is large. The result is showed in Figure 3.12.

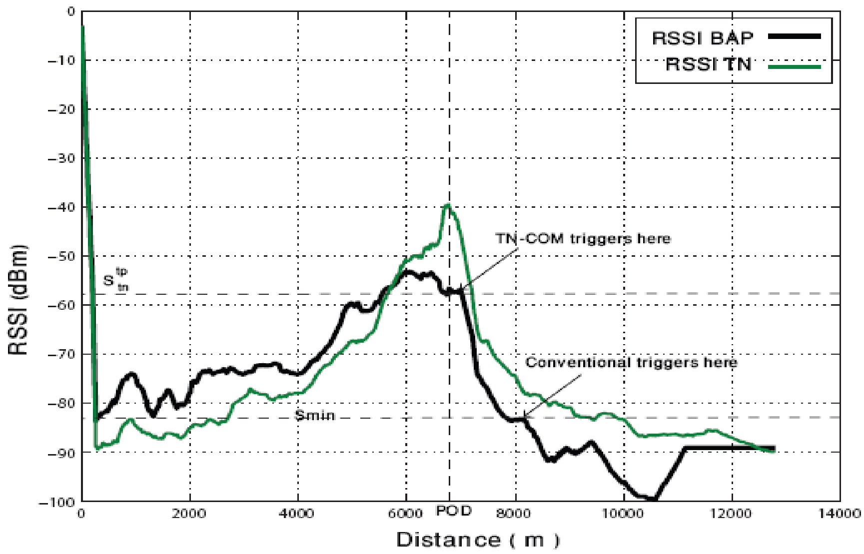

Figure 3.12: A case of using TN-COM.

TN-COM is works well if S_{pod} is sufficiently high. In deployments with weak signal coverage at the PoD, this algorithm is not benefited. The stand-alone trigger node (TN-STL) scheme is the solution for these situations. In this scheme a VHO is triggered when the RSSI from the TN is above some threshold, i.e., $S_{tn} > S_{tn}^{tp}$. The result is shown in Figure 3.13.

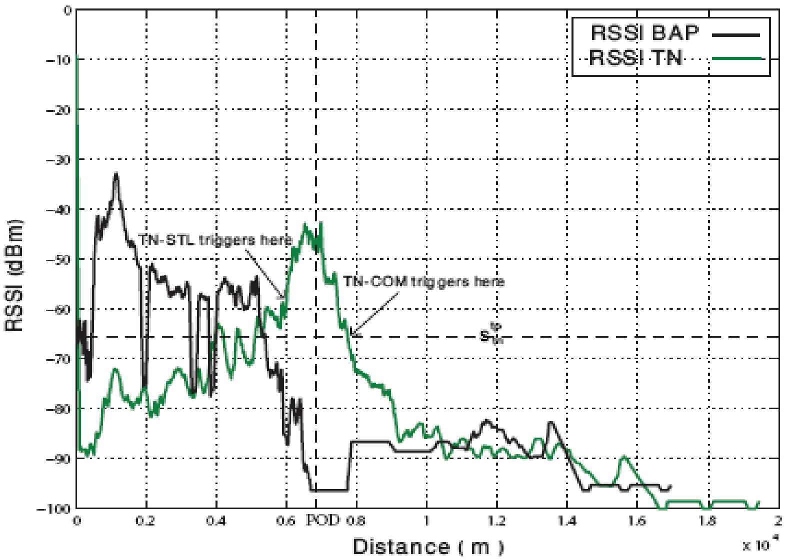

Figure 3.13: A case when using TN-STL.

Figure 3.12 compared with Figure 3.13, it is clearly shown that if we used LDU method with trigger node assisted WLAN-to-Cellular vertical handover then seamless vertical handover can easily be achieved.

3.9 Summary and Comments

Considering the above discussion, we have gathered a strong concept of the related works that have been done in our research area. We have shown different problems of vertical handover here, which clear our concepts and different problems related to these along with their solutions. Moreover, we have also shown how these problems are different from our lastly discussed LDU algorithm though they seem very closer. For early detection of vertical handover (VHO), the media independent handover (MIH) function is discussed briefly. The cost estimation of vertical handover is discussed here shortly. We also discussed the handover delay estimation using layer-2 triggering. Lastly we explained the LDU method which is incorporating the delaying handoff and trigger node assisted vertical handover for early detect vertical handover. Our thesis is fully concentrated on LDU algorithm.

Chapter 4

Proposed Modified Markovian Model for Vertical Handover

Currently, there are various wireless networks deployed around the world. Examples include second and third generation (3G) of cellular networks (e.g., GSM/GPRS, UMTS, CDMA2000), metropolitan area networks (e.g., IEEE 802.16, WiBro), wireless local area networks WLANs (e.g., IEEE 802.11a/b/g, Hiper LAN), and personal area networks (e.g., Bluetooth).The combination of all these networks is usually called the beyond 3G (B3G) wireless networks. New high-tech mobile terminals will allow users to freely move and to switch connections among different access networks. In B3G networks, the emerging state-of-the-art mobile devices will be equipped with multiple network interfaces to access different networks. These new mobile devices will provide the user with great flexibility for network access and connectivity but also generate the challenging problem of mobility support among different networks. Users will expect to continue their connections without any disruption when they move from one network to another [23].

4.1 Introduction

In the context of cellular networks a handover is defined as the mechanism by which an ongoing connection is transferred from one base station (BS) to another [23]. The BSs are the infrastructure (i.e., antennas, towers) that is deployed by the cellular operator to provide service in a geographic area. In this simple case, if we consider that both BSs use the same access technology, as in current cellular systems, we can say that homogeneous wireless networks perform HHO [36]. Such handover mechanisms mainly use signal strength measurements from the surrounding BSs to trigger and to perform the handover. The HHO algorithm decides in which BS the connection should be transferred to. It is usually the BS which provides the highest signal level to the mobile device. On the other hand, if we consider heterogeneous wireless networks such as the B3G networks, with BSs from cellular networks using one access technology and access points (APs) from WLANs using a different one, we can say that a VHO is the mechanism by which an ongoing connection is transferred from one BS to an AP and vice versa [36]. The new handover process among networks using different technologies is defined as vertical handover (VHO). In this chapter, vertical handover designed using markovian decision process model [33, 10] is presented. We also present some modifications in markovian decision process model which are needed to work it with real environment.

4.2 Vertical Handover Method using Markovian Model

The WLAN-AP (Access Point) will terminate an MS's association if the link quality drops below S_{11} (Signal strength at WLAN link loss point). Now we present the vertical handover using two-dimension Markovian decision process model. The capacity of the AP is discretized such that a new call consumes a single "channel" at the highest data rate. The AP is assumed to handle at most N concurrent calls at this data rate. This assumption is used for new voice connections that are made inside the indoor WLAN coverage area. When a WLAN is installed for high capacity VoIP, the AP density is usually high so that the highest bit rate can be used for each link inside the nominal coverage area i.e., a high $S_{\min}$ (minimum indoor WLAN signal strength). For maintaining capacity, WLAN-AP will restrict for the advertised data rates. An AP will advertise two data rates: 1) R_1 and 2) R_2. We assume that the VHO is triggered when the MS link drops from R_1 to R_2. If the MS cannot maintain the data rate at R_2 before the call has completed or the VHO has succeeded, then the call is forcefully terminated.

After model the vertical handover using two dimension markovian decision process, we calculate the handover dropping rate and new call blocking probability. These two probabilities are very important for performance analysis of the vertical handover mechanism. The markovian model is memoryless. We use this term for describing new call arrivals in WLAN-AP. Figure 4.1 shows the Markov decision process model describing the WLAN-AP. New calls arrive according to a Poisson process with mean arrival rate λ. A given call may be completed after an exponentially distributed time $1/\mu$. An active call may also initiate a VHO at a rate of h. Immediately after initiating the VHO, the MS starts to experience R_2, and the call starts to consume X channels, instead of one channel, which it consumed at data rate R_1. VHO events are assumed to be rare in comparison with new call arrivals; thus only a single VHO event can be outstanding at any given time.

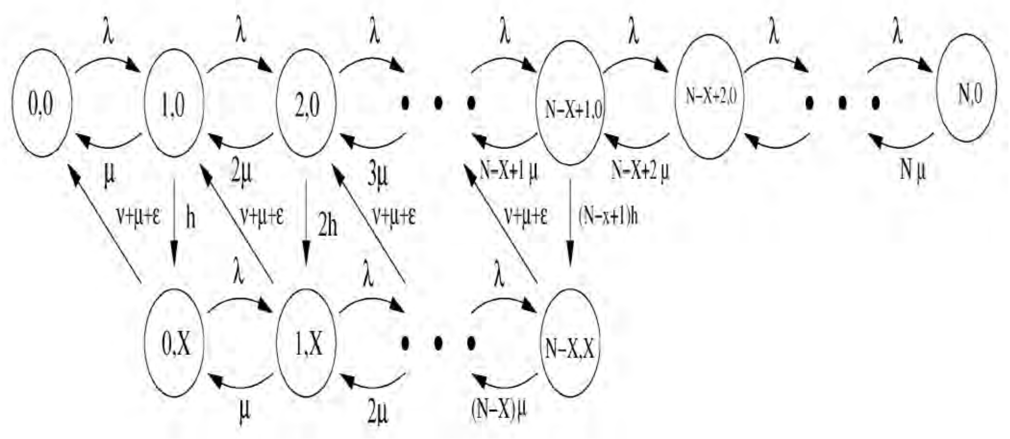

Figure 4.1: Markov process for conventional vertical handover.

A call that has shifted to a lower data rate can be completed with a rate μ, successfully finish the VHO with rate v, or be dropped with rate ε if it requires rate adjustment to R_1. Here, the state is described by $s(i,j)$, where i is the number of new calls operating at R_1. Additionally, if $j = 0$, then there is no call that is actively handing over; otherwise, there is a single call that is attempting a handover. One call is initiating handover but it is not successfully complete the handover process due to various reasons then the call is dropped this is call handover dropping. This diagram arises from the two-dimensional Markov chain with the state space

$$S = \begin{cases} \{(i,j)|\ 0 \le i < n,\ j = 0\} \\ \{(i,j)|\ 0 \le i < n-x,\ j = x\} \end{cases} \tag{4.1}$$

where i denotes the number of new calls in the WLAN-AP and j denotes wether any call initiates or attempts handoff or not in the WLAN-AP. Let n be the threshold value for the new calls and $n-x$ is the threshold value for the handoff initiated call. Here we assume that when one call initiates handoff it consumes maximum x channels which in normal case it consume one channel.

Now, we present the probability transition. Let $s(i,j;\bar{i},\bar{j})$ denote the probability transition rate from state (i,j) to state $(\bar{i},\bar{j})$. Here, i denotes the number of call and j denotes the number of channel occupied by i call. The Markovian decision process model has the following transition probability:

$$\begin{aligned}
&s(i,j;i+1,j)=\lambda && (0\le i<n,\ j=0)\\
&s(i,j;i-1,j)=i\mu && (0<i\le n,\ j=0)\\
&s(i,j;i-1,j_1)=ih && (0<i\le n-x+1,\ j=0, j_1=x)\\
&s(i,j;i,j_1)=\nu+\mu+\varepsilon && (0\le i\le n-x,\ j=x, j_1=0)\\
&s(i,j;i+1,j)=\lambda && (0\le i<n-x,\ j=x)\\
&s(i,j;i-1,j)=i\mu && (0<i\le n-x,\ j=x)
\end{aligned} \tag{4.2}$$

where (i,j) is a feasible state in S. Let $s(i,j)$ denote the steady-state probability that there are i new calls and j handoff calls in the WLAN-AP. So, the offered load for new and handover services are $\rho=\lambda/\mu$ and $\rho_h=h/(\nu+\mu+\varepsilon)$, respectively. From the detailed balance equation, we obtain

$$\Pr\{s(i,j)\}=\begin{cases}\frac{\rho}{i}.\Pr\{s(0,0)\} & 0<i\le n, j=0\\ (i+1).\rho_h.\frac{\rho}{i}.\Pr\{s(0,0)\} & 0<i\le n-x, j=x\end{cases} \tag{4.3}$$

From the normalization, i.e. $\sum_{i=0,j=0}^{i=n}\Pr\{s(i,j)\}+\sum_{i=0,j=x}^{i=n-x}\Pr\{s(i,j)\}=1$, $\Pr\{s(0,0)\}$ can be found as

$$\Pr\{s(0,0)\}=\left[\sum_{i=0,j=0}^{i=n}\frac{\rho}{i}+\sum_{i=0,j=x}^{i=n-x}(i+1).\rho_h\cdot\frac{\rho}{i}\right]^{-1} \tag{4.4}$$

Handover dropping occurs when one of two events occurs: 1) when the MS operating at R_2 needs to switch to third data rate, which is not supported by the conventional vertical handover method and 2) when the MS is experiencing R_1 and needs to rate adjust to R_2 , but there are no available channels. From this we obtain the formula for handover dropping probability as follows:

$$B_{handover}^{LDU'}=\left(\sum_{i=n-x+2}^{n}\Pr\{s(i,0)\}ih+\sum_{i=0}^{n-x}\Pr\{s(i,x)\}\varepsilon\right)\Big/\left(\sum_{i=0}^{n}\Pr\{s(i,0)\}ih\right) \tag{4.5}$$

From the equation it is clearly shown that from state $s(0,0)$ to state $s(n-x+1,0)$, there are no calls dropped because for these states the calls are adjust to state $s(0,x)$ to state $s(n-x,x)$. In the rest of states from $s(n-x+2,0)$ to state $s(n,0)$ have the dropping probabilities. There are also dropping probabilities from state $s(0,x)$ to state $s(n-x,x)$.

New call is blocked when there are no available channels to admit the call (new call). So, the new call blocking probability is found by summing over the probabilities of being in states $S(n,0)$ and $S(n-x,x)$. Thus, the new call blocking probability is given by

$$B'_{Call-block} = \Pr\{S(n,0)\} + \Pr\{S(n-x,x)\} \quad (4.6)$$

4.3 Modified Markovian Model for Conventional Vertical Handover

A call initiates vertical handover with a data rate h but sometimes maybe scenario arising that some of calls return back to its same WLAN-AP. If a call initiates vertical handover it may be returned back to the previous network this important term is not considered when design the Markovian decision process model for conventional vertical handover method. We redesign the Markov decision process model with consider this important phenomenon. Let, the handover return-back probability be the $r1$. Now we have to calculate the handover dropping probability and new call blocking probability for the modified Markovian decision process model which is designed for the conventional vertical handover method.

The modified Markovian decision process model for conventional vertical handover method is shown in Figure 4.2. From state $s(n-x+2,0)$ to state $s(n,0)$ have the dropping probabilities. There are also dropping probabilities from state $s(0,x)$ to state $s(n-x,x)$. The handover dropping is occurred for the same reasons in modified Markovian decision process model which is occurred in Markovian decision process model but the calculation is some bit different. For the new call blocking probability for the modified Markovian model is same like Markovian model, this is only different in $(n-x)$ state.

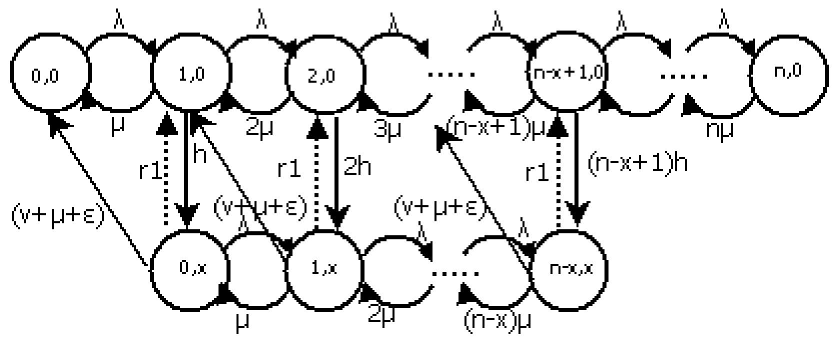

Figure 4.2: Modified Markovian model for conventional vertical handover method.

Now, we present the probability transition for modified Markovian model. Let $s(i, j; \bar{i}, \bar{j})$ denote the probability transition rate from state (i, j) to state $(\bar{i}, \bar{j})$. Here, i denotes the number of call and j denotes the number of channel occupied by i call. The Markovian decision process model has the following transition probability:

$$
\begin{aligned}
&s(i, j; i+1, j) = \lambda && (0 \le i < n,\ j = 0) \\
&s(i, j; i-1, j) = i\mu && (0 < i \le n,\ j = 0) \\
&s(i, j; i-1, j_1) = ih && (0 < i \le n-x+1,\ j = 0, j_1 = x) \\
&s(i, j; i, j_1) = v + \mu + \varepsilon && (0 \le i \le n-x,\ j = x, j_1 = 0) \\
&s(i, j; i+1, j) = \lambda && (0 \le i < n-x,\ j = x) \\
&s(i, j; i-1, j) = i\mu && (0 < i \le n-x,\ j = x) \\
&s(i, j; i+1, j_1) = r1 && (0 \le i \le n-x,\ j = x, j_1 = 0)
\end{aligned}
\tag{4.6}
$$

Only one state transition probability is added for modified Markovian decision process model. where (i, j) is a feasible state in S. Let $s(i, j)$ denote the steady-state probability that there are i new calls and j handoff calls in the WLAN-AP. So, the offered load for new and handover services are $\rho = \lambda/\mu$ and $\rho_h = h/((v + \mu + \varepsilon) + r1)$, respectively. Here, handover return-back probability be the $r1$. A call that has shifted to a lower data rate can be completed with a rate μ, successfully finish the VHO with rate v, or be dropped with rate ε. From the detailed balance equation, we obtain

$$\Pr\{s(i,j)\} = \begin{cases} \frac{\rho}{i}.\Pr\{s(0,0)\} & 0<i\le n, j=0 \\ (i+1).\rho_h.\frac{\rho}{i}.\Pr\{s(0,0)\} & 0<i\le n-x, j=x \end{cases} \tag{4.7}$$

From the normalization, i.e. $\sum_{i=0,j=0}^{i=n} \Pr\{s(i,j)\} + \sum_{i=0,j=x}^{i=n-x} \Pr\{s(i,j)\} = 1$, $\Pr\{s(0,0)\}$ can be found as

$$\Pr\{s(0,0)\} = \left[\sum_{i=0,j=0}^{i=n} \frac{\rho}{i} + \sum_{i=0,j=x}^{i=n-x} (i+1).\rho_h.\frac{\rho}{i} \right]^{-1} \tag{4.8}$$

The new call blocking probability is found by summing over the probabilities of being in states $S(n,0)$ and $S(n-x,x)$. Thus, the new call blocking probability is given by

$$B'_{Call-block} = \Pr\{S(n,0)\} + \Pr\{S(n-x,x)\} \tag{4.9}$$

4.4 Simulation Result

We are using MATLAB for performance measurement of our proposed conventional vertical handover method. At first, we formulate the Markovian model using global balance equation and get the mathematical result and after that using random Markovian parameters value we get the empirical or experimental result. Using the student t-Test from independent samples, we get the confidence level from mean and standard deviation which are calculated by mathematical and empirical modelled value. A t-Test is any statistical hypothesis test in which the test statistic follows a Student's t distribution if the null hypothesis is supported. It is most commonly applied when the test statistic would follow a normal distribution if the value of a scaling term in the test statistic were known. In our thesis, we calculate or simulate the call dropping probability (CDP) and call blocking probability (CBP) using Table 2.1 Markov parameters.

Table 2.1: Markov parameters.

Parameter	Value
N	72 channels
X	2 channels
Y	18 channels
Z	36 channels
R_1	72 Mbps
R_2	9 Mbps
R_3	1 Mbps
R_4	0.5 Mbps
S_{tp}	-45 dBm
T_{vho}	7 sec
T_{LDU}	0.05 sec
μ	0.004-0.0060 sec^{-1}
ν	0.001-0.2 sec^{-1}
ε	0.0044-0.044 sec^{-1}

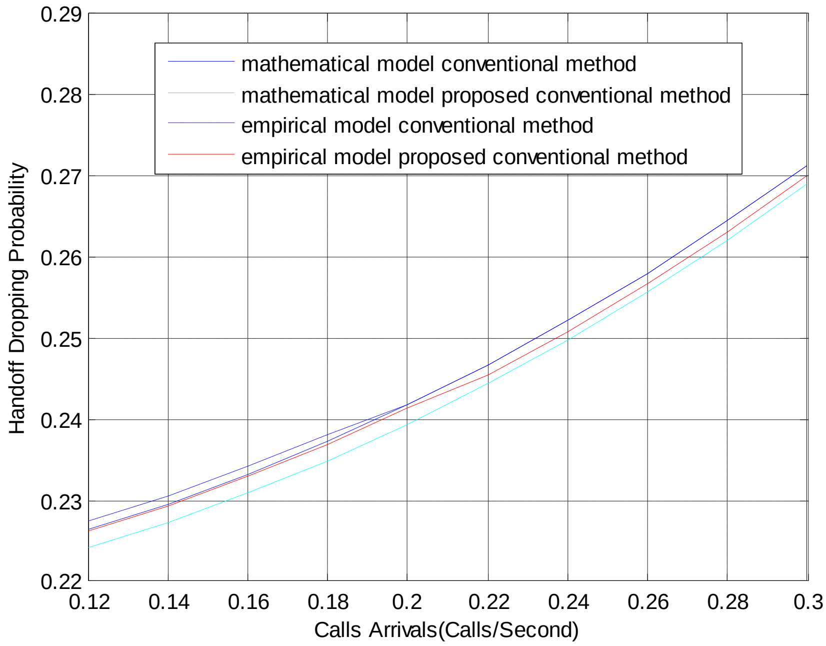

Figure 4.3: Handover-dropping probability (with confidence level 95 percent) when h=0.0000690-0.0000735 sec^{-1}.

From these simulation results, it was shown that if we modified conventional vertical handover method then we get better handoff dropping probability then previous one. Actually we must be calculated the return back probability of conventional vertical handover method because it is a common scenario in handover process.

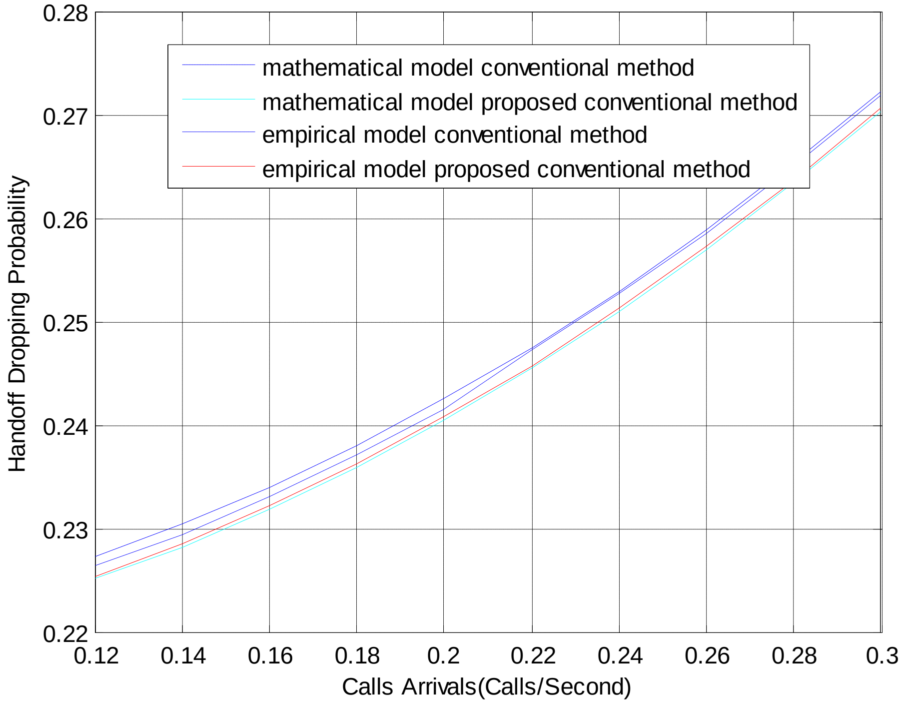

Figure 4.4: Handover-dropping probability (with confidence level 95 percent) when h=0.0000940-0.0000944 sec^{-1}.

In Figure 4.3 and Figure 4.4, we see the handover dropping probabilities for two handover rates. This is explained by noting that, at higher handover rates, the system starts to experience higher capacity due to the early termination of handover calls. This additional capacity results in a lower handoff-dropping probability. In Figure 4.5, we see the new call blocking probability; here also we see the slow improvement of proposed modified conventional vertical handover method. In Figure 4.6, for two initiated handover return probability we see the two handoff probabilities and there is a greater change of handoff probability and this is a remarkable improvement of vertical handover method.

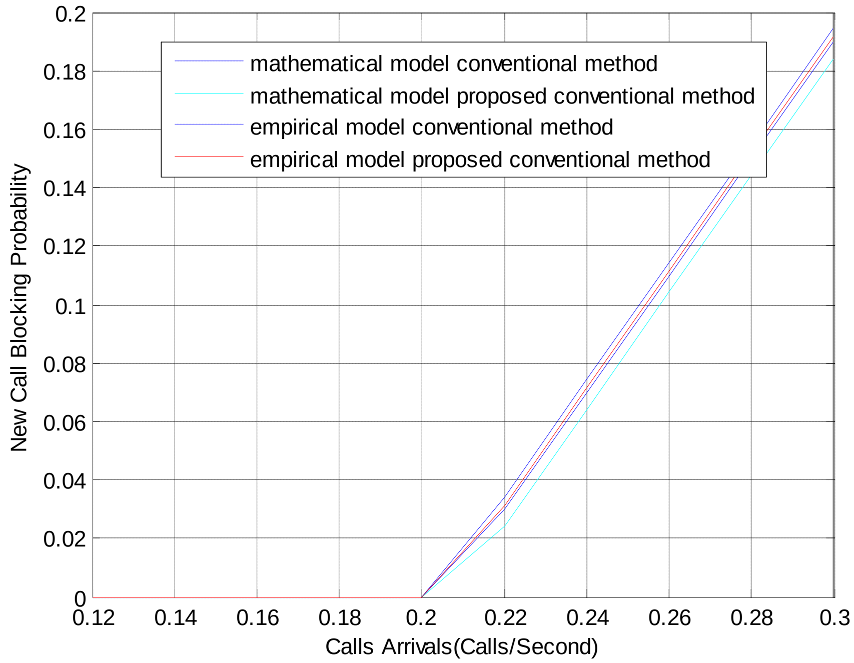

Figure 4.5: New call blocking probability (with confidence level 95 percent) when h=0.000500 - 0.000555 sec^{-1}.

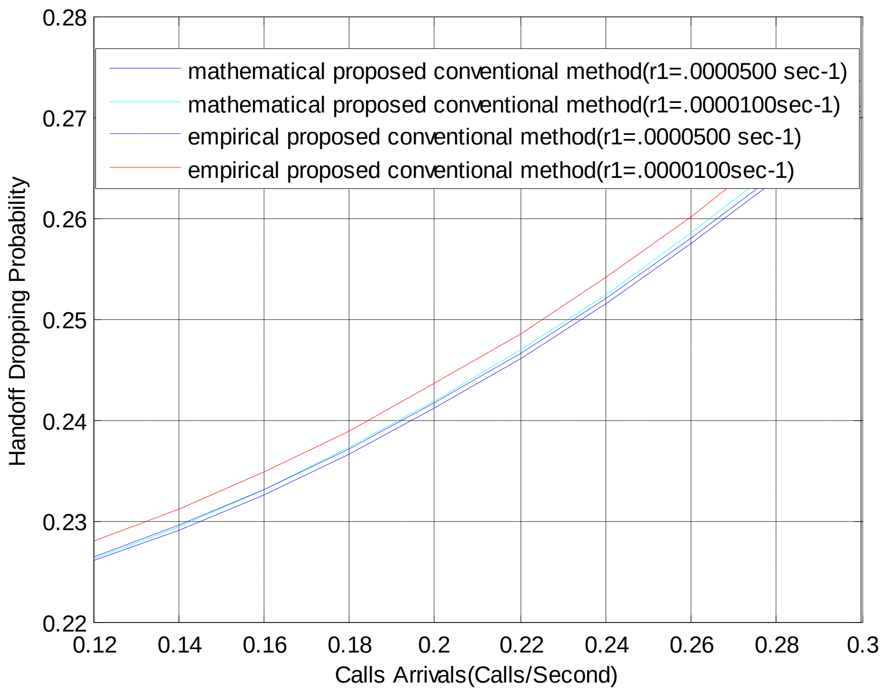

Figure 4.6: Handoff dropping probability (with confidence level 95 percent) for two return back probabilities when h=0.0000725-0.0000730 sec^{-1}.

4.5 Summary and Comments

The vertical handover method which is present in this chapter it is a traditional vertical handover mechanism. The Markovian decision process is designed for it to get the handover performance parameters which are compared with the limited data rate usage (LDU) method. We have the modifications on LDU method which is also creating same influences on the conventional vertical handover method. So we modified it to cope it with real life environment and make it real for performances calculation. The modifications which are done in conventional vertical handover method is very important and crucial also.

Chapter 5

Proposed Modified LDU and Extended LDU Method

Seamless wireless local area network (WLAN)-to-cellular handover can often be very difficult to achieve. A particularly bad scenario may occur when mobile users exit from indoor WLAN coverage to outdoors during active voice connections. It is very difficult to successfully complete the vertical handover unless the WLAN deployment has carefully been engineered. There is a restriction in WLAN deployments for the use of lower data rates. Limited data rate usage (LDU) algorithm improves the vertical handover performance without adversely affecting the WLAN capacity. In vertical handover process, our target is to achieve successfully done the vertical handover such that handover dropping rate is minimum. Actually, Users always expect to continue their connections without any disruption when they move from one network to another.

5.1 Introduction

The multimodal wireless devices are access high speed wireless local area network (WLAN) coverage when it is available and to communicate via the cellular network in other situations. Dual-mode (DM) handsets with WLAN and cellular interfaces are becoming increasingly common. From the two types of architecture i.e. tightly coupled architecture and loosely coupled architecture, the LDU method focuses on loosely coupled dual-mode architecture. With the increase in cellular network users, there has been a growing demand for more services with diverse quality of service (QoS) requirements. Most of the existing mobile service providers are now successful in supporting their users to access telephony, paging, instant messaging, and trivial web-browsing on the same device. Future cellular network infrastructures such as beyond third Generation (B3G) and 4G are, therefore, evolving towards supporting an even broader range of real time multimedia services (e.g. phone calls, live audiovisual broadcasting, video conferencing, and e-business with a mobile decision support system) and non-real time data traffics (e.g. e-mail, text and multimedia messaging, and file transmissions) with different QoS assurances under various traffic conditions. With the proliferation of mobile devices, people accustomed to using high speed wired connections are expecting the same level of QoS by the cellular networks, especially for multimedia data transmissions. Extensive literature [36, 25, 3] has dealt with VHO techniques, including VHO detection, triggering, and connection forwarding. When design LDU method it have performed many experiments to characterize the potential handover performance in building-exit situations [33].

When an MS has a voice connection in WLAN coverage, the station continuously measures the quality of the downlink whenever voice packets are received. In addition, it may periodically test for better candidate APs, which would result in an improved link. This searching may proactively or reactively be performed, based on a preset scan threshold. Once the handover threshold has been reached, the MS would aggressively search for new candidate APs and, if found, would attempt a horizontal handover (HHO, i.e., an AP–AP handover). After the aforementioned procedures, if a candidate AP is not found, the MS would then initiate a VHO. HHO times are typically far smaller than loosely coupled VHO latencies, and these are expected to further decrease with IEEE 802.11 refinements (i.e., IEEE 802.11 k/r), which include proactive scanning and neighbour lists [32, 21]. For this reason, we assume that HHO attempts very quickly occur compared with VHO.

The rest of the chapter is organised as follows: Section 5.2 presents vertical handover measurement results. Section 5.3 describes the detailed LDU algorithm which is related to measurement result. Section 5.4 design Markovian model for LDU algorithm. Section 5.5 shows why modification is needed in existing LDU method and section 5.6 presents the proposed modified Markovian decision process model. Section 5.7 explained the proposed extended LDU method. The simulation results are explained in section 5.8. Trigger node assisted WLAN to Cellular vertical handover is presented in section 5.9. Finally, a summary and some concluding remarks are presented in Section 5.10.

5.2 Review of Vertical Handover

From section 2.6 we know that for successful seamless VHO as that in which the triggering and establishment of the cellular call leg is completed before the WLAN link is lost. From Figure 5-3 and Figure 5-4, it is shown that $P_{success}$ stays relatively constant up to a certain pinch off value of t_{vho}, after which it starts to quickly decrease. The pinch-off point increases as S_{11} is chosen to be smaller and further away from the PoD (Point of departure), effectively increasing the distance that the mobile user has to travel before losing the link. For instance, Figure 5-3 shows that, at S_{11} = -80 dBm, the success probability stays almost constant and very close to 100% VHO latencies of up to 5 sec, compared with 8 sec for S_{11} = -85 dBm. One can think of the pinch-off point as where the tightest guarantees on $P_{success}$ can be given. These observations regarding $P_{success}$ can be explained by stating that the probability density function (pdf) of t_{margin} corresponding to larger S_{11} values has a larger coefficient of variation and a smaller mean than the pdfs corresponding to smaller S_{11} values. The smaller mean of t_{margin} associated with larger S_{11} values explains the smaller pinch-off value. The higher decreasing rate of $P_{success}$ associated with larger S_{11} values is due to the higher coefficient of variance at these values of S_{11} [33, 24].

In order for threshold based VHO algorithms to yield acceptable handover success rates, wore case WLAN coverage must be very high in the target WLAN coverage area, i.e. a high $S_{\min}$. However, the MS must be must be allowed the MS must be allowed to hold the link long enough while the cellular call leg is being established. The results in Figure 5-4, for example, show that an MS needs to maintain the WLAN link to RSSI values (and corresponding data rates) close to the noise floor to accomplish a successful VHO. As previously discussed, this is a problem since many modern high-capacity WLAN installations may restrict AP–MS data rates (and, as a result, S_{11}), so that high-capacity operation can be ensured. In this section, we propose a simple LDU algorithm that will temporarily suspend this restriction, so that VHOs can be accomplished in the presence of high-capacity WLAN installations.

5.3 Limited Data Rate Usage Method

In a conventional system, the AP will terminate an MS's association if the link quality drops below S_{11}. In LDU, however, the AP–MS link quality is permitted to drop to a value of as low as $S_{disassocite}$ ($\leq S_{11}$) for up to a time period denoted by T_{LDU}. In LDU, a timer is kept in the AP for each associated MS MS_i and is denoted by $MS_i.Timer$. If MS_i's link quality

$MS_i.RSSI$ drops below S_{11}, the timer begins running until it reaches a value of T_{LDU}. Note that, if the link recovers before the timer reaches T_{LDU}, then the timer is reset, and the process continues. However, if the link quality remains below S_{11} for this time period or if the link quality ever drops below $S_{disassocitte}$, then MS_i is disassociated. The intent behind the LDU algorithm is to permit MSs to hold the WLAN link at values less than S_{11} for a limited period of time, so that the VHO can successfully be accomplished. Enforcing a fixed time period prevents stations from indefinitely holding the link at low data rates, which might adversely affect the capacity of the AP. The value of T_{LDU} must be greater than the time needed for VHO with a high probability.

The capacity of the AP is discretized such that a new call consumes a single "channel" at the highest data rate. The AP is assumed to handle at most N concurrent calls at this data rate. This assumption is used for new voice connections that are made inside the indoor WLAN coverage area. When a WLAN is installed for high capacity VoIP, the AP density is usually high so that the highest bit rate can be used for each link inside the nominal coverage area i.e., a high $S_{\min}$ (Minimum indoor WLAN signal strength). In non-LDU or conventional method, two data rates are advertised i.e. R_1 and R_2. An LDU AP is advertised third data rate R_3 [this is only permitted for MSs that have initiated a vertical handover]. Here the vertical handover is triggered when the MS link drops from R_1 to R_2. If the MS cannot maintain the data rate at R_2 before the call has completed or the VHO has succeeded, then the call is forcefully terminated. However, the LDU AP allows the MS to rate adjust down to R_3 and to maintain the link until either the call is completed or the vertical handover has succeeded.

5.4 Markovian Model for LDU Method

Figure 5.1 shows the Markov decision process model describing the WLAN-AP. New calls arrive according to a Poisson process with mean arrival rate λ. A given call may be completed after an exponentially distributed time $1/\mu$. An active call may also initiate a VHO at a rate of h. Immediately after initiating the VHO, the MS starts to experience R_2, and the call starts to consume X channels, instead of one channel, which it consumed at data rate R_1. VHO events are assumed to be rare in comparison with new call arrivals; thus only a single VHO event can be outstanding at any given time. A call that has shifted to a lower data rate can be completed with a rate μ, successfully finish the VHO with rate ν, or be dropped with rate ε if it requires rate adjustment to R_1. Here, the state is described by $s(i, j)$, where i is the number of new calls operating at R_1 . Additionally, if $j = 0$, then there is no call that is actively handing over; otherwise, there is a single call that is attempting a handover.

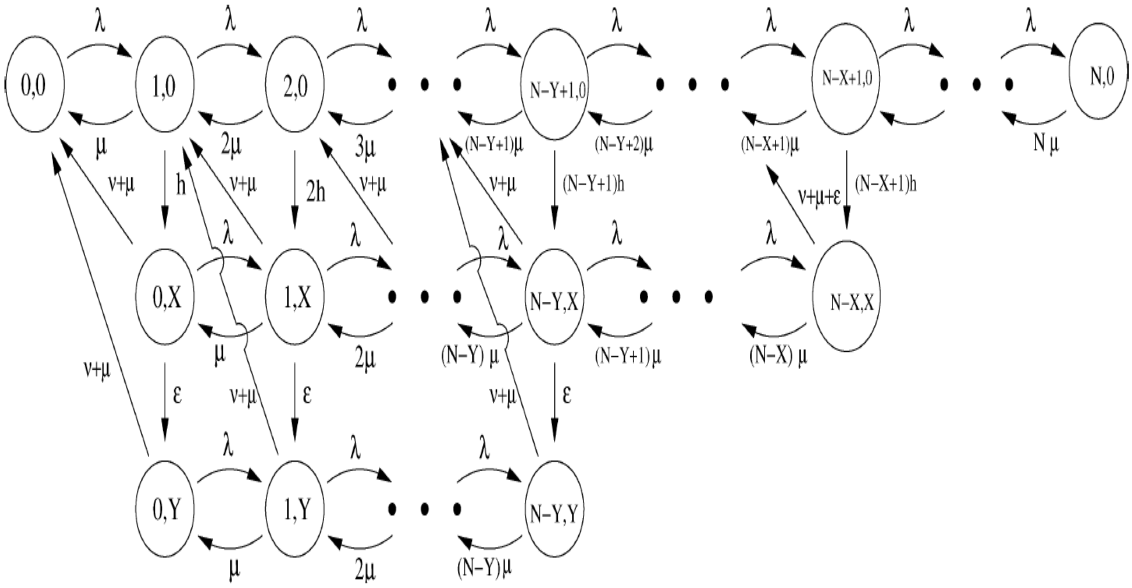

Figure 5.1: Markovain model for limited data rate usage method.

An additional row is added to allow MSs to rate adjust to third data rate R_3. An Ms that is experiencing R_2 and needs to rate adjust is allowed to operate at third data rate R_3, and the calls starts to consume Y channels instead of the X channels it consumed at second data rate R_2. For performance measurements in vertical handover methods, in following section 5.4.1 and section 5.4.2 we calculate most important two performance probabilities of the LDU method.

5.4.1 Handover Dropping Probability

In previous section 4.2, it explained that for two events handover dropping occurs in conventional vertical handover method. But in LDU method, handover dropping occurs when a call attempts to rate adjust and there are no more channels available. Therefore handover dropping occurs from state $s(n-y+1,x)$ to state $s(n-x,x)$. The states from $s(n-x+2,0)$ to state $s(n,0)$ have the dropping probabilities in previous conventional vertical handover method. There are no calls dropping from state $s(0,x)$ to state $s(n-y,x)$ because these states rate adjustment with third data rate R_3 from state $s(0,y)$ to state $s(n-y,y)$. The Markovian decision process model has the following transition probability:

$$\begin{aligned}
&s(i,j;i+1,j)=\lambda && (0\le i<n,\ j=0)\\
&s(i,j;i-1,j)=i\mu && (0<i\le n,\ j=0)\\
&s(i,j;i-1,j_1)=ih && (0<i\le n-x+1,\ j=0, j_1=x)\\
&s(i,j;i,j_1)=v+\mu && (0\le i\le n-x,\ j=x, j_1=0)\\
&s(i,j;i+1,j)=\lambda && (0\le i<n-x,\ j=x)\\
&s(i,j;i-1,j)=i\mu && (0<i\le n-x,\ j=x)\\
&s(i,j;i,j_1)=v+\mu && (0\le i\le n-y,\ j=y,\ j_1=0)
\end{aligned}$$

So, the handover-dropping probability is written as

$$B_{handover}^{LDU}=\left(\sum_{i=n-x+2}^{n}\Pr\{s(i,0)\}ih+\sum_{i=n-y+1}^{n-x}\Pr\{s(i,x)\}\varepsilon\right)\Bigg/\left(\sum_{i=0}^{n}\Pr\{s(i,0)\}ih\right) \tag{5.1}$$

5.4.2 New Call Blocking Probability

The new call blocking probability is found by summing over the probabilities of being in state $S(n,0)$, state $S(n-x,x)$ and state $S(n-y,y)$. Thus, the new call blocking probability is given by

$$B_{call-block}=\Pr\{S(n,0)\}+\Pr\{S(n-x,x)\}+\Pr\{S(n-y,y)\} \tag{5.2}$$

5.5 Modification Requirements in LDU Method

A call initiates vertical handover with a data rate h but sometimes maybe scenario arising that some of the calls return back to its same WLAN-AP like as modified conventional vertical handover method. If a call initiates vertical handover it may be returned back to the previous network this important term is not considered when design the Markovian decision process model for LDU method. We redesign the Markov decision process model with consider this important phenomenon. Let, the handover return-back probability be the r_1 from state consumed channel x to consumed channel 1 and r_2 from state consumed channels y to consumed channels x. LDU method assumes that after consuming Y channels [After initiating VHO], no calls are dropped. But we are disagreed this point also. Because for the VHO initiated calls that are consumed X channels in the conventional method if some calls has dropped for the rate adjustment to third data rate R_3. As the same reason the calls that are consumed Y channels, some calls are dropped for the adjustment with the forth data rate R_4. The proposed modified LDU method is shown in Figure 5.2.

5.6 Proposed Modified LDU Method

The modified LDU method is shown in Figure 5.2. The initiated handover call return probability from consumed channels X to consumed channel 1 be $r1$ and from consumed channels Y to consumed channel X be $r2$. There is also call dropping probability when consumed Y channels to adjust with fourth data rate R_4 is $\varepsilon 2$.

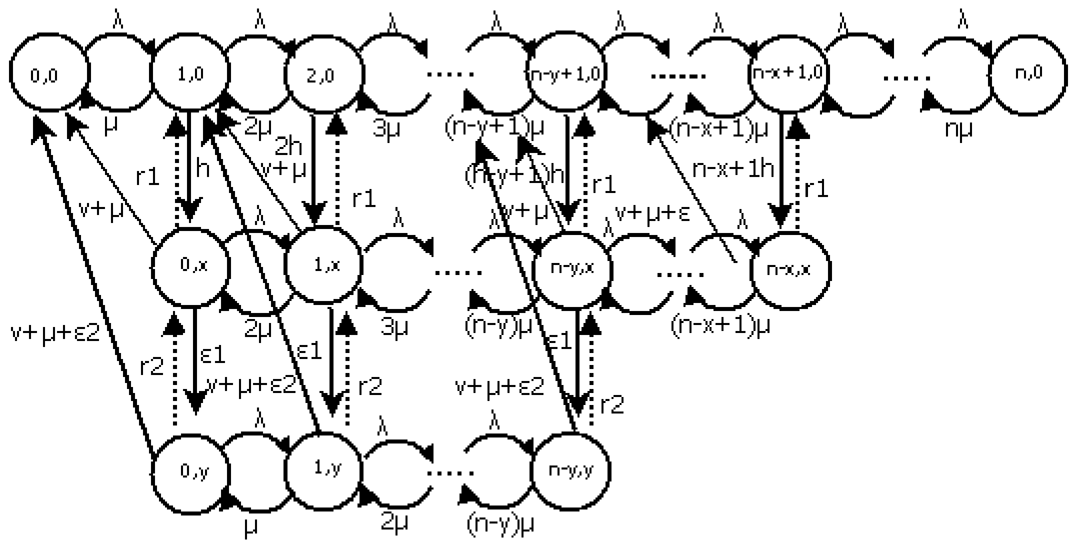

Figure 5.2: Proposed modified LDU method.

Now, we present the probability transition for modified Markovian model. Let $s(i,j;\bar{i},\bar{j})$ denote the probability transition rate from state (i,j) to state $(\bar{i},\bar{j})$. Here, i denotes the number of call and j denotes the number of channel occupied by i call. The Markovian decision process model has the following transition probability:

$$
\begin{array}{ll}
s(i,j;i+1,j)=\lambda & (0\le i<n,\ j=0)\\
s(i,j;i-1,j)=i\mu & (0<i\le n,\ j=0)\\
s(i,j;i-1,j_1)=ih & (0<i\le n-x+1,\ j=0, j_1=x)\\
s(i,j;i,j_1)=v+\mu & (0\le i\le n-x,\ j=x, j_1=0)\\
s(i,j;i+1,j)=\lambda & (0\le i<n-x,\ j=x)\\
s(i,j;i-1,j)=i\mu & (0<i\le n-x,\ j=x)\\
s(i,j;i+1,j_1)=r1 & (0\le i\le n-x,\ j=x, j_1=0)\\
s(i,j;i,j_1)=\varepsilon 1 & (0\le i\le n-y,\ j=x,\ j_1=y)\\
s(i,j;i,j_1)=r2 & (0\le i\le n-y,\ j=y,\ j_1=x)\\
s(i,j;i,j_1)=v+\mu+\varepsilon 2 & (0\le i\le n-y,\ j=y,\ j_1=0)
\end{array}
\tag{5.3}
$$

Here, (i,j) is a feasible state in S. Let $s(i,j)$ denote the steady-state probability that there are i new calls and j handoff calls in the WLAN-AP. So, the offered load for new and handover services are $\rho = \lambda / \mu$, $\rho_h = h/((\nu + \mu + \varepsilon) + r_1)$, $\rho_{hx} = h/((\nu + \mu) + r1)$ and $\rho_{hy} = \varepsilon 1/((\nu + \mu + \varepsilon 2) + r2)$, respectively. From the detailed balance equation, we obtain

$$\Pr\{s(i,j)\} = \begin{cases} \frac{\rho}{i}.\Pr\{s(0,0)\} & 0<i\leq n, j=0 \\ (i+1).\rho_{hx}.\frac{\rho}{i}.\Pr\{s(0,0)\} & 0<i\leq n-y, j=x \\ (i+1).\rho_h.\frac{\rho}{i}.\Pr\{s(0,0)\} & n-y<i\leq n-x, j=x \\ \rho_{hy}.\frac{\rho}{i}.\Pr\{s(0,0)\} & 0<i\leq n-y, j=y \end{cases} \tag{5.4}$$

From the normalization, i.e. $\sum_{i=0,j=0}^{i=n} \Pr\{s(i,j)\} + \sum_{i=0,j=x}^{i=n-x} \Pr\{s(i,j)\} + \sum_{i=0,j=y}^{i=n-y} \Pr\{s(i,j)\} = 1$, $\Pr\{s(0,0)\}$ can be found as

$$\Pr\{s(0,0)\} = \left[\sum_{i=0,j=0}^{i=n} \frac{\rho}{i} + \sum_{i=0,j=x}^{i=n-y} (i+1).\rho_{hx}.\frac{\rho}{i} + \sum_{i=n-y+1,j=x}^{i=n-x} (i+1).\rho_h.\frac{\rho}{i} + \sum_{i=0}^{n-y} \rho_{hy}.\frac{\rho}{i} \right]^{-1} \tag{5.5}$$

The new call blocking probability is found by summing over the probabilities of being in states $S(n,0)$ and $S(n-x,x)$. Thus, the new call blocking probability is given by

$$B_{call-block} = \Pr\{S(n,0)\} + \Pr\{S(n-x,x)\} + \Pr\{S(n-y,y)\} \tag{5.6}$$

5.7 Proposed Extended LDU Method

In LDU method, we found calls that are initiated vertical handover with consuming Y channels are dropped for adjust with third channels. In our proposed extended LDU method, we exposes third channels by dividing the T_{LDU} time with two data rates R_3 and R_4. In R_3 data rate, it consumes Y channels and in R_4 data rate it consumes Z channels. The extended LDU method is shown in Figure 5.3.

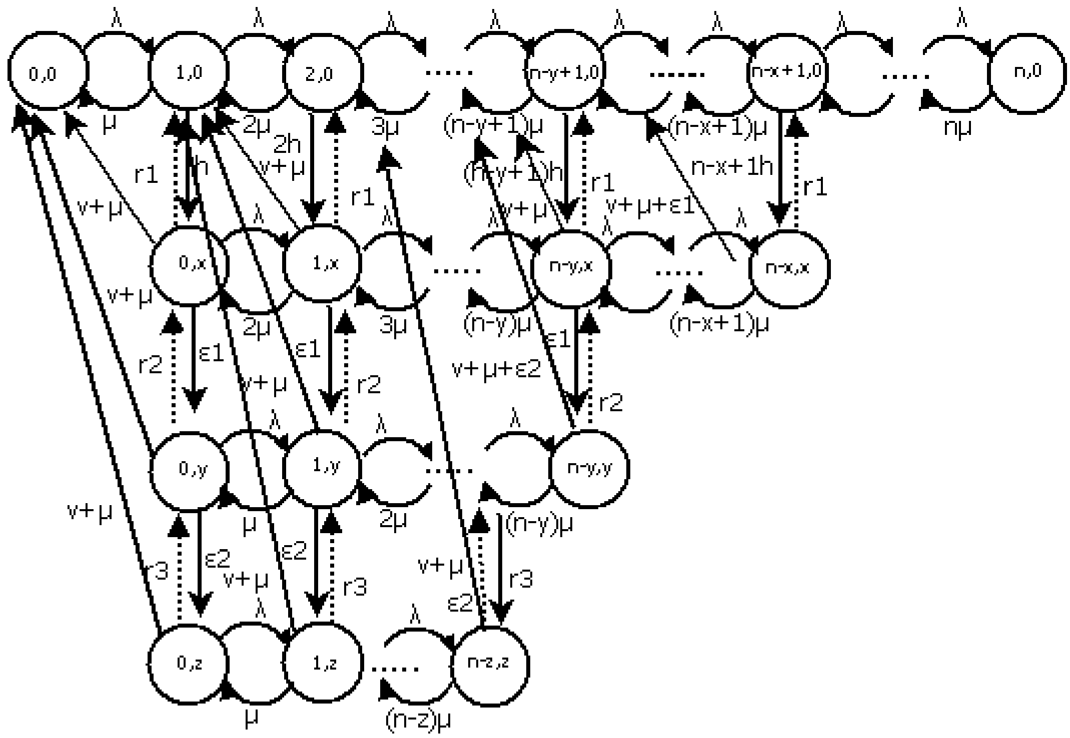

Figure 5.3: Extended LDU method.

By exposing the third channels the calls which are consuming second channels can be adjusted with the third channels and for adjusting third channels no calls are dropped. Now to calculate the performance of this method we have to get the global balance equation.

The Markovian model which is designed for extended LDU method has the following transitional probability:

$$
\begin{array}{ll}
s(i,j;i+1,j)=\lambda & (0\le i<n,\ j=0)\\
s(i,j;i-1,j)=i\mu & (0<i\le n,\ j=0)\\
s(i,j;i+1,j)=\lambda & (0\le i<n-x,\ j=x)\\
s(i,j;i-1,j)=i\mu & (0<i\le n-x,\ j=x)\\
s(i,j;i-1,j_1)=ih & (0<i\le n-x+1,\ j=0, j_1=x)\\
s(i,j;i,j_1)=v+\mu & (0\le i\le n-y,\ j=x, j_1=0)\\
s(i,j;i,j_1)=v+\mu+\varepsilon_1 & (n-y<i\le n-x,\ j=x, j_1=0)\\
s(i,j;i+1,j_1)=r_1 & (0\le i\le n-x,\ j=x, j_1=0)\\
s(i,j;i,j_1)=\varepsilon_1 & (0\le i\le n-y,\ j=x,\ j_1=y)\\
s(i,j;i,j_1)=r_2 & (0\le i\le n-y,\ j=y,\ j_1=x)\\
s(i,j;i,j_1)=v+\mu & (0\le i\le n-y,\ j=y,z\ j_1=0)\\
s(i,j;i+1,j)=\lambda & (0\le i<n-z,\ j=z)\\
s(i,j;i-1,j)=i\mu & (0<i\le n-z,\ j=z)\\
s(i,j;i,j_1)=\varepsilon_2 & (0\le i\le n-y,\ j=y,\ j_1=z)\\
s(i,j;i,j_1)=r_3 & (0\le i\le n-z,\ j=z,\ j_1=y)\\
s(i,j;i,j_1)=v+\mu+\varepsilon 2 & (n-z<i\le n-y,\ j=y,\ j_1=0)
\end{array}
\tag{5.7}
$$

Here, (i,j) is a feasible state in S. Let $s(i,j)$ denote the steady-state probability that there are i new calls and j handoff calls in the WLAN-AP. So, the offered load for new and handover services are $\rho=\lambda/\mu$, $\rho_h=h/((v+\mu+\varepsilon)+r_1)$, $\rho_{hx}=h/((v+\mu)+r1)$, $\rho_{h'}=\varepsilon_1/((v+\mu+\varepsilon_2)+r_2)$, $\rho_{hy}=\varepsilon 1/((v+\mu)+r2)$ and $\rho_{hz}=\varepsilon_2/((v+\mu)+r_3)$ respectively. From the detailed balance equation, we obtain

$$
\Pr\{s(i,j)\}=\begin{cases}
\frac{\rho}{i}.\Pr\{s(0,0)\} & 0<i\le n, j=0\\
(i+1).\rho_{hx}.\frac{\rho}{i}.\Pr\{s(0,0)\} & 0<i\le n-y, j=x\\
(i+1).\rho_h.\frac{\rho}{i}.\Pr\{s(0,0)\} & n-y<i\le n-x, j=x\\
\rho_{hy}.\frac{\rho}{i}.\Pr\{s(0,0)\} & 0<i\le n-z, j=y\\
\rho_{h'}.\frac{\rho}{i}.\Pr\{s(0,0)\} & n-z<i\le n-y, j=y\\
\rho_{hz}.\frac{\rho}{i}.\Pr\{s(0,0)\} & 0<i\le n-z, j=z
\end{cases}
\tag{5.8}
$$

the normalization , i.e. $\sum_{i=0,j=0}^{i=n} \Pr\{s(i,j)\} + \sum_{i=0,j=x}^{i=n-x} \Pr\{s(i,j)\} + \sum_{i=0,j=y}^{i=n-y} \Pr\{s(i,j)\} + \sum_{i=0,j=z}^{i=n-z} \Pr\{s(i,j)\} = 1$

, $\Pr\{s(0,0)\}$ can be found as

$$\Pr\{s(0,0)\} = \left[\sum_{i=0,j=0}^{i=n} \tfrac{\rho}{i} + \sum_{i=0,j=x}^{i=n-y} (i+1).\rho_{hx}.\tfrac{\rho}{i} + \sum_{i=n-y+1,j=x}^{i=n-x} (i+1).\rho_{h}.\tfrac{\rho}{i} + \sum_{i=0,j=y}^{n-z} \rho_{hy}.\tfrac{\rho}{i} + \sum_{i=n-z+1,j=y}^{n-y} \rho_{h'}.\tfrac{\rho}{i} + \sum_{i=0,j=z}^{n-z} \rho_{hz}.\tfrac{\rho}{i} \right]^{-1} \tag{5.9}$$

The new call blocking probability is found by summing over the probabilities of being in states $S(n,0)$ and $S(n-x,x)$. Thus, the new call blocking probability is given by

$$B_{call-block} = \Pr\{S(n,0)\} + \Pr\{S(n-x,x)\} + \Pr\{S(n-y,y)\} + \Pr\{S(n-z,z)\} \tag{5.10}$$

5.8 Simulation Result

At first we present the new call blocking probability for LDU and modified LDU. The modified LDU have the better new call blocking probability then the LDU method. We have the changes in two probabilities of new call probabilities: because for the consumes X and Y channels we change the handoff initiated call return back probability. The clock blocking probability result is shown in Figure 5.3. In Figure 5.4 we see the modified LDU method compared with conventional LDU algorithm. Here we see the conventional LDU algorithm performances are little bit better than modified LDU algorithm.

In Figure 5.5 and Figure 5.6 we show the LDU and modified LDU method for different handover rates than Figure 5.5 and we get the better performances and also it compares two different handover initiated call return back probability. In handoff dropping probability, we see the for the higher handoff rates, the system starts to experience higher capacity and better handoff dropping probability due to the early termination of handover calls same as conventional method explained before.

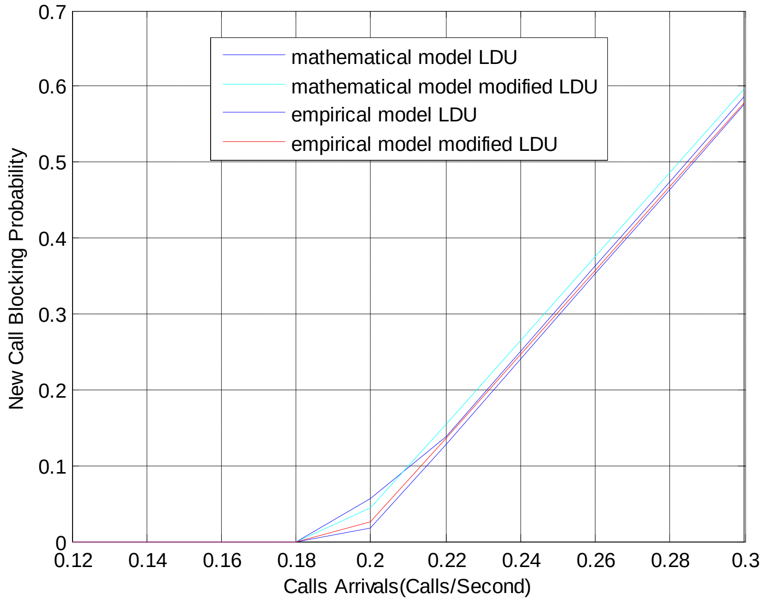

Figure 5.4: New call blocking probability (with confidence level 95 percent) when h=0.000495-0.000555 sec^{-1}.

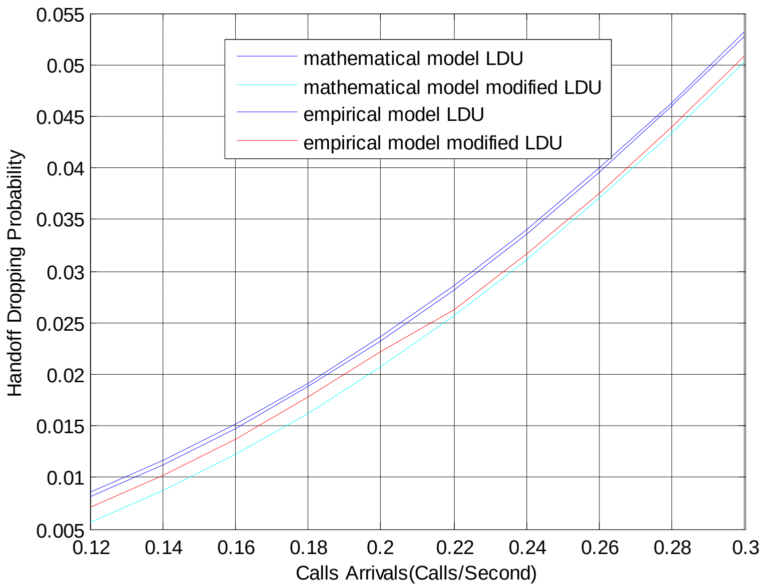

Figure 5.5: Handoff dropping probability (with confidence level 95 percent) when h=0.0000645-0.0000750 sec^{-1}.

In Figure 5.8, we compared the conventional, proposed conventional, LDU, modified LDU and extended LDU method.

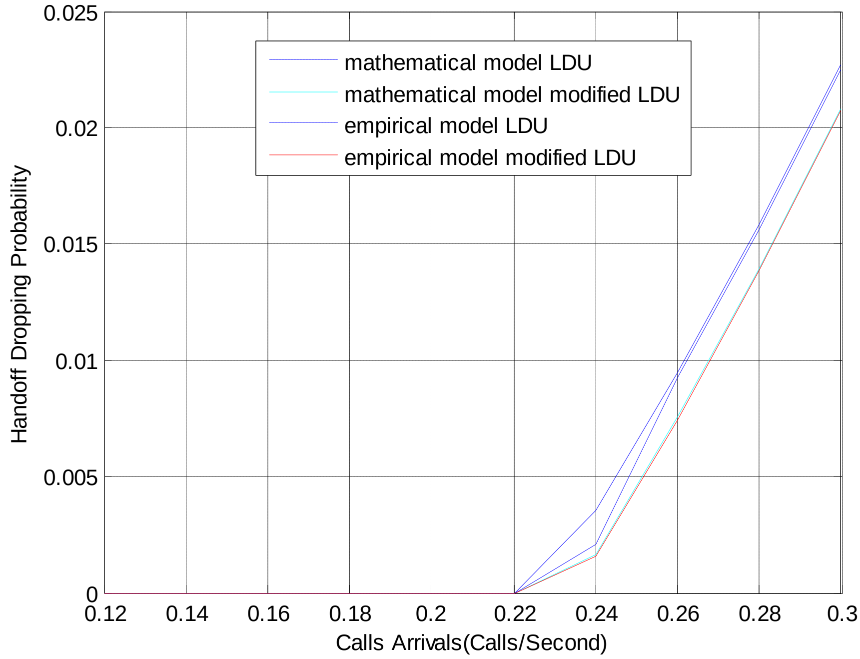

Figure 5.6: Handoff dropping probability (with confidence level 95 percent) when h=0.000200-0.000250 sec^{-1}.

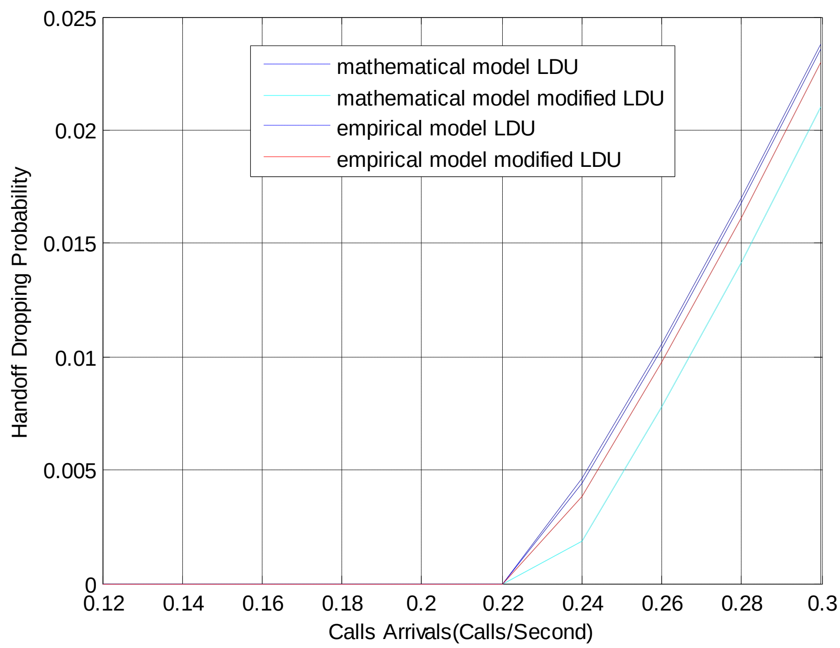

Figure 5.7: Handoff dropping probability (with confidence level 95 percent) when h=0.000395-0.000450 sec^{-1}.

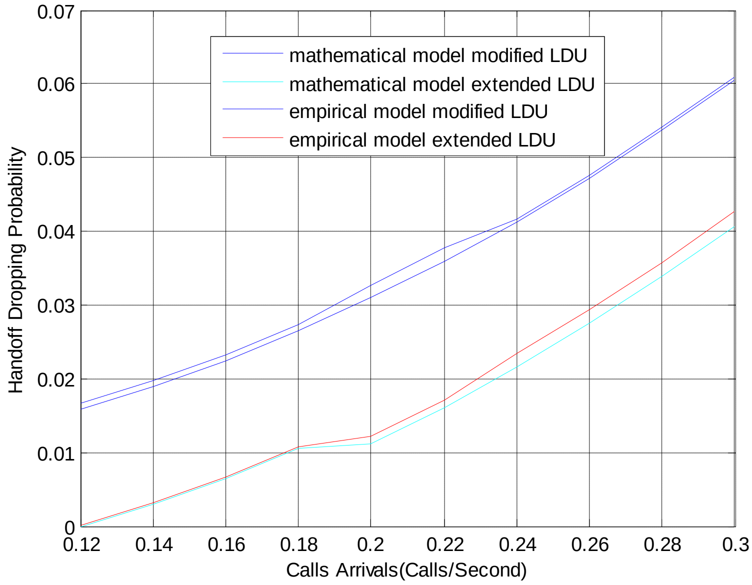

Figure 5.8: Handoff dropping probability between extended and modified LDU when h=0.0000685-0.0000740 sec^{-1}.

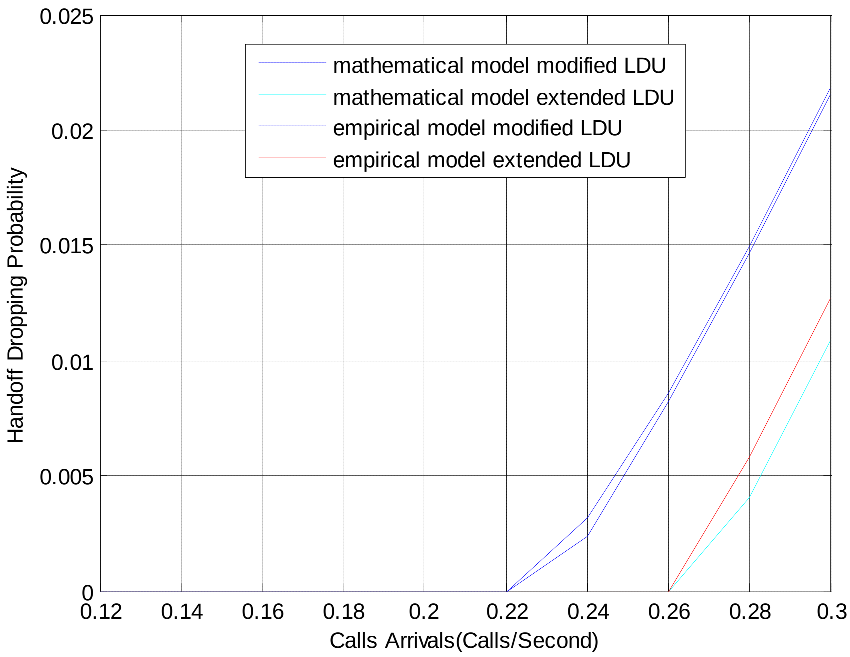

Figure 5.9: Handoff dropping probability between extended and modified LDU when h=0.000190-0.000265 sec^{-1}.

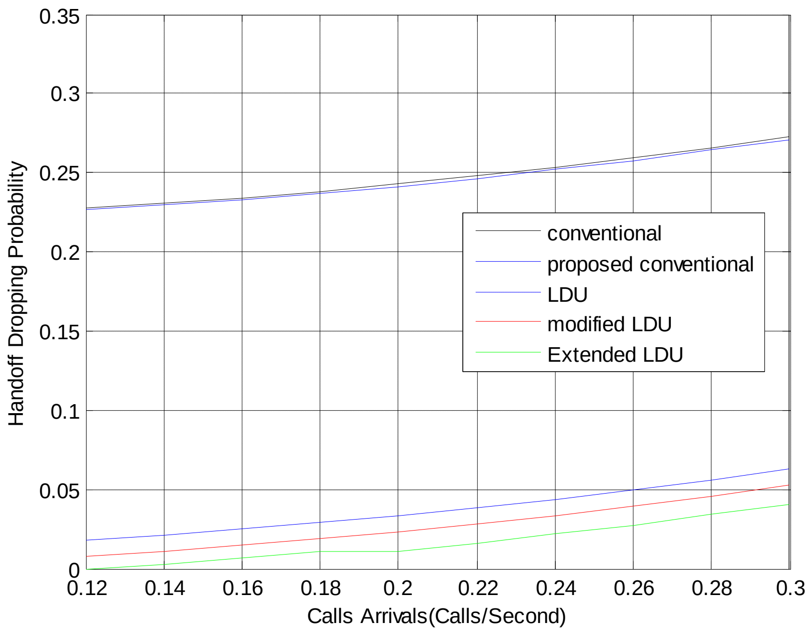

Figure 5.10: Handoff dropping probability when h=0.0000685-0.0000745 sec^{-1}.

5.9 Trigger Node Assisted WLAN to Cellular Vertical Handover

To provide successful VHO the WLAN link has to be maintained until the cellular connection is established. This is very difficult given the time constraints for vertical handover in loosely coupled cellular-WLAN architecture. Trigger node assisted WLAN to Cellular vertical handover is an explicit trigger node to assist early detection of a VHO when transitioning out of WLAN coverage [24], which will give the handset enough time to connect to the cellular network before losing its WLAN link. A trigger node is a very simple IEEE 802.11 device that merely transmits beacons and is placed at the building exits. In section 3.7 we describes it details. So by using modified LDU algorithm with trigger node IEEE 802.11 device we can perform seamless vertical handover successfully with T_{LDU} time.

5.10 Summary and Comments

The LDU method is the best one method for vertical handover. From the vertical handover performance measurement it is shown that if S_{11} (WLAN link loss point) is larger by delaying handoff time then the success rate of vertical handover changes dramatically. The delaying handoff technique which is used in LDU method is the fully new one concept. But unfortunately in LDU algorithm, they don't incorporate some of the important parameters. By incorporating this concept we proposed a modified LDU method. By dividing two channels (R_3 and R_4) in T_{LDU} time, we proposed extended LDU method. We also show the performances to incorporate these parameters in modified LDU method and extended LDU method.

Chapter 6

Conclusion and Future works

6.1 Conclusion

During VHO, a call switches its connectivity from one network to another. In the conventional method, the switching decision is taken as soon as the signal strength goes below a certain limit. In some cases, it is observed that the mobile devices come back to its previous network after hand off decision is initiated. The limited data rate usage (LDU) algorithm exploits this critical switching time and delayed the hand off initiation up to a limit a call can be continued with its previous network. The major domain specific contributions of this thesis are:

- Seamless wireless local area network (WLAN)-to-Cellular handover can often be very difficult to achieve. A particularly may occur when mobile users exit from indoor WLAN coverage to outdoor during active voice connections. LDU algorithm exposes a new idea that the handoff rate can be improved significantly by incorporating delaying handoff.
- Unfortunately, LDU algorithm did not consider the basic assumption that a call can be returned back to previous state from its extended time. We have modified the Markovian decision process models for both LDU and conventional methods by incorporating a probability for coming back to the previous network from the state of implementing hand offs.
- In LDU method, we found calls that are initiated vertical handover with consuming Y channels are dropped for adjust with third channels. In our proposed extended LDU method, we exposes third channels by dividing the T_{LDU} time with two data rates R_3 and R_4.

6.2 Future works

There are different ideas those can be considered as future works of this thesis work are listed below:

- In LDU method and modified LDU method it is assumed that VHO events are rare in comparison with new call arrivals; thus only a single event can be outstanding at any given time. But in real scenario may be two or more VHO calls can be occurred at the same time.
- If we think the conventional method which is consumed X channels in one VHO call this can be expanded with channel consumption such as: $2X$, $3X$ …… NX . In modified LDU method also this can be expanded with the increasing of channels consumption such as: $2X$, $3X$ …… NX and $2Y$, $3Y$ …… NY . The modified LDU method can be so realistic by using the fourth data rate.

We proposed modified LDU algorithm incorporating a common scenario which is not considered in LDU algorithm. We think this modification is a new and exciting idea in WLAN-to-Cellular vertical handover methods.

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