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# **WLAN-3G Interworking for future high data rate networks**

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## **Master's Thesis**

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<b>Abstract</b> <p>Advanced wireless mobile communication systems such as 3<sup>rd</sup> Generation (3G) provide users high mobility but less data rate. On the other hand, WLAN systems offer high data rate with less mobility. However, there is a need for public wireless access: to cover the increasing demand for high data-intensive applications and to enable smooth online access to corporate data services in hot spots. Therefore, one possibility to supply this need could be achieved through the interworking between both technologies, i.e., WLAN-3G interworking together.</p> <p>The main focus is to present and describe WLAN-3G interworking: aims, features, architectural methods, and development for future high data rate networks. In addition, the research provides an analytical model and a simulated model that can be used for evaluating the performance of the mobile IP method, the gateway method, and the emulator method which are used to implement WLAN-3G interworking.</p> <p>As a consequence, the mobile IP method suffers from high handover delay. The gateway method has lower handover delay than the mobile IP method. However, the emulator method has the lowest handover delay.</p>	
<b>Keywords:</b> WLAN, 3G, UMTS, WCDMA, Interworking, Architecture	

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

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## ABBREVIATIONS

1G	1 <sup>st</sup> Generation
2G	2 <sup>nd</sup> Generation
3G	3 <sup>rd</sup> Generation
3GPP	3 <sup>rd</sup> Generation Partnership Project
3GPP2	3 <sup>rd</sup> Generation Partnership Project 2
AAA	Authentication, Authorization and Accounting
AMPS	Advance Mobile Phone Service
AP	Access Point
APN	Access Point Name
AR	Access Router
ARIB	Association of Radio Industries and Businesses
BS	Base Station
BSS	Basic Service Set
CDMA	Code Division Multiple Access
CDMA2000	Code Division Multiple Access 2000
CN	Core Network
COA	Care Of Address
CS	Circuit Switch
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
CWTS	China Wireless Telecommunication Standard Group
DHCP	Dynamic Host Connection Protocol
DIAMETER	Diameter is an evolution of Radius protocol, and hence is the naming. ( <i>diameter = 2 * radius</i> )
DSSS	Direct Sequence Spread Spectrum
EDGE	Enhanced Data rates for GSM Evolution
ETSI	European Telecommunications Standards Institute
FA	Foreign Agent
FHSS	Frequency Hopping Spread Spectrum
FSK	Frequency Shift Keying
GGSN	GPRS Gateway Support Node
GMM	GPRS mobility management
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
HA	High Agent
HIPERLAN	High PERFORMANCE Radio LAN
HLR	Home Location Register
HRDSSS	High Rate Direct Sequence Spread Spectrum
HSDPS	High Speed Downlink Packet Access
IBSS	Independent Basic Service Set
IETF	Internet Engineering Taskforce
IEEE	Institute of Electrical and Electronic Engineers
IMS	IP Multimedia Subsystem
IMT-2000	International Mobile Telecommunications 2000
IP	Internet Protocol
IR	Infrared
ISM	Industrial, Scientific and Medical
ITU	International Telecommunication Union
L1/L2	Layer1/Layer2
LAN	Local Area Network

---

MGW	Media Gateway
MSC	Mobile services Switching Centre
NMT	Nordic Mobile Telephone
OFDM	Orthogonal Frequency Division Multiplexing
PDC	Personal Digital Cellular
pdf	Power distribution function
PDP	Packet Data Protocol
PS	Packet Switch
PSTN	Public Switched Telephone Network
QoS	Quality of Service
RADIUS	Remote Authentication Dial-In User Service
RA	Router Area
RAN	Radio Access Network
RANAP	Radio Access Network Application Protocol
RNC	Radio Network Controller
RRC	Radio Resource Control
RRM	Radio Resource Management
RTS/CTS	Ready To Send /Clear To Send
SGSN	Serving GPRS Support Node
SIP	Session Initiation Protocol
SM	Session Management
SS7	Signaling System number 7
TD SDMA	Time Division Synchronous Multiple Access
TD CDMA	Time Division Code Division Multiple Access
TD SCDMA	Time Division Synchronous Code Division Multiple Access
TIA	Telecommunications Industry Association
TTA	Telecommunications Technology Association
TTC	Telecommunications Technology Committee
UE	User Equipment
UMTS	Universal Mobile Terrestrial System
UTRAN	Universal Terrestrial Radio Access Network
UWB	Ultra Wide Band
VAP	Virtual Access Point
VLR	Visiting Location Register
VoIP	Voice over IP
WCDMA	Wideband Code Division Multiple Access
WISP	Wireless Internet Service Provider
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Network
WWW	World Wide Web

# 1. INTRODUCTION

## 1.1 Background

The wireless telecommunication networks are in huge expansion and the current and 3G mobile telecommunication networks as well. However, one willing in this huge expansion is that all telecommunication networks and systems are being merged together towards 4G, and beyond to form the future high data rate telecommunication networks. It will support a multitude of enhanced services and applications.

One main issue of these future high data rate networks is the interworking between Wireless Local Area Network (WLAN) system and 3G mobile system that provides standard interfaces to cover different applications and services.

## 1.2 Problem Background

The mobile telecommunication systems such as 3G enjoy various valuable positive key features like high mobility but suffer from some negative key features like low data rate. The same phenomenon, but vice versa, applies to WLAN systems that enjoy high data rate as a valuable positive key feature and suffer from low mobility as a negative key feature.

In addition, there is a need for public wireless access: to cover the increasing demand for high data-intensive applications and to enable smooth online access to corporate data services in hot spots.

Therefore, when considering how to cover the public wireless access need and also considering the main key positive features of both WLAN and 3G systems then, one could think about utilizing these positive key features of both WLAN and 3G systems. This includes the interworking between both 3G and WLAN systems together.

Unlike the conventional WLAN and 3G systems each one considered alone, the interworking between WLAN and 3G systems has more restrictive features and requirements; which have led to different interworking architecture methodologies.

Some literature and 3<sup>rd</sup> Generation Partnership Project (3GPP) standards provide some proposals to implement WLAN-3G interworking: features, design, architecture, and

methods. However, this area is still under research and development, [17], [19], and [20].

In this thesis, WLAN-3G interworking design principles, features, and methods are addressed.

### **1.3 Thesis Scope**

This thesis addresses the design principles, features, architecture methods of implementation of WLAN-3G interworking. This will be done with a certain level of abstraction. Hardware design and real experiments are not within the scope of this thesis. However, some basic principles are provided as an abstraction for real practical implementations.

The main WLAN-3G interworking issues are addressed: features, architecture methods, and evaluation. For example: the mobile IP method, the gateway method, and the emulator method- which are used to implement WLAN-3G interworking- will be addressed in the context of features, architecture, and evaluation.

### **1.4 Objectives**

The objective of this thesis is to describe the basic principles as well as the methods of WLAN-3G interworking. In addition, one objective is to evaluate those interworking methods in some case studies.

### **1.5 Method**

Through the available literature studies, the problems described in Section 1.2 are addressed. The basic WLAN-3G interworking principles and methods will be described based on the available literature studies of WLAN and 3G as well as the 3GPP standards in Release 6. However, the developed simulation and the results from some literature are also addressed to reflect the evaluation of WLAN-3G interworking methods.

### **1.6 Thesis Structure**

After the introduction in this chapter, the second chapter gives an overview of 3G telecom network. The main features, the network model and the architecture, the main standardization bodies involved, and the services are presented.

Next, in Chapter 3, WLAN telecom network is viewed. The main features of IEEE 802.11 series of standardizations and models are pointed out.

After introducing 3G network and WLAN network as a separated networks, Chapter 4 illustrates how 3G provides a real solution for the increasing demands of the public wireless access service and how it can cooperate with WLAN to enhance this demand.

The architectural methods which are used to implement WLAN-3G interworking are addressed in Chapter 5. It looks at how the interworking works. It describes the basic features of the different alternatives of WLAN-3G interworking; pointing out their advantages, drawbacks, and their possible impact on the WLAN and 3G networks themselves.

In Chapter 6, some results of the current researches and some simulations developed in this thesis are addressed; in order to evaluate the interworking methods that were presented in Chapter 5.

Finally, summary and conclusions are drawn in Chapter 7.

# 2. 3G TELECOM NETWORK

## 2.1 Background

To understand 3G wireless mobile networks, it is necessary to first examine the evolution of wireless mobile communication standards. 1<sup>st</sup> Generation (1G) of wireless mobile networks was introduced in the early 1980's. 1G was analog and supported the first generation of analog cell phones. 1G offered basic wireless voice transmission based on circuit switching and analog signaling. It included signaling protocols such as: Signaling System number 7 (SS7) and Frequency Shift Keying (FSK)- based signaling in Nordic Mobile Telephone (NMT). 1G was only able to provide relatively low quality voice services with limited capacity. Beginning in the 1990's service providers began to migrate to 2<sup>nd</sup> Generation (2G) wireless mobile technology. 2G improved the quality of voice transmission by using digital circuit switching technology rather than analog. Users were able to receive simple email or text messages. These changes made networks cheaper, more efficient, and easier to maintain; leading to an exponential growth in the mobile phone industry. 2.5G was developed as an overlay technology for existing 2G networks. 2.5G improved upon 2G technology and gave enhancements to the existing 2G networks allowing for transmission speeds from 64 kbps to 144 kbps, so allowing for larger text messaging and emails as well as limited web browsing. Clearly, the major improvement of 2.5G to 2G was the implementation of packet switching technology. However, 3G will be a deliberate migration to faster, data-centric wireless networks. The immediate goal is to raise transmission speeds from 125 kbps to 2 Mbps to allow for global roaming and video transmissions. The goal of 3G is to be able to give wireless phones the same functionalities as a telephone, TV, and PC. With this level of service, the user will have the world at their fingertips, whenever and wherever they want. Table 2.1 summarizes the main features of 1G, 2G and 3G [1], and [2].

Table 2.1 Main features of wireless mobile generations [2]

Generation	Access Technology	Feature
1G	<ul style="list-style-type: none"> <li>• Advance Mobile Phone Service (AMPS)</li> <li>• NMT</li> </ul>	<ul style="list-style-type: none"> <li>• Analog voice service</li> <li>• No data service</li> </ul>
2G	<ul style="list-style-type: none"> <li>• Code Division Multiple Access (CDMA)</li> <li>• Global System for Mobile Communications (GSM)</li> <li>• Personal Digital Cellular (PDC)</li> </ul>	<ul style="list-style-type: none"> <li>• Digital voice service from 9.6 kbps to 14.4 kbps</li> <li>• Not always on data connection</li> </ul>
3G	<ul style="list-style-type: none"> <li>• Wideband Code Division Multiple Access (WCDMA)</li> <li>• CDMA 2000</li> <li>• Time Division Synchronous Multiple Access (TD SDMA)</li> </ul>	<ul style="list-style-type: none"> <li>• Superior voice quality and data always add on</li> <li>• Up to 2 Mbps always- on data</li> <li>• Broadband data services like video and multimedia</li> <li>• Enhanced roaming</li> <li>• Circuit and packet switched networks</li> </ul>

## 2.2 What is 3G

The definition and standards of 3G are addressed in this section.

### 2.2.1 3G Definition

3G is a generic name for a set of mobile technologies - which was supposed to be launched by the end of 2001- which use a host of high-tech infrastructure networks, handsets, base stations, switches and other equipment to allow mobiles to offer high-speed Internet access, data, and video and CD-quality services. Data speeds in 3G networks should enable up to 2 Mbps [3].

According to IMT 2000, 3G is a term coined by the global cellular community to indicate the next generation of mobile service capabilities such as higher capacity and en-

hanced functionalities which allow advanced services and applications including multimedia [4].

Universal Mobile Terrestrial System (UMTS) is a so-called 3G broadband transmission of text, voice, video, and multimedia at data rates up to and possibly higher than 2 Mbps, offering a consistent set of services to mobile computer and phone users no matter where they are located in the world [5].

### 2.2.2 3G Standards

The organizations of 3G standardization are the official forums that develop the actual and full standards and specifications. International Telecommunication Union (ITU) started the process of defining the standard for 3G systems, referred to as International Mobile Telecommunications 2000 (IMT-2000). In Europe, European Telecommunications Standards Institute (ETSI) was responsible for UMTS standardization process.

- **3GPP**  
3GPP is a global standard organization that was formed to specify 3G cellular systems often referred as UMTS [6].
- **3<sup>rd</sup> Generation Partnership Project (3GPP2)**  
3GPP2 is a collaborative effort between five official standard developing organizations, which are: Association of Radio Industries and Businesses (ARIB), China Wireless Telecommunication Standard Group (CWTS), Telecommunications Industry Association (TIA), Telecommunications Technology Association (TTA), and Telecommunications Technology Committee (TTC). It was born out of IMT-2000. Currently, 3GPP2 is working on All-IP network specifications for Code Division Multiple Access 2000 (CDMA2000) networks [7].
- **IMT-2000**  
IMT-2000 is ITU globally coordinated definition of 3G and covers key issues such as frequency spectrum use and technical standards [4]. The primary CDMA variants that will be used in IMT-2000 3G networks are WCDMA, Time Division Code Division Multiple Access (TD-CDMA), TD-SCDMA, and CDMA-2000, [3].

## 2.2.3 3G Spectrum

Several frequency bands are identified for IMT-2000 systems in different regions as shown in Figure 2.1. The spectrum for UMTS lies between 1900 MHz to 2025 MHz and 2110 MHz to 2200 MHz.

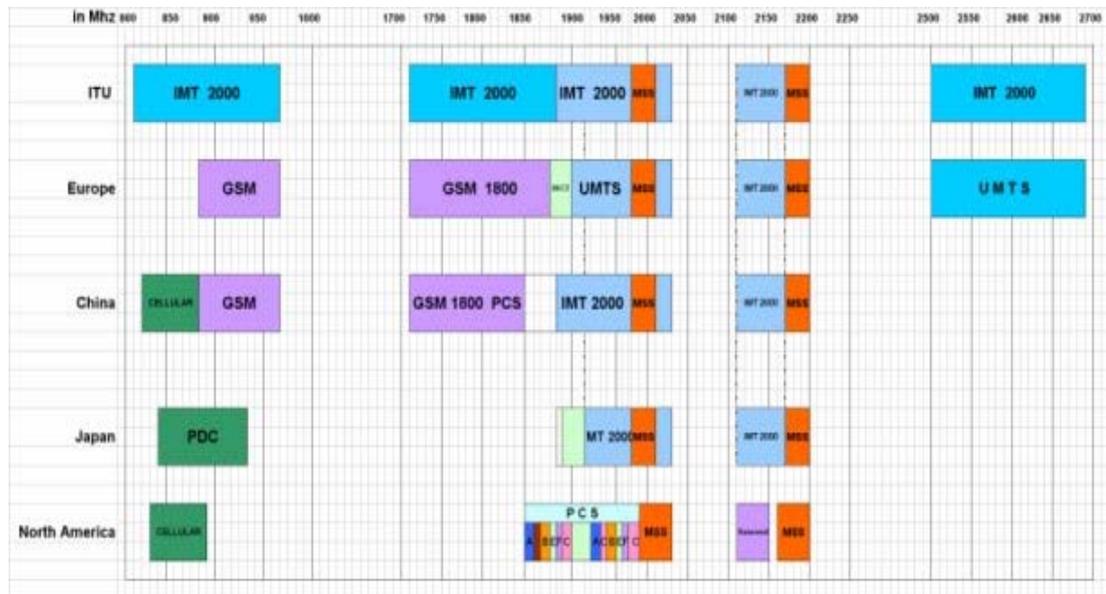


Figure 2.1 3G spectrum [5]

## 2.3 3G Network

UMTS network consists of three interacting domains: Core Network (CN), Universal Terrestrial Radio Access Network (UTRAN), and User Equipment (UE). The main function of CN is to provide switching, routing, and transit for user traffic. CN also contains databases and network management functions.

The basic architecture of CN for UMTS is based on GSM network with General Packet Radio Service (GPRS). All equipment has to be modified for UMTS operation and services. UTRAN provides the air interface access method for UE. BS is referred to as Node-B and control equipment for Node-B is called Radio Network Controller (RNC).

CN is divided into circuit switched and packet switched domains. Some of the circuit switched elements are: Mobile services Switching Centre (MSC), Visiting Location Register (VLR), and Gateway MSC. Packet switched elements are: Serving GPRS Support Node (SGSN), and GPRS Gateway Support Node (GGSN). Some network elements, like EIR, Home Location Register (HLR), VLR, and AUC are shared by both domains.

3G network has been evolved through: Release 99, Release 4, Release 5, and Release 6. Figure 2.2 and Figure 2.3 show only the main network elements involved in 3GPP Release 4 and Release 5 network models. Detailed information is provided in [6], [8], and [9].

The most important difference between GSM/GPRS and 3GPP Release 99 is the employment of a new radio access network based on WCDMA technology. Release 4 allows a single control element such as MSC server to control a pool of Media Gateways (MGW's). In Release 5, IP technology will be supported on larger scale towards All-IP network and the new IP Multimedia Subsystem (IMS) will enable offering new multimedia services.

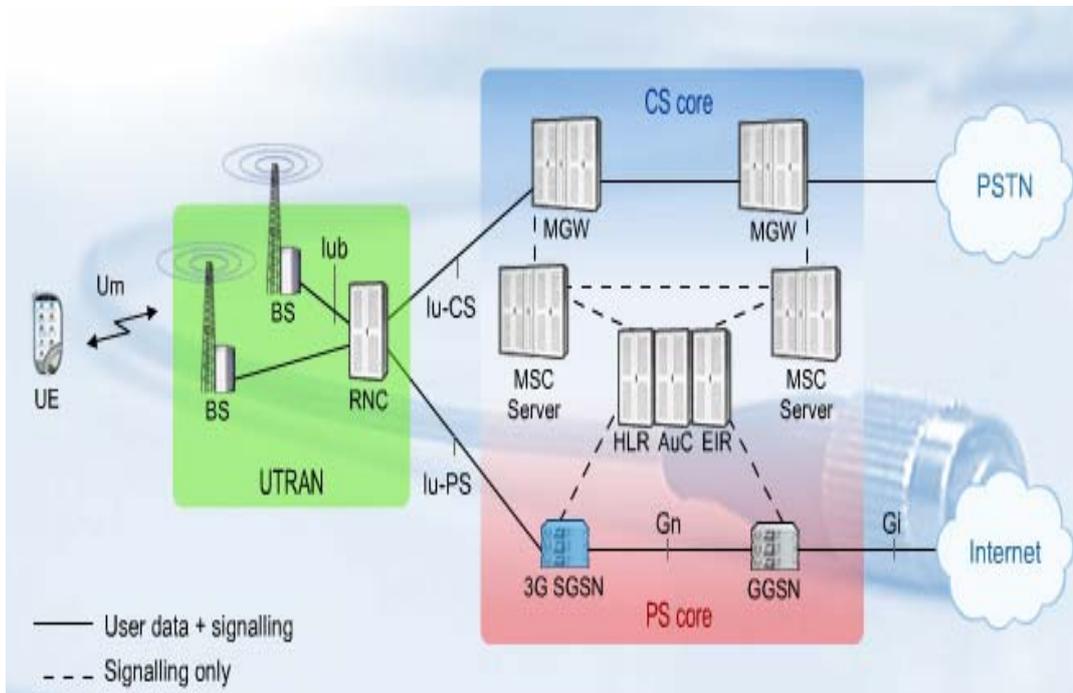


Figure 2.2 3GPP Release 4 network model, [9]

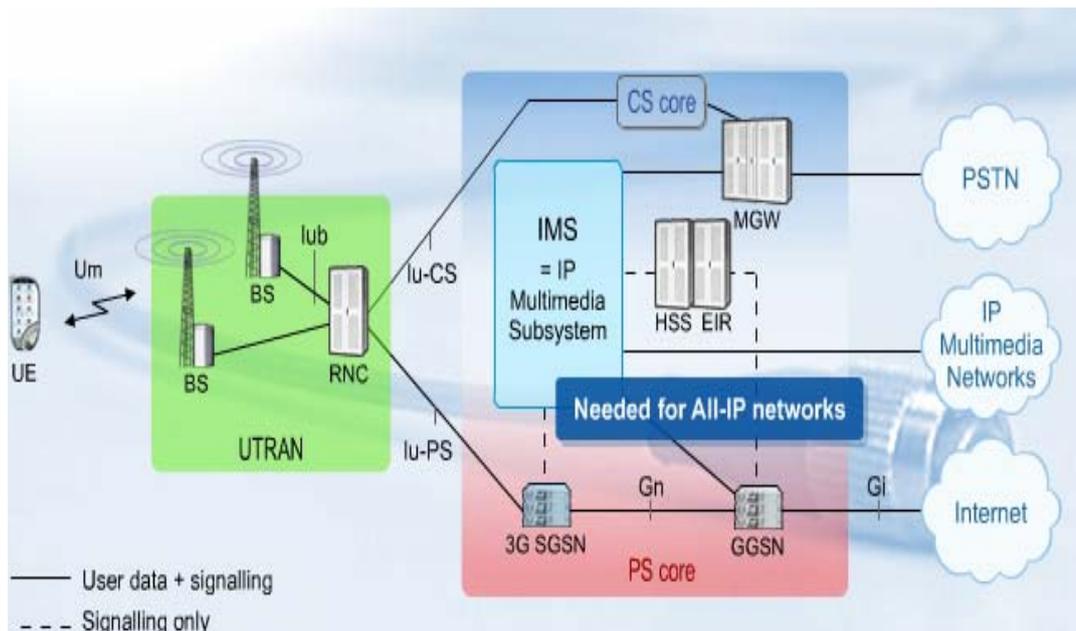


Figure 2.3 3GPP Release 5 network model, [9]

## 2.4 3G Services

From the user point of view the main advantage of UMTS will be a broad offer of services. Speed, variety and user-friendliness of the services will be significantly improved as compared with GSM [10].

In addition to increasing capacity for more users, 3G services deliver fast and secure wireless connections to the Internet and exciting new data applications for mobile devices. These applications and services include position location and mapping, audio and video content, application downloading over the airwaves, multimedia messaging, video conferencing, multi-user games and more [11].

Bearer services have different Quality of Service (QoS) parameters for maximum transfer delay, delay variation and bit error rate. Offered data rate targets are:

- 144 kbps satellite and rural outdoor
- 384 kbps urban outdoor
- 2048 kbps indoor and low range outdoor

3G network services have different QoS classes for four types of traffic:

- ***Conversational Class***

The main features of this class: real time traffic, preserve time variation between information entities of a stream, stringent and low delay (end to end delay less than 400 ms). For example: voice and bidirectional video/audio applications.

- ***Streaming Class***

The main features of this class: real time traffic, preserve time variation between information entities of a stream, and low delay (less than a few seconds). For example: streaming video/audio applications.

- ***Interactive Class***

The main features of this class: best effort traffic, request response pattern, preserve payload content (data integrity), and delay is less than a few seconds. For example: web browsing and network games applications.

- ***Background Class***

The main features of this class: best effort traffic, destination is not expecting the data within certain time (delay is not critical), and preserve payload content (data integrity). For example: telemetry and email applications.

## 2.5 Summary

This chapter started from one side of the big picture, where the essentials of 3G network were described briefly; the main features, network architecture and services. In the next chapter, the same process will be applied on WLAN telecom network.

# 3. WLAN TELECOM NETWORK

As there has been a huge development in the mobile telecommunication technologies, there has also been another huge development in WLAN technologies which can not be ignored; especially in the high affordable data rates that exceed those in the mobile technologies. Therefore, this chapter comes to present a brief overview for WLAN technology: main features, principles, standards, and services.

## 3.1 Background

Everything is going wireless. The prohibitive cost of building wired network infrastructures has paved the way for wireless network technologies on a global scale. The market of wireless communications has grown rapidly since the introduction of IEEE 802.11b WLAN standards, which offer performance more nearly comparable to that of Ethernet. Business organizations value the simplicity and scalability of WLAN's and the relative ease of integrating wireless access and the ability to roam with their existing network resources such as servers, printers, and internet.

WLAN's typically augment or replace wired computer networks, providing users with more flexibility and freedom of movement within the workplace. Users can access the company intranet or even World Wide Web (WWW) from anywhere on the company campus without relying on the availability of wired cables and connections.

Various industries have discovered the benefits WLAN which can bring to daily tasks and to the balance sheet. WLAN provides users with more flexibility and freedom of movement within the workplace [12], and [13].

## 3.2 What is WLAN

In this section, definition, benefits, and standards are previewed briefly.

### 3.2.1 WLAN Definition

WLAN is a flexible data communication system, which can be used for applications in which mobility is necessary, in home or indoor business environment. Signals in WLAN are transmitted via radio waves [12]. Thus, WLAN can be identified as a closely grouped system of devices that communicate via radio waves instead of wires.

WLAN supports seamless connectivity, flexibility, mobility, more reliability, lower installation time, installation on difficult to wire area, higher rates, and long term cost savings; which are not available in wired LANs.

### 3.2.2 WLAN Benefits

Wireless networks offer the following productivity, convenience, and cost benefits over traditional wired networks:

- ***Mobility***  
WLAN allows users real-time access to information from anywhere in their organization, without having to find a place to connect to the network via an Ethernet connection; thereby increasing productivity.
- ***Reliability***  
In WLAN environment, fewer wires and connectors translate to fewer problems for users and network administrators.
- ***Ease and Speed of Installation***  
Installing a wireless system can be fast and easy and can eliminate the need to pull cable through walls and ceilings. Thus, WLAN's do not require expensive and time-consuming cable installations which form a key particular benefit in difficult - to- wire areas.
- ***Affordability***  
WLAN installation and costs can be significantly lower than those incurred with wired networks; especially in environments that require frequent moves, changes and modifications.
- ***Scalability***  
WLAN systems are easy to configure and rearrange to accommodate a wide variety of topology settings and number of users. Configurations can be easily changed and ranged from peer-to-peer networks suitable for a small number of users to large infrastructure networks that enable roaming over a broad area.
- ***Reach of the network***  
WLAN systems can be extended to places which can not be wired.
- ***Flexibility***  
WLAN systems offer more flexibility and adapt easily to changes in the configuration of the network.
- ***Reduced cost of ownership***

While the initial investment required for wireless network hardware can be higher than the cost of wired network hardware, overall installation expenses and life-cycle costs can be significantly lower in dynamic environments.

### 3.2.3 WLAN Standards

IEEE has developed most standards of WLAN, which come as an alphabet soup of IEEE 802.11x series: IEEE 802.11a, IEEE 802.11b, IEEE 802.11g ... IEEE 802.11n. In IEEE 802.11x series, all of the definition, features, specifications, and requirements are standardized as will be briefly described here.

The standards of IEEE802.11 proposed different implementations for the physical layer:

- Infrared (IR) transmission never implemented
- Frequency Hopping Spread Spectrum (FHSS)
- Direct Sequence Spread Spectrum (DSSS)
- High Rate Direct Sequence Spread Spectrum (HRDSSS)
- Orthogonal Frequency Division Multiplexing (OFDM)

IEEE 802.11b provides rates up to 11 Mbps and operates in the 2.4 GHz Industrial, Scientific and Medical (ISM) band. However, rates up to 54 Mbps are achieved in IEEE 802.11a which operates in the 5 GHz band and utilizes OFDM technology. Table 3.1 illustrates a brief summary of the main features of the IEEE 802.11x standards.

Table 3.1 Main features WLAN IEEE 802.11 a, b, and g standards, [16]

Standard	IEEE 802.11a	IEEE 802.11b	IEEE 802.11g
Frequency Band	• 5 GHz	• 2.4 GHz	• 2.4 GHz
Data Rate	• Up to 54 Mbps	• Up to 11 Mbps	• Up to 54 Mbps
Radio	• OFDM	• DSSS	• OFDM/DSSS
Range	• Lower	• Higher	• Higher
RF Interference Potential	• Good	• Lower	• Lowest
Interoperability	• Not interoperable with anyone	• Not interoperable with IEEE 802.11a	• Interoperable with IEEE 802.11b
Multimedia Application Support	• Better than IEEE 802.11b	• Lower than IEEE 802.11a	• Lower than IEEE 802.11a

### 3.3 WLAN Network Models

WLAN network models and medium access are described here.

#### 3.3.1 WLAN Network Architectures

IEEE 802.11 standards define what comprises Basic Service Set (BSS). BSS has two or more fixed, portable, and/or moving nodes or stations that can communicate with each other over the air in a geographically limited area.

Two configurations are specified in the standards:

- Ad hoc mode
- Infrastructure mode

The ad-hoc mode is also referred to as the peer-to-peer mode or Independent Basic Service Set (IBSS) as illustrated in Figure 3.1(a). This ad-hoc mode enables mobile stations to interconnect with each other directly without the use of Access Point (AP). All stations are usually independent and equivalent in the ad-hoc network. Stations may broadcast and flood packets in the wireless coverage area without accessing Internet. The ad-hoc configuration can be deployed easily and promptly when the users involved cannot access or do not need a network infrastructure. For instance, participants of a conference can configure their laptops as a wireless ad-hoc network and exchange data without much effort.

However, as indicated in Figure 3.1 (b), in the infrastructure mode there are AP's which bridge the mobile stations and the wired network. BSS's can be connected by a distributed system which normally is LAN. The coverage areas of BSS's usually overlap. Handover occurs when a station moves from a coverage area of one AP to a coverage area of another AP. Although, the radio range of BSS limits the movement of wireless stations, seamless roaming among BSS's can construct a campus wide wireless network service [15].

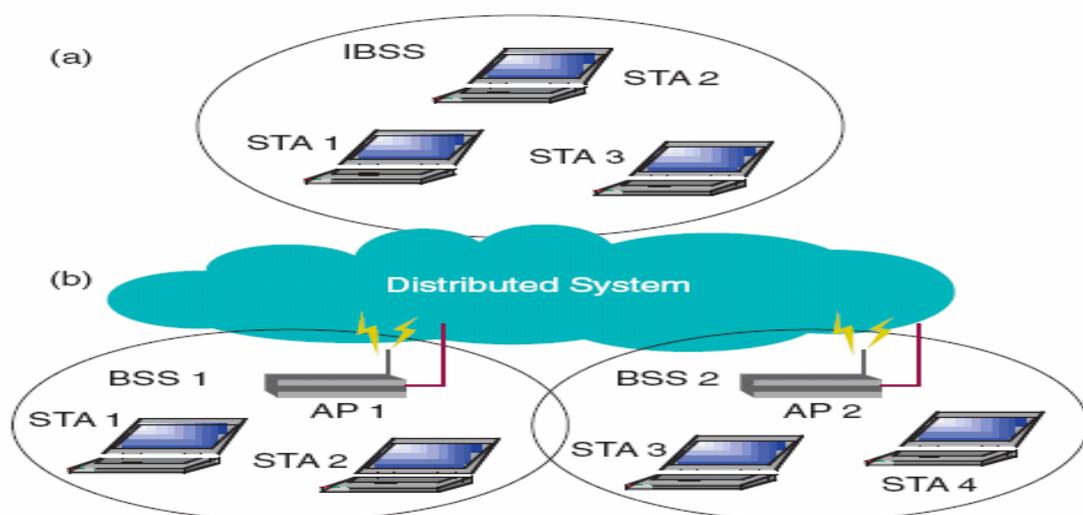


Figure 3.1 WLAN network architectures: (a) Ad hoc mode, and (b) Infrastructure

### 3.3.2 Medium Access Method

IEEE 802.11 uses Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) to access medium. The basic idea of CSMA/CA is: If a station wants to transmit, it first senses the medium. If the medium is busy, the station defers its transmission to a later time. Otherwise, it is allowed to use the medium.

Because of the hidden node problem, collisions could occur. For example, if both station A and C try to send data to station B at the same time then a collision will occur. To avoid collisions, a Ready To Send /Clear To Send (RTS/CTS) mechanism is implemented. When a station gets the chance to send, it sends RTS message first. The destination returns CTS message. After that, the source station can begin to send the data. Since, collisions may not be detected by the source station; the destination will acknowledge via ACK message every packet.

## 3.4 WLAN Services

WLAN's mainly liberate users from dependence on hard-wired access to the network backbone, giving them anytime, anywhere network access. This freedom to roam offers numerous user services for a variety of work environments, some examples are:

- Easy, real-time network access for on-site consultants or auditors.
- Network managers can move employees, set up temporary offices, or install printers and other equipment without the cost and complexity of wires and cables. Executives can access vital company information from the boardroom through handheld devices equipped with WLAN cards.
- Improved database access for roving supervisors such as production line managers, warehouse auditors, or construction engineers.
- Simplified network configuration for temporary setups such as trade shows or conference rooms.
- Employees can maintain real-time pricing and inventory information.
- Faster access to customer information for service vendors and retailers, resulting in better service and improved customer satisfaction.
- Location-independent access for network administrators, for easier on-site troubleshooting and support.
- Real-time access to study group meetings and research links for students.

- Students and instructors can communicate anywhere on campus. WLAN's eliminate the need for students to visit computer labs or dorm rooms to download assignments.
- Immediate bedside access to patient information for doctors and hospital staff.
- Hotels and restaurants can process guest reception information, process room service orders, and track guest baggage. Car rental agencies can process car returns curbside.

### **3.5 Summary**

This chapter started from the other side of the big picture, where the essentials of WLAN network were described briefly; the main features, network architecture and services.

From now on, both sides of the big picture will be treated together as what will be seen in the remaining chapters.

## 4. 3G FOR WLAN

After giving an overview about 3G network and WLAN network; each network being described alone as a completely separated system without relevance to the other system, now it is time to consider and treat both systems being integrated together.

In this chapter, a vision of future high data rate networks will be glanced to reflect the significant importance of changing the ways of thinking about revolution only in mobile technology side alone without considering what has been achieved in WLAN technology side; especially the huge rates that WLAN offers and they could not be ignored. However, compared to WLAN technology rates, mobile technology rates are still suffering from being low.

Based on the huge data rates in WLAN, a new way of thinking has been arisen in which WLAN technology is being involved in the development of 3G technology. This means that WLAN is integrated or interworked with 3G to address some features of the future wireless networks.

The reasons behind this new trend will be explored and discussed here illustratively as what will be seen in this chapter.

### 4.1 On The Future High Data Rate Wireless Networks Vision

Some ideas and thoughts are discussed in this section; to illustrate the nature of the future wireless networks for high data rate.

#### 4.1.1 Starting From 3G

In 3G, WCDMA air interface was initially designed to support a wide variety of services with different QoS requirements having a maximum bit rate of 2 Mbps. In order to satisfy the future service and application needs several technical enhancements have been studied and standardized for WCDMA in 3GPP.

The development of 3G will follow a few key trends, and the evolution following these trends will continue as long as the physical limitations or backward compatibility re-

quirements do not force the development to move from evolution to revolution. The key trends include:

- Voice services will stay important in foreseeable future, which means that capacity optimization for voice services will continue.
- Together with increasing use of IP-based applications, the importance of data as well as simultaneous voice and data will increase.
- Increased need for data means that the efficiency of data services needs to be improved as well as delay and average and peak user data rates.
- When more and more attractive multimedia terminals emerge in the markets, the usage of such terminals will spread from office, homes, and airports to roads, and finally everywhere. This means that high-quality, high-data-rate applications will be needed everywhere.
- When the volume of data increases, the cost per transmitted bit needs to decrease in order to make new services and applications affordable for everybody.

As a summary for 3G development objectives; the development of 3G will follow a few continuing key trends: increasing capacity optimization for voice services, increasing IP-based applications, supporting simultaneous voice and data improving services efficiency, delay, and average and peak user data rates, making more attractive multimedia terminals to be spread out everywhere, achieving high-quality high-data-rate everywhere, and finally decreasing cost to be affordable for everybody, [18].

### **4.1.2 Is 3G Enough**

Recently, mobile business professionals have increasingly been looking for an efficient way to access corporate information systems and databases remotely through the Internet backbone.

However, the high data rate demands of typical office applications (e.g., large email attachment downloading) often calls for very high transmission capacity. Furthermore, certain hot spots like airports and railway stations are natural places to use the services. However, in these places the time available for information download is typically fairly limited.

Wireless telecommunication networks have been developed dramatically. Not only in 3G technology but also in other technologies such as: WLAN, Wireless Personal Area Network (WPAN), Ultra Wide Band (UWB) etc. One question arises here, that is: Is 3G enough? The answer of this question seems to be negative. This is very clear from the huge developments rather than in 3G in which the services and profits exceed what's gained in 3G. Also, this reinforced from 3G development circle itself which has expanded to involve new technologies to cope with increasing wireless users demands. Nowadays, there are talks about 4G and perhaps beyond coming concurrently with 3G which has not been completed and launched effectively yet. Therefore, future wireless networks are being developed beyond 3G.

One clear side is the data rate trends. The data rate trends are summarized in Figure 4.1 and Figure 4.2 where it is obvious that in evolution path of 3G, very high data rates are achieved in hot spots with WLAN rather than in cellular-based standards.

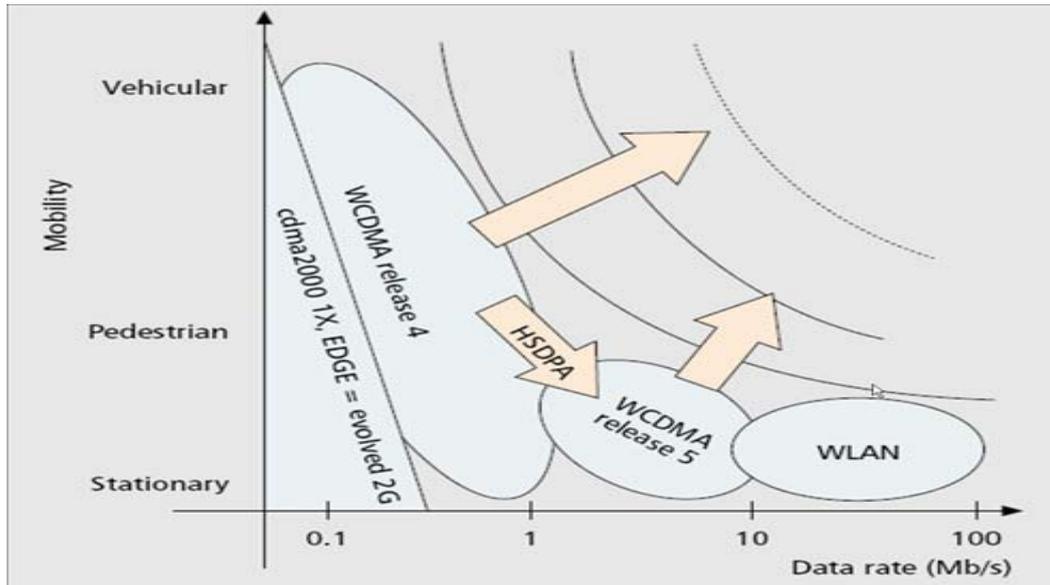


Figure 4.1 Data Rate Trends [18]

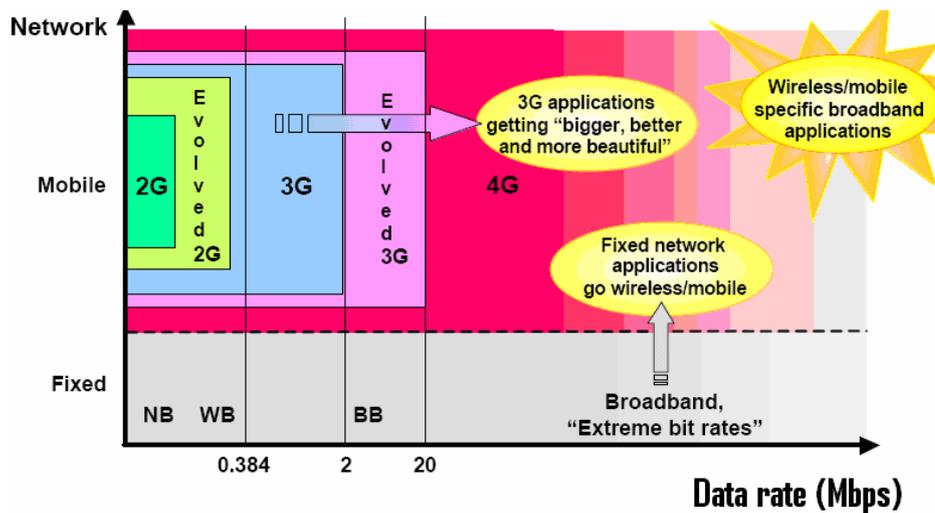


Figure 4.2 Networks vs. Data rate

### 4.1.3 Addressing WLAN

It is very clear from Section 4.1.2 that the huge amount of data rates that can be achieved through WLAN technologies such as the development of picocell and personal area network technologies (e.g., WLAN and Bluetooth) for office, public, and home in-door solutions.

Current WLAN products are able to provide data rates up to 54 Mbps. WLAN's have been mostly used as wireless replacement for wired LAN's in the office environment.

Together with high-data-rate cellular access, WLAN has the potential to fulfill end user demands in hot spot environments. WLAN offers an interesting possibility for cellular operators to offer additional capacity and higher data rates for end users without sacrificing the capacity of cellular users, since WLAN's operate on unlicensed frequency bands. Furthermore, solutions exist that enable operators to utilize the existing cellular infrastructure investments and well established roaming agreements for WLAN network subscriber management and billing.

#### **4.1.4 Key Objectives**

In the light of the above there is a clear need for a public wireless access solution that could cover the increasing demand for data-intensive applications and enable smooth online access to corporate data services in hot spots.

Among future wireless networks is 4G; wherein 4G can be defined as a conceptual framework for or a discussion point to address future needs of a universal high speed wireless network that will interface with wireline backbone network seamlessly. However, 4G can be imagined as an integrated wireless system that enables seamless roaming between technologies. A user can be operating in cellular technology network and get handed over to a satellite-based network and back to a fixed wireless network, depending upon the network coverage and preference of charging.

In some authors' opinion [18], before considering some future wireless system as belonging to 4G, it must possess capabilities that by far exceed those in 3G systems. Judging from an application and services point of view, one distinguishing factor between 3G and 4G will still be the data rate. 4G should support at least 100 Mbps peak data rates in full-mobility wide area coverage and 1 Gbps in low-mobility local area coverage.

#### **4.1.5 Future Vision**

As mentioned earlier, services, applications, and even core network are evolving with high speed, and distinguishing different generations is not really possible anymore. The evolution, and sometimes revolution, is a very significant trend. The other major trend is that access methods will be less tightly coupled to the network. After a certain point, evolution is no longer an answer to air interface development, and revolutionary concepts must also be considered. Figure 4.3 illustrates the evolution of 2G/3G cellular and WLAN standards and the revolutionary step toward future wireless systems. GSM evolution will continue in parallel with WCDMA. For instance, cdma2000-1X will be followed by 1XeV-DO (high-bit-rate data only) and 1XeVDV (high-bit-rate data and voice) standards. Looking at development in the Internet and applications, it is clear that the complexity of the transferred content is rapidly increasing and will increase further in the future. Generally, it can be said that the more data rate is available, the more data rate applications will consume. In order to justify the need for a new air interface, targets need to be set high enough to ensure that the system will be able to serve long in

the future. A reasonable approach would be to aim at 100 Mbps in full-mobility wide area coverage and 1 Gbps in low-mobility local area coverage with a next-generation cellular system in about 2010 in standards fore. Also, the future application and service requirements will bring new requirements to the air interface and new emphasis on air interface design. One such issue, which already strongly impacts 3G evolutions, is the need to support IP and IP-based multimedia, [18].

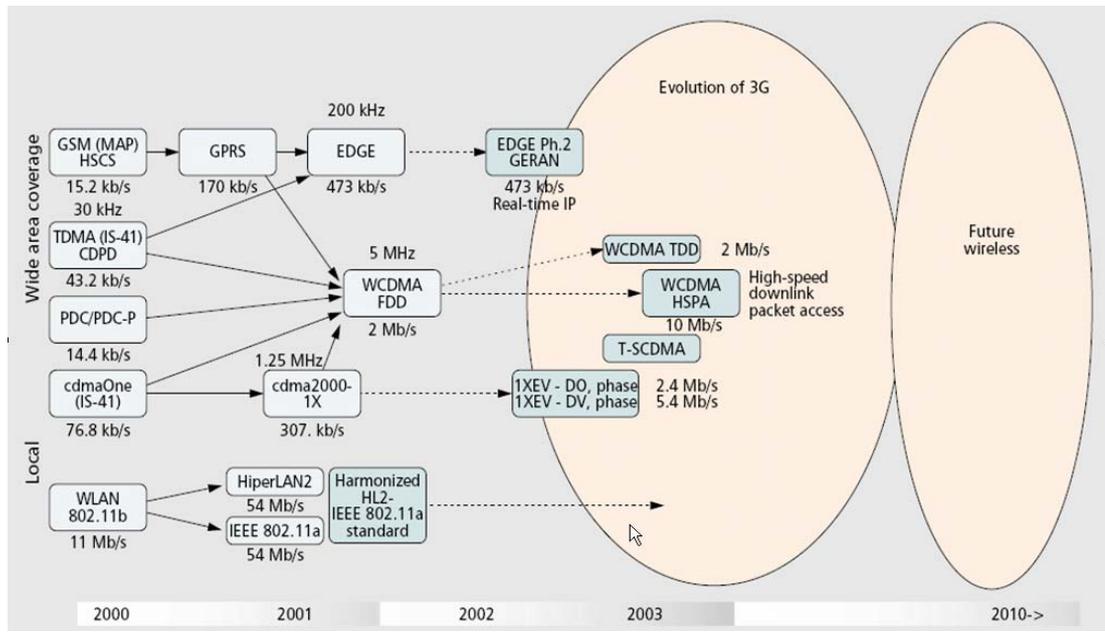


Figure 4.3 Wireless Networks Development Path, [18]

## 4.2 3G vs. WLAN

In this section, a comparison between 3G and WLAN technologies is illustrated to highlight the key points in each one of them. Hence, this paves the way towards the thinking of the interworking between 3G and WLAN.

Table 4.1 illustrates the basic key points as a comparison between 3G and WLAN technologies. However, other detailed comparisons between 3G and some particular WLAN technologies are illustrated in Tables: 4.2-4.4.

Table 4.1 3G vs. WLAN -Key point comparison

Key Point	3G	WLAN
Standards	<ul style="list-style-type: none"> <li>• WCDMA,CDM2000</li> </ul>	<ul style="list-style-type: none"> <li>• IEEE 802.11, other IEEE802. series</li> </ul>
Maximum Data Rate	<ul style="list-style-type: none"> <li>• Up to 2 Mbps</li> </ul>	<ul style="list-style-type: none"> <li>• 11 Mbps, 54 Mbps ... Up to 100 Mbps</li> </ul>
Business operators	<ul style="list-style-type: none"> <li>• Mobile phone companies</li> </ul>	<ul style="list-style-type: none"> <li>• Individuals &amp; Wireless Internet Service Provider (WISP)</li> </ul>
Mobility	<ul style="list-style-type: none"> <li>• Higher</li> </ul>	<ul style="list-style-type: none"> <li>• Lower</li> </ul>
Coverage Area	<ul style="list-style-type: none"> <li>• Several kilometers</li> </ul>	<ul style="list-style-type: none"> <li>• Several 100 meters</li> </ul>
RF Interference Potential	<ul style="list-style-type: none"> <li>• Lower</li> </ul>	<ul style="list-style-type: none"> <li>• Higher</li> </ul>
License	<ul style="list-style-type: none"> <li>• Yes</li> </ul>	<ul style="list-style-type: none"> <li>• No</li> </ul>
Multimedia application support	<ul style="list-style-type: none"> <li>• Good</li> </ul>	<ul style="list-style-type: none"> <li>• Better</li> </ul>

Table 4.2 3G vs. WiFi

Key Point	3G	WLAN
Standards	<ul style="list-style-type: none"> <li>• WCDMA,CDMA2000</li> </ul>	<ul style="list-style-type: none"> <li>• IEEE 802.11</li> </ul>
Maximum Data Rate	<ul style="list-style-type: none"> <li>• 2 Mbps</li> </ul>	<ul style="list-style-type: none"> <li>• 54Mbps</li> </ul>
Mobility	<ul style="list-style-type: none"> <li>• Higher</li> </ul>	<ul style="list-style-type: none"> <li>• Lower</li> </ul>
Coverage Area	<ul style="list-style-type: none"> <li>• Several kilometers</li> </ul>	<ul style="list-style-type: none"> <li>• 100 meters</li> </ul>
License	<ul style="list-style-type: none"> <li>• Yes</li> </ul>	<ul style="list-style-type: none"> <li>• No</li> </ul>
Main Advantages	<ul style="list-style-type: none"> <li>• High Range</li> <li>• High Mobility</li> </ul>	<ul style="list-style-type: none"> <li>• High Data Rate</li> <li>• Cheap</li> </ul>
Main Disadvantages	<ul style="list-style-type: none"> <li>• Relatively low speed</li> <li>• Expensive</li> </ul>	<ul style="list-style-type: none"> <li>• Short range</li> </ul>

Table 4.3 3G vs. Wi-Max

Key Point	3G	WMAN
Standards	<ul style="list-style-type: none"> <li>• WCDMA,CDMA2000</li> </ul>	<ul style="list-style-type: none"> <li>• IEEE 802.16</li> </ul>
Maximum Data Rate	<ul style="list-style-type: none"> <li>• 2 Mbps</li> </ul>	<ul style="list-style-type: none"> <li>• 100 Mbps</li> </ul>
Mobility	<ul style="list-style-type: none"> <li>• Higher</li> </ul>	<ul style="list-style-type: none"> <li>• Lower</li> </ul>
Coverage Area	<ul style="list-style-type: none"> <li>• Several kilometers</li> </ul>	<ul style="list-style-type: none"> <li>• Up to 50 Kilometers</li> </ul>
License	<ul style="list-style-type: none"> <li>• Yes</li> </ul>	<ul style="list-style-type: none"> <li>• No</li> </ul>
Main Advantages	<ul style="list-style-type: none"> <li>• High Range</li> <li>• High Mobility</li> </ul>	<ul style="list-style-type: none"> <li>• High Data Rate</li> <li>• Range</li> </ul>
Main Disadvantages	<ul style="list-style-type: none"> <li>• Relatively low speed</li> <li>• Expensive</li> </ul>	<ul style="list-style-type: none"> <li>• Interference</li> </ul>

Table 4.4 3G vs. Mobile-Fi

Key Point	3G	WLAN
Standards	<ul style="list-style-type: none"> <li>• WCDMA,CDM2000</li> </ul>	<ul style="list-style-type: none"> <li>• IEEE 802.20</li> </ul>
Maximum Data Rate	<ul style="list-style-type: none"> <li>• 2 Mbps</li> </ul>	<ul style="list-style-type: none"> <li>• 16Mbps</li> </ul>
Mobility	<ul style="list-style-type: none"> <li>• High</li> </ul>	<ul style="list-style-type: none"> <li>• High</li> </ul>
Coverage Area	<ul style="list-style-type: none"> <li>• Several kilometers</li> </ul>	<ul style="list-style-type: none"> <li>• Several kilometers</li> </ul>
License	<ul style="list-style-type: none"> <li>• Yes</li> </ul>	<ul style="list-style-type: none"> <li>• Yes</li> </ul>
Main Advantages	<ul style="list-style-type: none"> <li>• High Range</li> <li>• High Mobility</li> </ul>	<ul style="list-style-type: none"> <li>• High Data Rate</li> <li>• Mobility</li> </ul>
Main Disadvantages	<ul style="list-style-type: none"> <li>• Relatively low speed</li> <li>• Expensive</li> </ul>	<ul style="list-style-type: none"> <li>• High cost</li> </ul>

Hence, from the previous illustrative comparisons mentioned above, it is very clear that the main key advantages of 3G are: the high mobility and high range. While, the high speed is the key advantage of WLAN. Figure 4.4 summarizes those key advantages.

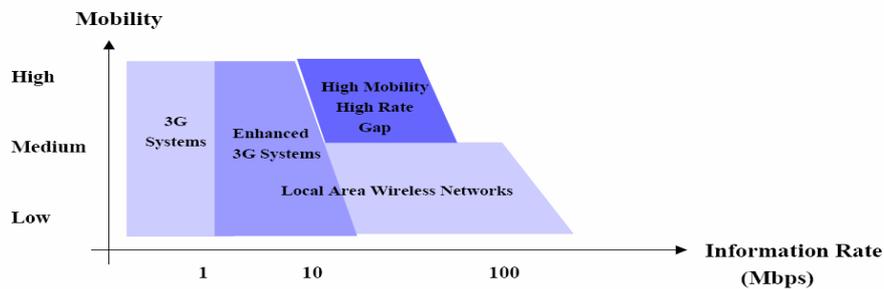


Figure 4.4 Mobility vs. Data Rates for 3G & WLAN

### 4.3 Thinking Towards The Interworking Between 3G & WLAN

The ongoing standardization of WLAN, research and development activities worldwide, which target bit rates higher than 100 Mbps, combined with the recent successful deployment of WLAN's in numerous hotspots justify the fact that WLAN technology will play a key role in wireless data transmission. Cellular network operators have recognized this fact, and strive to exploit WLAN technology and integrate this technology into their cellular data networks.

Moreover, when recalling the key points of mobile technologies which offer high mobility but with low rates (< 2 Mbps) and that of WLAN technologies which offer high rates (~100 Mbps) but with low mobility. Then, one thing could be highlighted here, that is why the benefits of both technologies are not utilized and combined together to address a new generation of technology that covers the increasing ubiquitous public wireless user demands for high data-intensive applications and enables smooth online access to corporate data services in hot spots.

Therefore, there is currently a strong need for interworking/ integrating mechanisms between WLAN's and cellular data networks; especially when thinking of the key advantages of each one of them being merged and utilized all together as proposed in Figure 4.5.

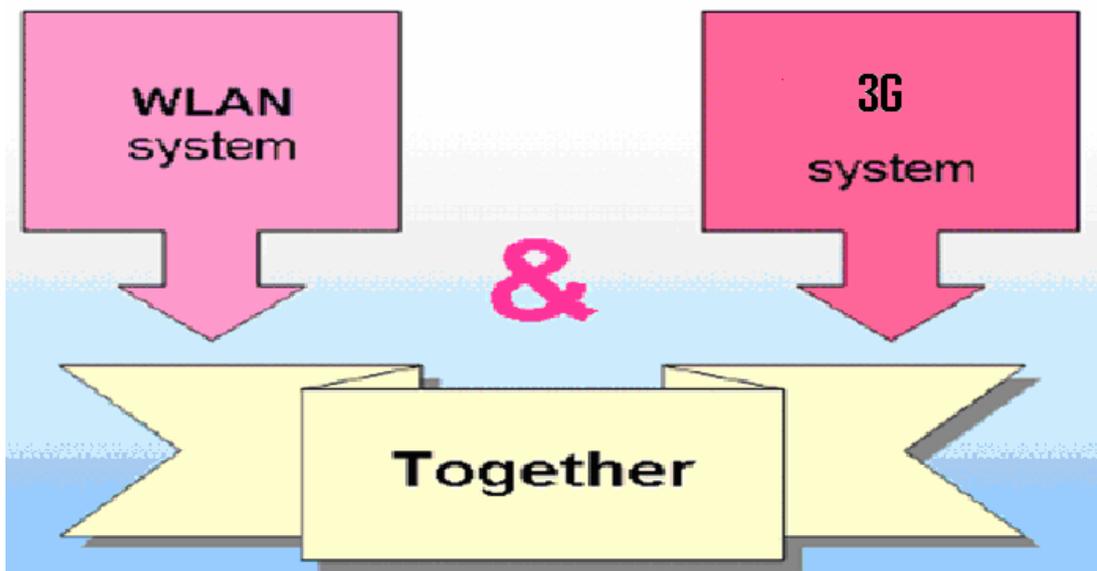


Figure 4.4 Proposal of Interworking both 3G and WLAN systems together

## 4.4 Summary

Different discussion, visions, and comparisons of related issues in 3G and WLAN have been presented in this chapter.

However, after having all the previous discussions, from now on the focus will be on the details of the interworking between 3G and WLAN as will be presented in the next chapters.

## 5. WLAN-3G INTERWORKING ARCHITECTURE METHODS

In this chapter, WLAN-3G interworking architecture methods are addressed and discussed in detail. This includes: the definition of the interworking and how it works. It describes the basic features of the different alternatives for WLAN-3G interworking; pointing out their advantages, drawbacks, and their possible impact on WLAN and 3G networks themselves.

According to 3GPP Release 6 [17], the intent of WLAN-3G interworking is to extend 3G services and functionality to WLAN access environment. Thus WLAN effectively becomes a complementary radio access technology to 3G.

WLAN provides access to services located in WLAN's and/or networks behind WLAN. In WLAN-3G interworking, 3G system functionalities can reside behind WLAN or in parallel to WLAN. In the case of 3G system functionalities located behind WLAN, the interworking between 3G system and WLAN may include:

- Enabling usage of 3GPP system functionalities between mobile terminals and 3GPP systems via the WLAN such as providing SIP calls.
- Utilising 3G system functionalities to complement the functionalities available in WLAN such as providing charging means, authentication, authorization, and accounting functions.

In a case when the WLAN is seen as a parallel system to 3G system, the interworking between the systems may include:

- Creation of mechanisms for selecting and switching between WLAN and 3G systems

Enabling any of these interworking cases mentioned above may result in modifications or additions in 3G systems, in WLAN's, or in both [17].

## 5.1 WLAN-3G Interworking General Overview

### 5.1.1 Definition

WLAN-3G Interworking is used generally to refer to the interworking between 3G system and WLAN family of standards. This means combining or integrating both of WLAN and 3G technologies altogether to utilize the benefits of them.

WLAN can provide high data rates capabilities and 3G can provide high mobility capabilities. Thus, the new WLAN-3G interworking system will combine both of these key capabilities: high data rate and high mobility together.

WLAN-3G interworking addresses the new generation technology that covers the increasing ubiquitous public wireless user demands for high data-intensive applications and enables smooth online access to corporate data services in hot spots.

### 5.1.2 The Big Picture

Figure 5.1 illustrates a general conceptual view of a WLAN-3G interworking system. The following issues can be noticed:

- ◆ The end user devices such as laptops, palmtops, and phones that can access networks based on both WLAN and 3G technologies are already becoming available.
- ◆ A user of this WLAN-3G network would prefer to have exactly *one service subscription with one service provider*, typically called its *home network provider*.
- ◆ The subscribers' credentials in the form of authentication information (e.g., shared secret keys), the profile information (e.g., class of service, minimum data rate), and the accounting information will be stored in a network-based authentication, authorization, and accounting (AAA) server called *home AAA*.
- ◆ This single account will enable the user to access data and voice services anywhere, any time, receive exactly *one billing statement*, *roam* freely among all networks with which the user's provider has agreements, and get similar *QoS*.
- ◆ Using a single account on different networks in this way requires that network providers be able to authenticate each other's users and obtain their service profile parameters. This is enabled by roaming agreements established among service providers using AAA protocols, such as RADIUS or DIAMETER, and AAA broker networks.

The emerging integrated WLAN-3G wireless networks will offer two roaming services:

- ◆ Simple IP service that offers integrated billing and subscriber profiles, but does not guarantee session continuity across network boundaries.
- ◆ Mobile IP service that enables seamless handoffs/ handovers between WLAN-3G networks to preserve ongoing sessions [19].

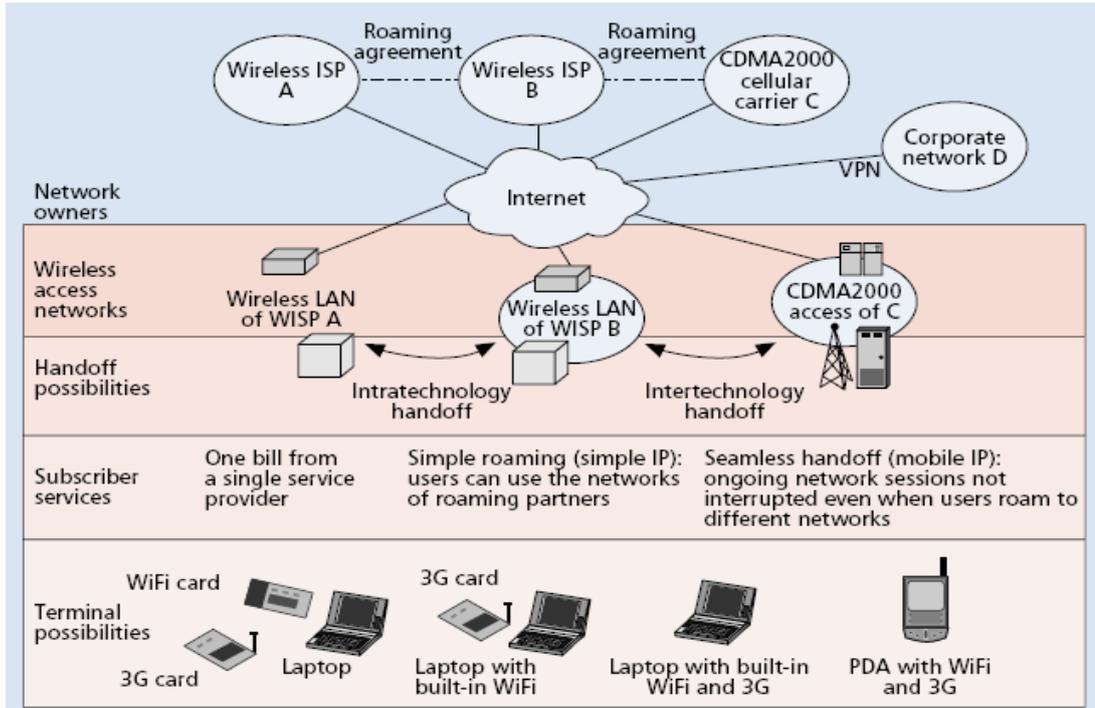


Figure 5.1 WLAN-3G Interworking: The Big Picture [19]

## 5.2 WLAN-3G Interworking Architectural Methods

The main architectural methods which are proposed for integrating WLAN and 3G technologies together are:

- ❖ The mobile IP architectural method
- ❖ The gateway architectural method
- ❖ The emulator architectural method

### 5.2.1 The Mobile IP Architectural Method

The architectural mobile IP method used to implement WLAN-3G interworking is illustrated in Figure 5.2. In this method, WLAN and 3G are peer to- peer networks.

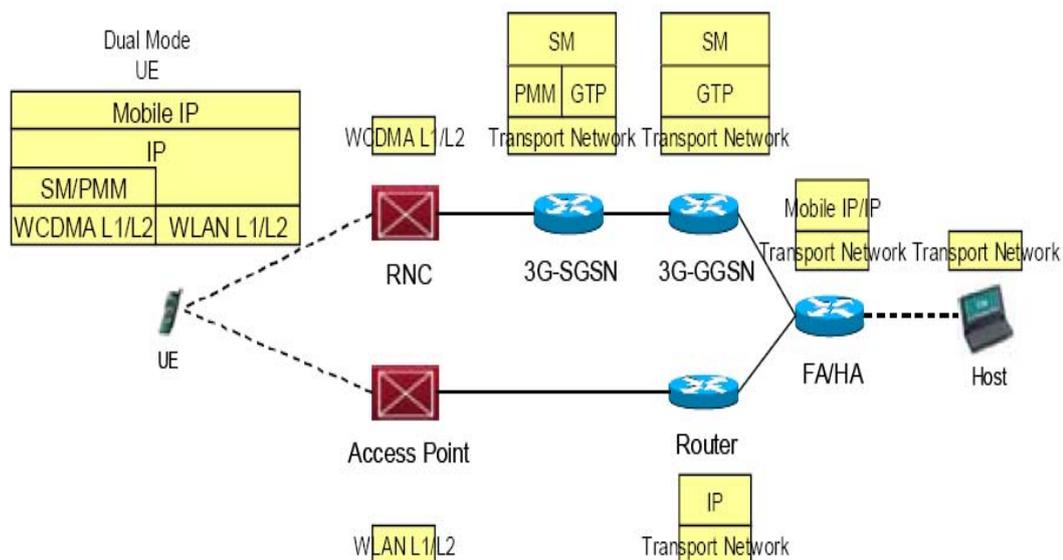


Figure 5.2 WLAN-3G Interworking: The Mobile IP Architectural Method, [20]

However, the main characteristics of this method are:

- ♦ In 3G network, UE uses standard 3G Session Management (3G SM) and GPRS mobility management (GMM) to handle Packet Data Protocol (PDP) sessions and roaming between WCDMA radio access networks.
- ♦ In WLAN, UE uses IP directly. As for the mobility management in WLAN, mobile IP might be used.
- ♦ Mobile IP is employed to restructure connections when UE roams from WLAN network to 3G network or vice versa.

- ◆ The protocol stack for UE is a dual mode which contains both 3G and WLAN stacks.
- ◆ The handover from 3G network to WLAN network is done by disabling UE 3G stack and using IP stack.
- ◆ The same IP can be maintained in case of WLAN-3G handover so this gives a kind of continuous session connectivity.
- ◆ Foreign Agent (FA) and Home Agent (HA) are installed in Access Router (AR) in WLAN and in GGSN in 3G so that FA/HA can help routers to tunnel and forward the data packets.
- ◆ Outside its home network, UE is identified by Care Of Address (COA) associated with its point of attachment a co-located FA that manages de-encapsulation and delivery of packets.
- ◆ UE registers its COA with HA which resides in UE's home network and is responsible for intercepting datagrams addressed to the UE's home address as well as encapsulating them to the associated COA.
- ◆ The datagrams to UE is always routed through HA, while the datagrams from UE are relayed along an optimal path by the Internet routing system, though which it is possible to employ reverse tunneling through HA.

### 5.2.1.1 Handover

WLAN-3G handover procedure using the mobile IP method is illustrated in Figure 5.3. The figure shows two different handover scenarios. The upper part of the figure is 3G to WLAN handover and the lower part of the figure is WLAN to 3G handover. The two handover scenarios are described as follows:

- ◆ **3G to WLAN handover scenario**

Let us assume that 3G is the home network for UE so the handover procedure is as follows.

- ◆ Initially, UE is sending or receiving data packets from 3G network.
- ◆ Once UE decides or the network decides to handover to WLAN, it starts with a set of Layer1/Layer2 (L1/L2) hand-over procedures.
- ◆ The UE might move to WLAN for a period of time, and moves back to the original UMTS later.
- ◆ To prevent UMTS detaches UE because that UMTS does not receive the periodical Router Area (RA) update message from UE, UE can send PDP/MM context standby message to its

SGSN that helps UE to reduce the re-attach effort if it moves back to the UMTS within a period of time.

- ◆ After that, UE can access IP network and sends an *Agent Solicitation* to locate a local FA. The local FA replies to UE, and then UE can send *Registration Request* to its HA.
- ◆ After updating COA in HA, the packets sent to the home network, will be forwarded to the visited network.

◆ **WLAN to 3G handover scenario**

This scenario is similar to the previous one mentioned above. However, the only difference is that if UE does not attach the network or activate PDP session before, then it should attach the network and activate a session before getting the service. Moreover, as mentioned above, if UE has already had a session which is not time out or it sent PDP/MM context standby message to 3G before, the original PDP session can be kept in use.

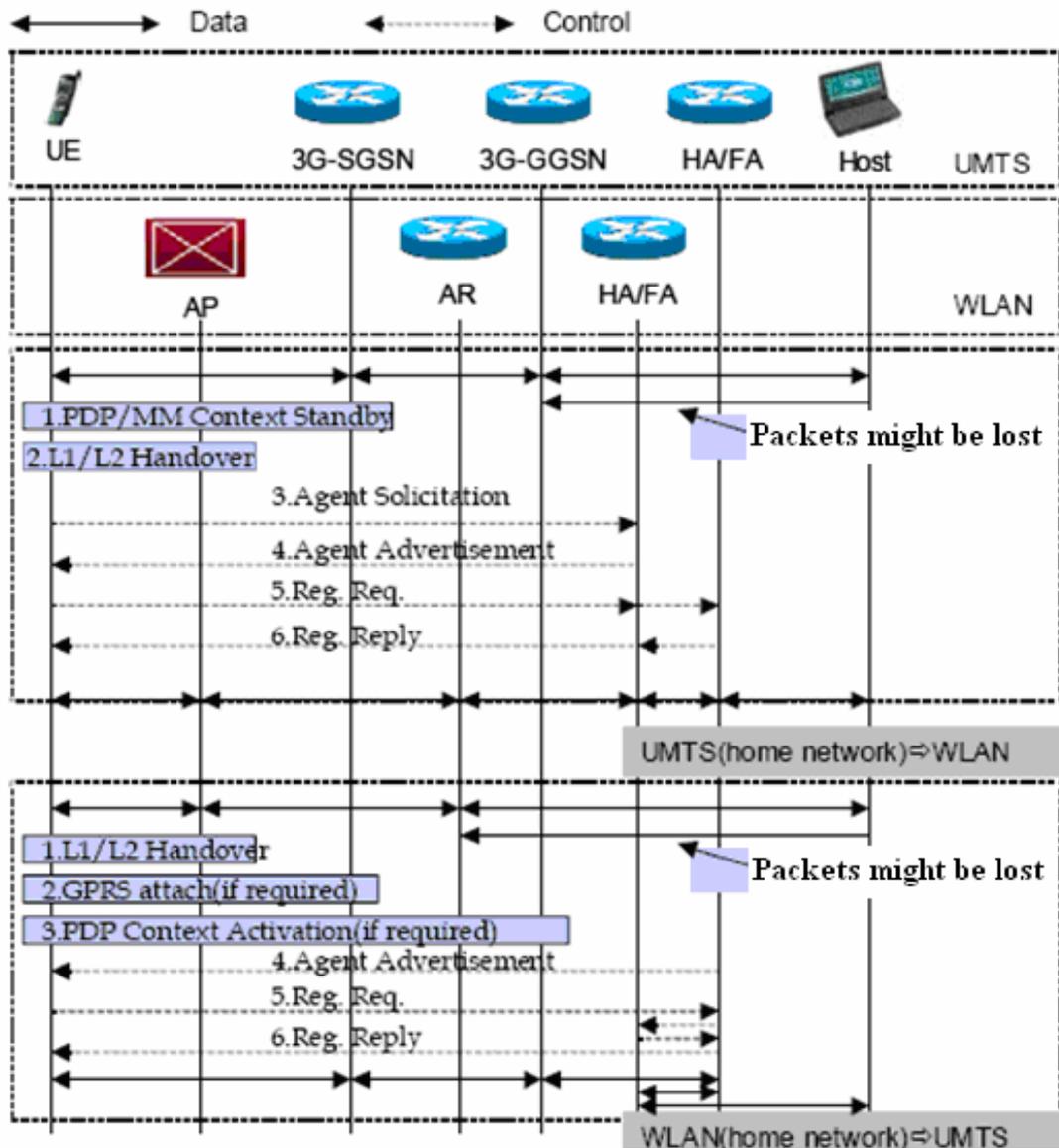


Figure 5.3 WLAN-3G Handover using The Mobile IP Method, [20]

### 5.2.1.2 Pros & Cons

The advantage of this mobile IP architectural method is that it is based on the mobile IP which makes IP address mobile. The same IP is used which solves the multiple address problem and gives a kind of continuous session connectivity.

To solve the packet duplication due to the lifetime of the routers, some conventions on both WLAN and 3G networks are needed. The databases of both networks may need to communicate to overcome the packet duplication issue.

The disadvantage of mobile IPv4 is the triangle routing. This could be overcome in the mobile IP when using the optimized routing. This is so important for real-time applications such as audio or video transmission.

In general, the existing mobile IP, WLAN and 3G standards are quite enough and mature to support the mobile IP method. However, the handover latency and the packet loss are its two major problems.

### 5.2.2 The Gateway Architectural Method

The architectural gateway method used to implement WLAN-3G interworking is illustrated in Figure 5.4. Also, in this method, WLAN and 3G are peer to-peer networks.

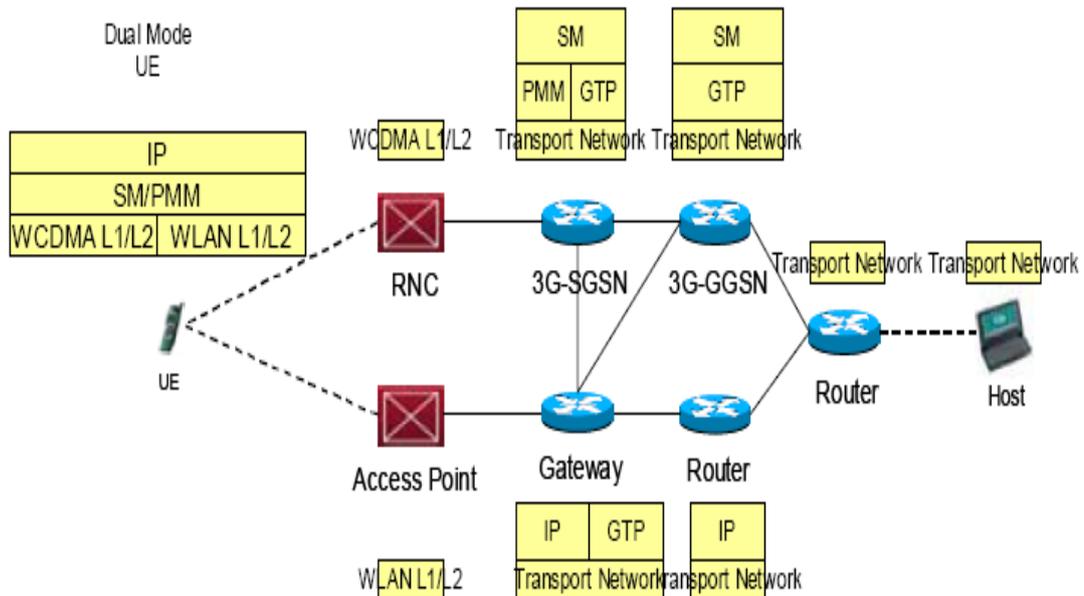


Figure 5.4 WLAN-3G Interworking: The Gateway Architectural Method, [20]

However, the main characteristics of this method are:

- ◆ A gateway is used to interconnect WLAN and 3G networks together.
- ◆ The gateway is an intermediate server (mobile proxy) that is implemented between WLAN and 3G and handles mobility and routing.
- ◆ Here, UE uses standard SM and GMM to access the 3G network and uses the standard IP to connect to the WLAN network.
- ◆ In WLAN, UE may use mobile IP to handle the mobility within WLAN but this is not necessary.
- ◆ For users having interworking services, the control signals and data packets are routed through the gateway.
- ◆ The gateway method aims to separate the operations of the two networks and enables the intersystem roaming of the two networks.
- ◆ The merits of this method are that the two networks can be operated independently and the mobile IP is not necessary.

### 5.2.2.1 Handover

WLAN-3G handover procedure using the gateway method is illustrated in Figure 5.5. The figure shows two different handover scenarios. The upper part of the figure is 3G to WLAN handover and the lower part of the figure is WLAN to 3G handover. The two handover scenarios are described as follows:

- ◆ **3G to WLAN handover scenario**

Let us assume that 3G is the home network for UE so the handover procedure is as follows.

- ◆ Initially, UE is sending or receiving data packets from 3G network.
- ◆ Once UE decides or the network decides to handover to a WLAN, it starts with a set of L1/L2 handover procedures.
- ◆ Then, UE tries to obtain a gateway address, for example using Dynamic Host Connection Protocol (DHCP), in order to perform the intersystem handover procedures.
- ◆ UE sends a *DHCPDISCOVER* to ask a gateway address in the visited network and gateway replies UE with its IP address.
- ◆ After UE obtains the gateway address, it sends RA update to the gateway using its original IP address of the 3G network.

- ◆ Then, the gateway sends a standard *Update PDP Contexts Request* to GGSN to ask GGSN to change its SGSN address-in-use.
- ◆ Once a GGSN receives a PDP context request from a gateway, it knows that UE moves to WLAN environment.
- ◆ The gateway becomes SGSN temporarily; so packets to UE should go to the gateway instead of the old SGSN.
- ◆ As described in mobile IP method, since UE might moves back to 3G network, it is better not to delete UE's MM and PDP context for the performance issue.
- ◆ After the whole roaming procedures, UE sends the packets out using its original IP address of 3G network.

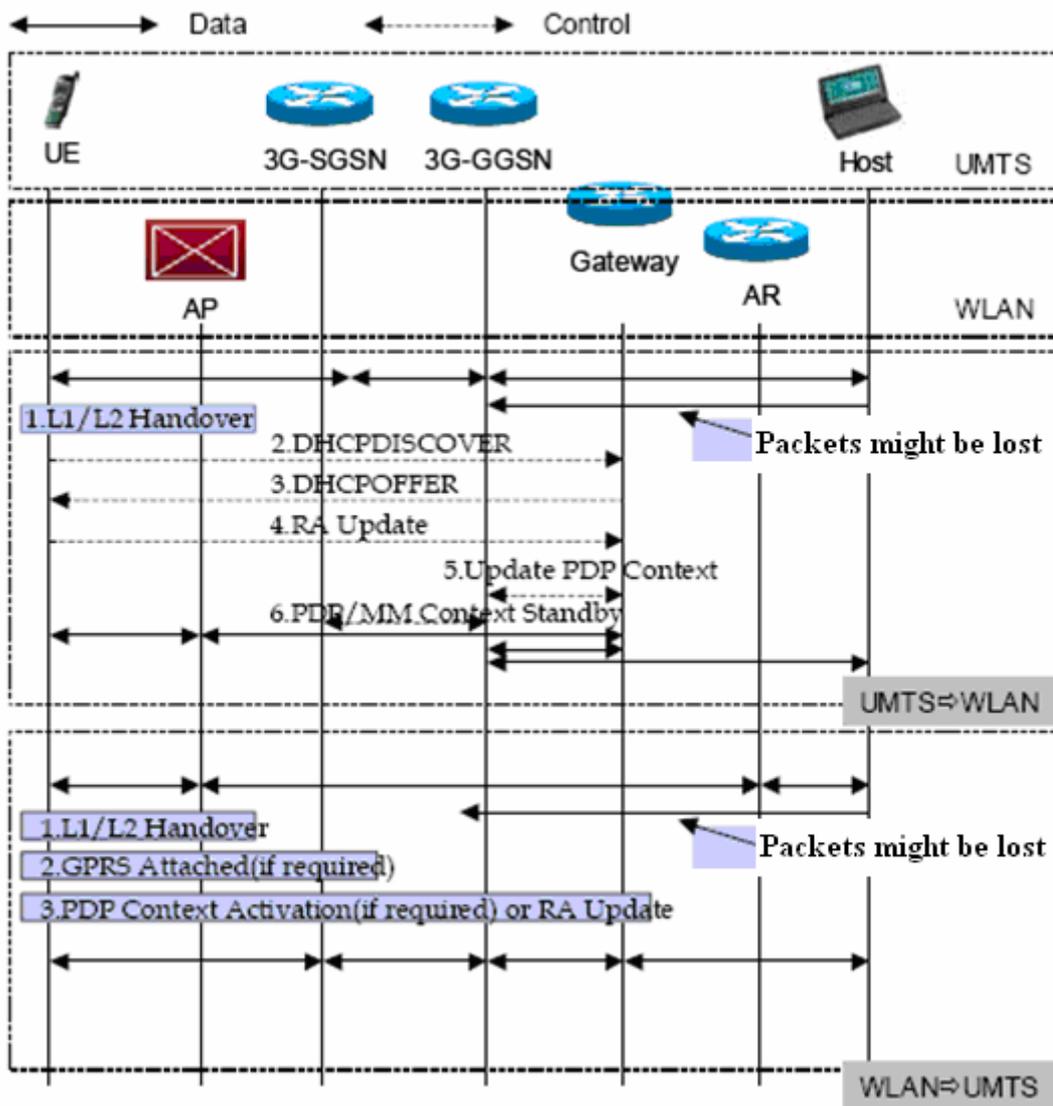


Figure 5.5 WLAN-3G Handover using The Gateway Method, [20]

- ◆ The packets from UE to Internet can be sent through WLAN network if WLAN does not perform ingress filtering on the 3G IP address. If WLAN applies the ingress filtering on non-WLAN IP addresses, then packets should go to the gateway and then to Internet. However, for these packets back to UE, should go to 3G network based on IP routing.
- ◆ GGSN recognizes that UE moves to WLAN and it tunnels the packets to the gateway.

- ◆ **WLAN to 3G handover scenario**

Let us assume that 3G is the home network for UE due to the fact that UE can access 3G radio access network only if UE is the subscriber of 3G network. Hence, the handover procedure is as follows.

- ◆ Initially, UE is sending or receiving data packets from WLAN network.
- ◆ Once UE decides or the network decides to handover to 3G network, it performs 3G standard procedures.
- ◆ If UE has already attached to 3G network and in the same RA, it can just start the service.
- ◆ If it is the first time to attach UE to the network, it should perform attach and PDP context activation and then it can start the service.
- ◆ In the attach procedures, UE uses the gateway as its Access Point Name (APN) to inform SGSN that it wants to use WLAN IP.
- ◆ During PDP context activation procedure, UE uses WLAN IP to request PDP context.
- ◆ Once the gateway detects the IP is WLAN IP and the security process is passed, it responses UE with the same WLAN IP.
- ◆ UE can use the same IP address that was used in WLAN.
- ◆ Here, the gateway simulates GGSN in 3G network.
- ◆ SGSN sends outgoing packets to the gateway and incoming packets go through the gateway to SGSN.
- ◆ Both incoming and out-going packets go through the same path.
- ◆ Internet hosts sending packets to WLAN UE, first go to the WLAN network, then received by the gateway, and then sent to SGSN and finally ended to UE.

### 5.2.2.2 Pros & Cons

The key merits of this gateway architectural method are that: Firstly, handover is faster and packet loss is less than in the mobile IP method since all signaling messages are routed within the internal network. Secondly, the mobile IP is not required so this leads to minimizing the encapsulation and routing inefficiencies with the mobile IP. Thirdly, the two 3G and WLAN networks can still handle their single mode users independently. Also, gateways (or proxies) are already in place in many organizations as firewalls or web servers. These gateways may be reused and utilized further for mobility management and inter-technology roaming.

However, Internet and 3G standards are not enough to support this gateway method. Some 3G protocols should be refined for additional controls and the exchange of AAA and HLR information should be further defined. Yet, this gateway method is not standardized. Obviously, in case of deploying a single gateway and it fails then it may lead to failure of the entire network so there is a need to have some fault tolerance and better gateway deployment.

### 5.2.3 The Emulator Architectural Method

The architectural emulator method used to implement WLAN-3G interworking is illustrated in Figure 5.6. Also, in this method, WLAN and 3G are peer to-peer networks.

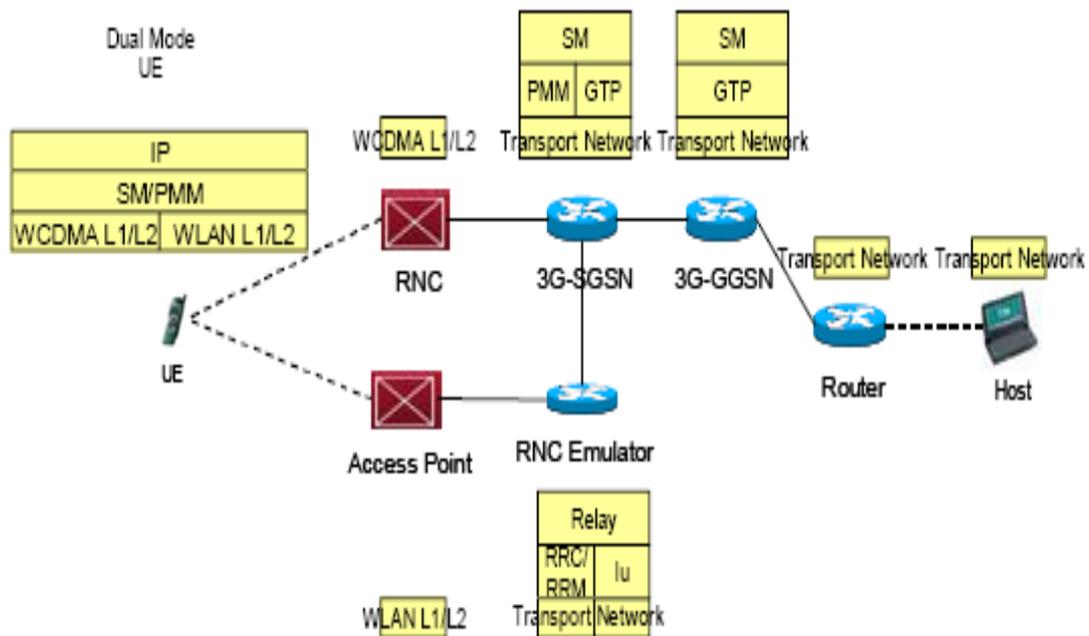


Figure 5.6 WLAN-3G Interworking: The Emulator Architectural Method, [20]

However, the main characteristics of this method are:

- ◆ WLAN AP is connected to the 3G network through 3G-SGSN.
- ◆ In this method, WLAN is treated as a routing area associated with 3G-SGSN; thus WLAN looks like RNC to 3G network.
- ◆ UE, whether connected to the 3G network or the WLAN, is always treated as a 3G user.
- ◆ The inter-system roaming arises only when UE is connected to WLAN network.
- ◆ A dual WLAN/3G mode UE is required to access both networks.
- ◆ The session management and the mobility management are handled by 3G SM and GMM.
- ◆ UE cannot access Internet through WLAN directly.
- ◆ This method tightly couples the two networks and WLAN can be viewed as a slave network of 3G. Due to this fact, this method is also called tightly coupled method.
- ◆ Here, every packet should pass through GGSN, which becomes the bottleneck.
- ◆ Running IP-sessions are not interrupted because the IP address of UE terminal is not changed.
- ◆ When UE leaves WLAN coverage area the service quality degrades; especially for those sessions which use WLAN high throughput capabilities.
- ◆ The key benefit of this method is that the handover delay is much lower than the two mobile IP method and gateway method.

### **5.2.3.1 Handover**

In this emulator method, WLAN-3G handover procedure is quite similar to 3G RNC handover. WLAN coverage area is treated as one routing area for CN. If UE enters or leaves a routing area, an update message is sent to CN of the 3G network; hence 3G-SGSN can simply distinguish RAN via routing areas.

However, this could be illustrated by an example as shown in Figure 5.7. From this figure the following can be noticed:

- ◆ When WLAN AP acts as an RNC then the handover procedures are equivalent to the serving RNC relocation between two WCDMA RNC's.
- ◆ The Radio Resource Management (RRM) and Radio Resource Control (RRC) of WLAN are different from WCDMA RRC and RRM.
- ◆ The parameters such as the radio link context carried in the *Relocation Request* message are translated into WLAN radio resource control method.

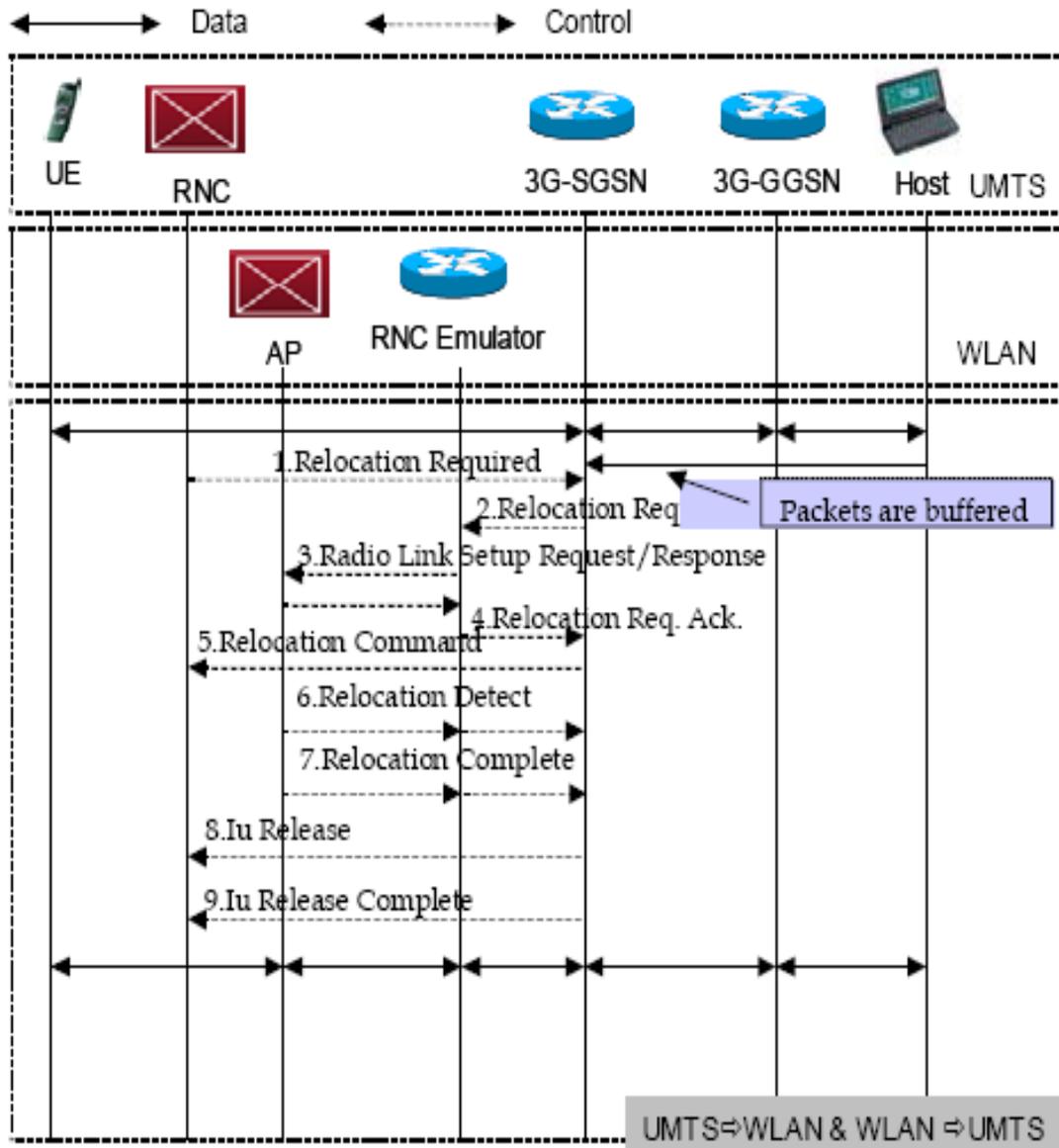


Figure 5.7 WLAN-3G Handover using The Emulator Method, [20]

### 5.2.3.2 Pros & Cons

As an advantage of this emulator method, mobility management, roaming, billing, and location related issues are taken care by 3G network. Moreover, this method provides a kind of compatibility integration of WLAN with GSM/GPRS/UMTS networks where WLAN UE credentials and security levels are of identical format to GSM/GPRS/UMTS. The strong security provided in 3G and QoS for real time services may now be provided over WLAN as well; thus resolving the drawbacks of the current IEEE 802.11a/b/g WLAN threats.

However, the key benefit of the emulator method is that the handover delay is much lower than the mobile IP method and the gateway method.

On the other hand, every packet should pass through GGSN, which becomes the bottleneck. Also, WLAN high data rates such as 11 Mbps/ 54 Mbps would be degraded to the rates of the 3G terminal (2 Mbps). In this method, a WLAN standard terminal needs to be modified which in turn would make them more expensive. Thus, the two attractive WLAN feature (speed and price) would be lost in this method.

Although, the emulator method achieves high efficiency, to use WLAN as 3G access stratum, it is not yet standardized. Basically, this emulator method and the other two mobile IP and gateway methods are not yet standardized and still under study.

### 5.2.4 Other Possible Architectural Methods

There are other proposed possible architectural methods used to integrate WLAN and 3G networks together. In this section we briefly present them.

As an alternative for the third emulator method, in which WLAN is interconnected to 3G through 3G-SGSN i.e. emulating RNC, another possible kind of emulator can be used to interconnect WLAN and 3G network through GGSN i.e. emulating 3G-SGSN. This is called 3G-SGSN emulator. However, the advantage of this method is that some overhead caused by available but not needed functionality is avoided compared with RNC emulator. If the 3G-SGSN emulator does the adaptation between WLAN and 3G packet formats, then GGSN can remain unaltered. On the other hand, GGSN might become a problem if its capacity is not designed to fulfil the growth of the traffic. If the adaptation is done by GGSN, taking into account the increased need for the data rate, the speed of WLAN can be utilized in full.

Another possibility to integrate WLAN and 3G together is to use Virtual Access Point (VAP) to interconnect both networks together. Unlike the emulator approach, here WLAN is the master network and 3G is the slave. The mobility is managed according to IEEE802.11 WLAN standard. From WLAN point of view, the entire 3G network appears as a basic service set associated with another access point (VAP in this case). The function of the VAP is to communicate with UE's connected through 3G, de-encapsulate their packets, and transmit them on the corporate WLAN. After this is done, the packets will reach the final destination through the router attached to the corporate WLAN. However, this VAP method does not have significant advantages over the previous methods. It is not clear how VAP will operate with normal WLAN AP's. The overhead of packets in this method is quite large, which makes the method inefficient.

## 5.3 Summary

WLAN-3G interworking big picture and its architecture methods have been illustrated in this chapter. With the highlight of: how the interworking works, the basic features of the different alternatives for WLAN-3G interworking; pointing out their advantages and drawbacks.

In the next chapter, case studies are addressed: some results of the current researches and some simulations were developed in this thesis; in order to evaluate some of the interworking methods that were presented in this chapter.

# 6. SIMULATION & EVALUATION

After having WLAN-3G interworking related issues explained, here some simulation will be demonstrated to evaluate certain aspects of WLAN-3G interworking.

As mentioned in chapter 5, the main methods used to implement WLAN-3G interworking are: the mobile IP methods, the emulator method, and the gateway method. Each one of these methods enjoys some pros and suffers from some cons. Here, case studies are addressed: based on results of the current researches and some simulations developed in this thesis; in order to evaluate some aspects of the interworking methods which were presented in chapter 5.

Basically, in this chapter, the main methods used to implement WLAN-3G interworking will be evaluated from the handover delay point of view. It will be seen how each method behaves in the case of handover and how long the user waits in case of handover between WLAN-3G service areas. All of these methods will be compared as well.

## 6.1 QoS of Wireless Networks

This will be an introduction to the evaluation metrics which used for evaluating 3G-WLAN interworking methods as will be seen later in this chapter.

Wireless networks differ from wired networks in the access technologies and the characteristics of the transmission medium. In this section some important characteristics of the wireless medium – which affect QoS of wireless networks- will be pointed out, [22].

### 6.1.1 Wireless Topology

The wireless network consists of wireless access points called Base Station (BS) in 3G or AP in WLAN, where each access point covers a certain geographical area. Frequency reuse is used in some wireless technologies such as GSM. However, in WCDMA, the frequency reuse factor equals to one.

## 6.1.2 Mobility

User mobility and wireless topology are the reasons why handover is necessary. Moreover, a wireless mobile user frequently changes its location; thus resulting in time varying bit error ratio and interference, which directly defines the QoS of the wireless network.

Handover schemes have what so called handover latency or handover delay. This is the time period during which the wireless mobile user is unable to send or receive IP packets or calls. In certain scenarios such as mobile IP – as will be seen later in this chapter the handover delay may be greater than what is acceptable for real time services.

Also, handover may cause packet losses or call dropping. Such losses may disrupt both real time and non real time services, and hence are undesirable.

User mobility introduces another problem: location control. It is necessary to track the wireless mobile users within the wireless network. Certain location management schemes are used in wireless networks for keeping track of wireless mobile users.

## 6.1.3 Bit Error Rate

Bit error in wireless links may occur due to different causes such as: interference, interference noise, multipath fading, and shadowing.

Fading or path loss is one of the main characteristics of signal propagation over a wireless link. One general formula for path loss is given in the following equation:

$$L = \frac{P_R}{P_T} = c \frac{1}{f^2 d^\alpha} \quad (6.1)$$

Where :

$P_R$  : is the received power at the receiver (the wireless access point or the wireless mobile user)

$P_T$  : is the transmitted power at the transmitter (the wireless access point or the wireless mobile user)

$f$  : is the frequency

$d$  : is the distance between the transmitter and the receiver

$\alpha$  : is a factor depends upon the characteristics of the wireless medium usually indicated as the path loss exponent. Typical values between 3 and 5.

$c$  : is a constant

Shadowing is a result of obstacles on the path of the radio waves (i.e. there is no line of sight between the wireless access point and the wireless mobile user). Furthermore, due to the reflection of the signal from surrounding objects such as buildings, different parts of the same signal may arrive to the receiver via different paths. This leads to what is

called multipath effect. Multipath is not desirable in some wireless networks such as GSM while it is helpful in other wireless networks such as WCDMA.

Interference is a result of the reuse of the same or adjacent frequency bands in the same of neighboring cells. WCDMA networks are robust to the interference due to the orthogonal spreading codes of the narrow band signals over wide frequency spectrum.

The above characteristics of the wireless medium determine the bit error. Also, the bit error rate depends on the location of the wireless mobile user. Therefore, all of these factors have to be taken into account in the design of wireless networks.

## 6.2 Handover in Wireless Networks

Since handover delay is the main feature which will be used in the evaluation of WLAN-G interworking methods, firstly, an overview about handover in wireless networks will be presented in this section.

As described above, mobility is the most important feature of a wireless network. Usually, continuous service is achieved by supporting handover (or handoff) from one cell to another. Handover is the process of changing the channel (frequency, time slot, spreading code, or combination of them) associated with the current connection while a call is in progress. It is often initiated either by crossing a cell boundary or by deterioration in quality of the signal in the current channel.

Poorly designed handover schemes tend to generate very heavy signaling traffic and, thereby, a dramatic degrades in QoS. The reason why handovers are critical in wireless networks is that neighboring cells are always using a disjoint subset of frequency bands, so negotiations have to take place between the wireless mobile user, the current serving wireless access point, and the next potential wireless access point. Other related issues, such as decision making and priority strategies during overloading, might influence the overall performance.

Handover is divided into two broad categories:

- Hard handovers: in which current resources are released before new resources are used. This is further divided into intracell and intercell handovers.
- Soft handovers: in which both existing and new resources are used during the handover process. This is further divided into soft handover and softer handover.

In a hard handover, the link to the prior wireless access point is terminated before or as the wireless mobile user is transferred to the new cell's wireless access point; the wireless mobile user is linked to no more than one BS at any given time. Figure 6.1 illustrates hard handover between the wireless mobile user (MS in this case) and the wireless access point (BS in this case) in wireless cellular network. In this figure, MS moves from one BS (BS1) to another (BS2). Here, the mean signal strength of BS1 decreases as the MS moves away from it. Similarly, the mean signal strength of BS2 increases as the MS approaches it.

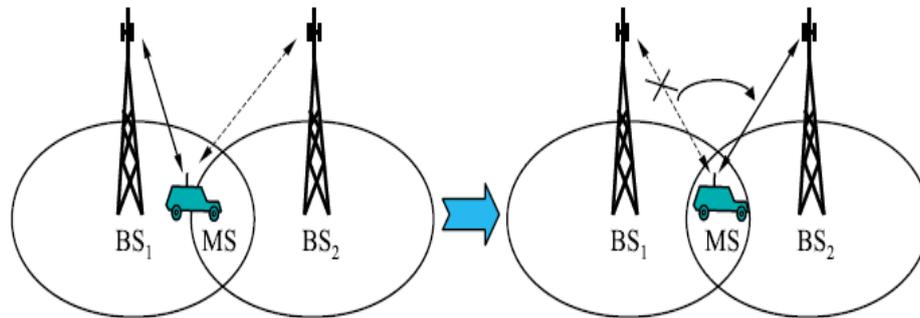


Figure 6.1 Hard handover in wireless cellular network

A hard handover occurs when the old connection is broken before a new connection is activated. The performance evaluation of a hard handover is based on various initiation criteria such as:

- **Relative signal strength:** in this method the strongest received wireless access point (BS) is selected at all times. The decision is based on measurement of the mean of the received signal. This method is observed to provoke too many unnecessary handovers, even when the signal of the current wireless access point is still at an acceptable level.
- **Relative signal strength with threshold:** This method allows a wireless mobile user (MS) to handover only if the current signal is sufficiently weak (less than certain threshold) and the other is the stronger of the two.

Basically, in this chapter, the hard handover is considered. The relative signal strength with threshold will be used as handover initiation criteria.

Reference to the handover in UMTS-WLAN interworking system, there are two handover scenarios as illustrated in Figure 6.2:

- **BS to AP scenario:** the wireless mobile user (MS) moves from UMTS area towards WLAN area leaving its previous serving wireless access point (BS) and approaching the new hosting wireless access point (AP).
- **AP to BS scenario:** the wireless mobile user (MS) moves from WLAN area towards UMTS area leaving its previous serving wireless access point (AP) and approaching the new hosting wireless access point (BS).

These handover scenarios will be used in evaluating 3G-WLAN interworking methods.

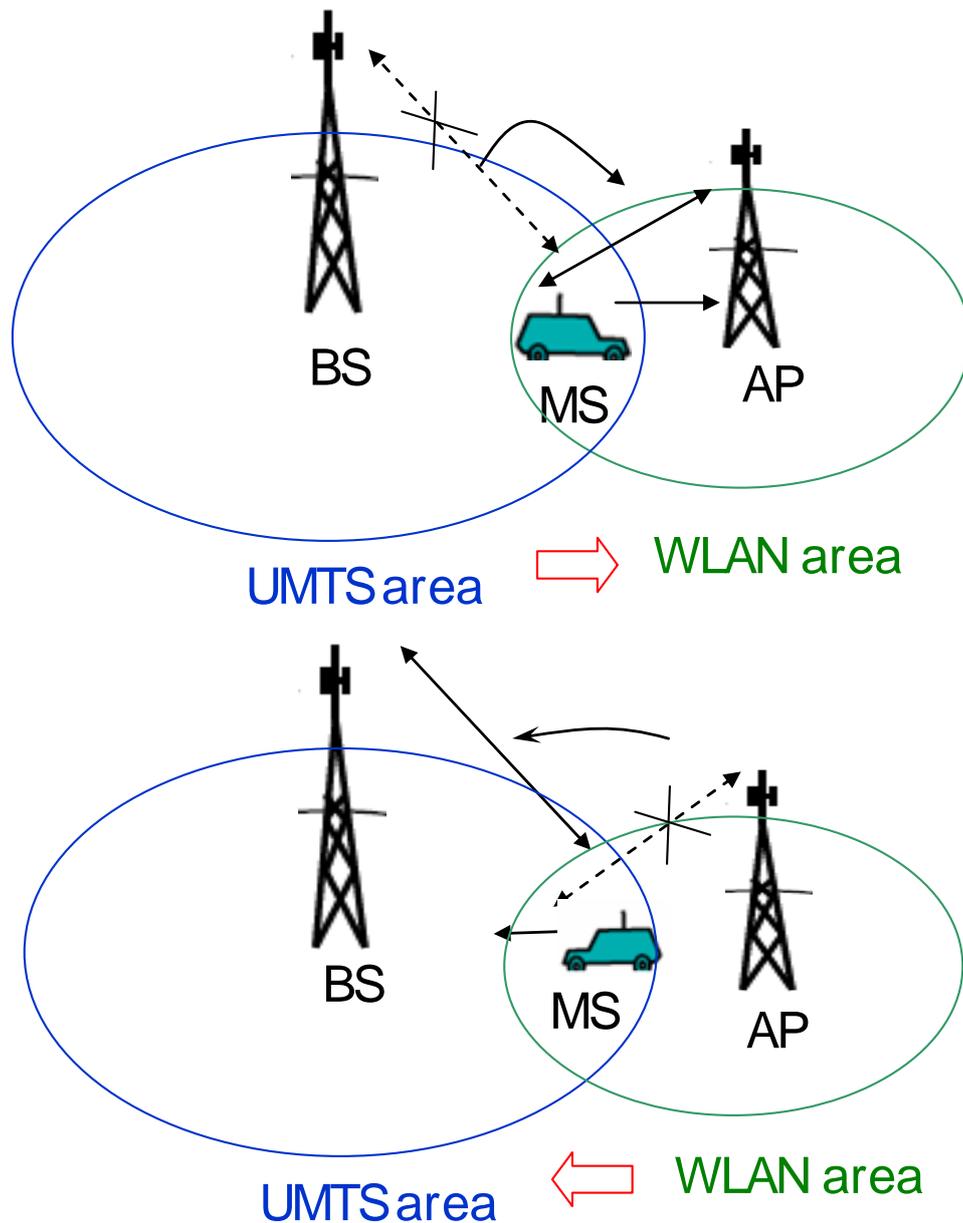


Figure 6.2 Handover scenarios in UMTS-WLAN

### 6.3 Performance Analysis

In this section, a comparative performance analysis of various 3G-WLAN interworking methods, namely, the mobile IP method, the gateway method, and the emulator method which were presented in the previous chapter.

### 6.3.1 Performance Metrics

There are several performance metrics that can be used to quantify the performance provided by a particular WLAN-3G interworking method. However, the following main performance metric will be used in evaluation the performance of such interworking methods:

- *Handover delay*: is the time between the initialization and the end of the hand-over between BS and AP. It is the time the wireless mobile user (MS) needs to wait until the handover process is completed among BS-AP. The handover delay,  $D_h$  can be formulated as:

$$D_h = D_t + D_w \quad (6.2)$$

Where:

$D_t$ : is the time spent in transmission between MS and AP/BS

$D_w$ : is the waiting time spent in handover processing in the network

In addition to handover delay performance metric, another parameter will used in the evaluation process such as: number of handovers between WLAN- UMTS networks, number of dropped calls between WLAN-UMTS networks.

### 6.3.2 Handover Delay in the Interworking Methods

As described in the previous chapter, various methods are used to implement WLAN-3G interworking. Each method has its own architecture and applies its own handover procedure. Mainly, the handover delay issue will be explained for the mobile IP method, the gateway method, and the emulator method and also these methods will be evaluated based on such performance metric.

The handover delay consists of two parts: the delay due to transmission and the waiting delay due to handover processing. The handover delay part due to transmission is common to all interworking methods since it depends only on the distance between MS and AP/BS; thus it can be eliminated from the comparison of the interworking methods.

However, the waiting delay due to handover processing is dependent on the network itself and the various involved components. Therefore, this part can not be eliminated from the comparison of the interworking methods. It represents the key part of the hand-over delay.

The handover delay differs from one interworking method to another. In the mobile IP method, see Figure 5.3, the various components of the waiting delay can be deduced as follows:

- In case of UMTS to WLAN handover, the waiting delay,  $D_w$  is the sum of:

$D_1$ : the time spent in PDP/MM context standby and L1/L2 handover data among UE, 3G-SGSN, 3G-GGSN, and host.

$D_2$ : the time spent in agent solicitation, advertisement, and registration controls among UE, WLAN HA/FA and UMTS HA/FA.

- In case of WLAN to UMTS handover, the waiting delay,  $D_w$  is the sum of:

$D'_1$ : the time spent in GPRS attach, PDP/MM context activation, and L1/L2 handover data among UE, AP, AR, and host.

$D'_2$ : the time spent in agent advertisement, and registration controls among UE, WLAN HA/FA and UMTS HA/FA.

In the gateway method, see Figure 5.5, the various components of the waiting delay can be deduced as follows:

- In case of UMTS to WLAN handover, the waiting delay,  $D_w$  is the sum of:

$D_3$ : the time spent in L1/L2 handover data among UE, 3G-SGSN, 3G-GGSN, and host.

$D_4$ : the time spent in DHCP setup, RA update and PDP context controls among UE, Gateway, 3G-SGSN, and 3G-GGSN.

- In case of WLAN to UMTS handover, the waiting delay,  $D_w$  equals:

$D'_3$ : the time spent in GPRS attach, PDP/MM context activation, and L1/L2 handover data among UE, AP, AR, host, and 3G-GGSN.

In the gateway method, see Figure 5.7, the components of the waiting delay can be deduced as follows:

- In case of UMTS to WLAN handover or WLAN to UMTS handover, the waiting delay,  $D_w$  equals:

$D_5$ : the time spent in L1/L2 handover data among UE, 3G-SGSN, 3G-GGSN, and host.

The previous analysis is summarized in the following relation:

$$D_w = \begin{cases} D_1 + D_2, \dots \dots \dots \text{umts} \rightarrow \text{wlan} : \text{mobileIP} \\ D'_1 + D'_2, \dots \dots \dots \text{wlan} \rightarrow \text{umts} : \text{mobileIP} \\ D_3 + D_4, \dots \dots \dots \text{umts} \rightarrow \text{wlan} : \text{gateway} \\ D'_3, \dots \dots \dots \text{wlan} \rightarrow \text{umts} : \text{gateway} \\ D_5, \dots \dots \dots \text{umts} \rightarrow \text{wlan} / \text{wlan} \rightarrow \text{umts} : \text{emulator} \end{cases} \quad (6.3)$$

As a rough estimate comparison, the handover processing components can be used to give a general indication about the interworking methods assuming all components have the same conditions.

For the mobile IP method and the gateway method,  $D_1$  is greater than  $D_3$  since they access the same components but  $D_1$  involves more data to be processed.  $D_2$  is greater than  $D_4$  since in  $D_2$  the processing occurs in the same UMTS network while it involves both WLAN network and UMTS network in  $D_4$ . Moreover,  $D_1$  is approximately similar to  $D_3$ . Thus, the waiting delay in the mobile IP method is greater than that in the gateway method.

For the emulator method, the waiting delay involves only one item which is processed in the same network since WLAN is considered as one cell of UMTS network so the handover is performed as it is within the UMTS network. Thus, it is expected that the emulator method has lower waiting delay than the mobile IP method and the gateway method.

As an expected summary, the emulator method has the lowest handover delay among the three interworking methods, and then comes the gateway method and then lastly the mobile IP method.

### 6.3.3 Performance Observations

This section demonstrates some performance studies of the three interworking methods. This is based on some publications found to have a relation with this topic [20], and [23].

Although those publications are concerned with interworking methods in different simulation network architectures and traffic models than what used here, some results can be *safely generalized* to the system model used here.

Furthermore, these performance studies will be used to validate the system model and to prove or confirm the deduced results and the drawn conclusions.

As illustrated in those publications [20], and [23], the performance studies are based on simulations. One simulation which will be described here will be used to confirm deduced results and the drawn conclusion.

The simulation environment for this simulation has a UMTS network and a WLAN network implemented using NS2, which developed by UC Berkeley. The simulation parameters are following:

- UMTS network has a 100 Mbps backbone with 5 radio network subsystems and offers 32 kbps data services.
- WLAN has 25 AP's and provides 100 kbps data service.
- It is assumed that 50 % of the users are WLAN users and the other 50 % of the users are UMTS users.
- Among all users, 50 % are dual mode users and might move in between two networks, and the other 50 % are single mode users using either WLAN or UMTS.

- Dual mode users have a 0.5 probability to enter WLAN network and a 0.5 probability to enter UMTS network.

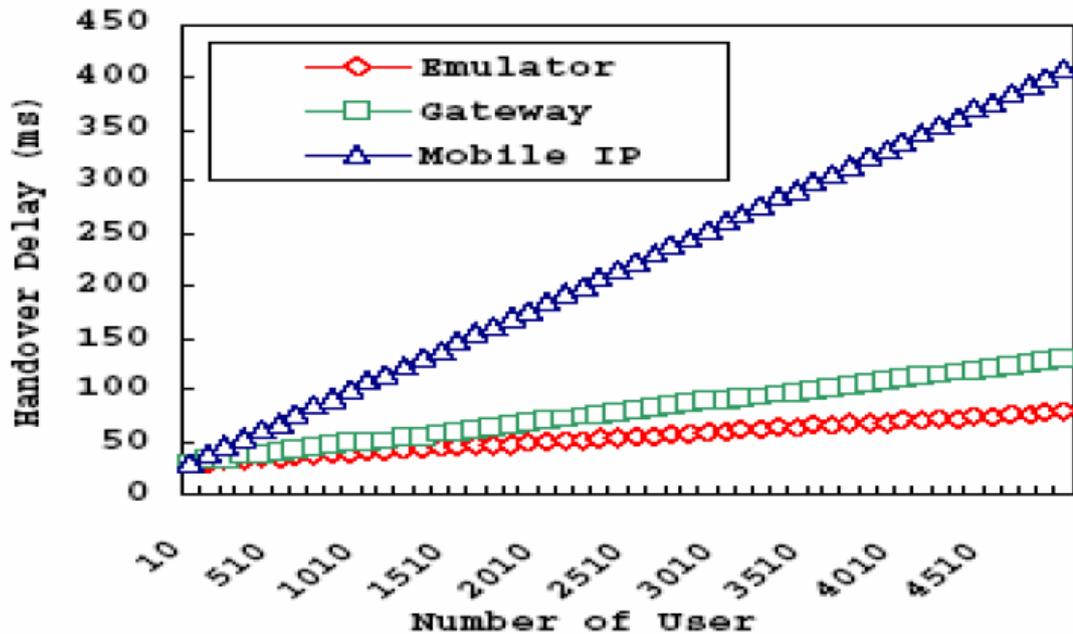


Figure 6.3 Handover delay for the different WLAN-UMTS Interworking methods

The three different interworking methods are compared here, i.e. the mobile IP method, the gateway method and the emulator method. Figure 6.3 shows the handover delay for those interworking methods. It is clear that the mobile IP method obtains the poorest performance since the signaling packets have to go to Internet (HA/FA). Also, the mobile IP method introduces more than 200 ms delay under this network configuration while the users are more than 2000. The delay might not be acceptable for real-time applications.

The gateway method and the emulator method involve the message exchange within intra-network only. The latency of the gateway method is a little bit higher than in the emulator method.

The result of this performance study confirms with the expected results obtained from the handover delay analysis in the previous section.

## 6.4 Simulation

In this section, a simulation model is developed using MATLAB to evaluate UMTS-WLAN interworking methods: the mobile IP method, the gateway method, and the emulator method. The simulation environment, parameters, assumptions, and approach are illustrated here.

### 6.4.1 System Model

The system model used in the simulation consists of a UMTS network and a WLAN being interworked using the three interworking methods.

Each network has a single wireless access point, i.e. UMTS has a single BS and WLAN has a single AP. The coverage area of each wireless access point is a circle with radius  $R$  and the wireless access point is located at the center of the coverage area. It is not necessary that both coverage areas are equal. Figure 6.4 shows the coverage areas for BS and AP.

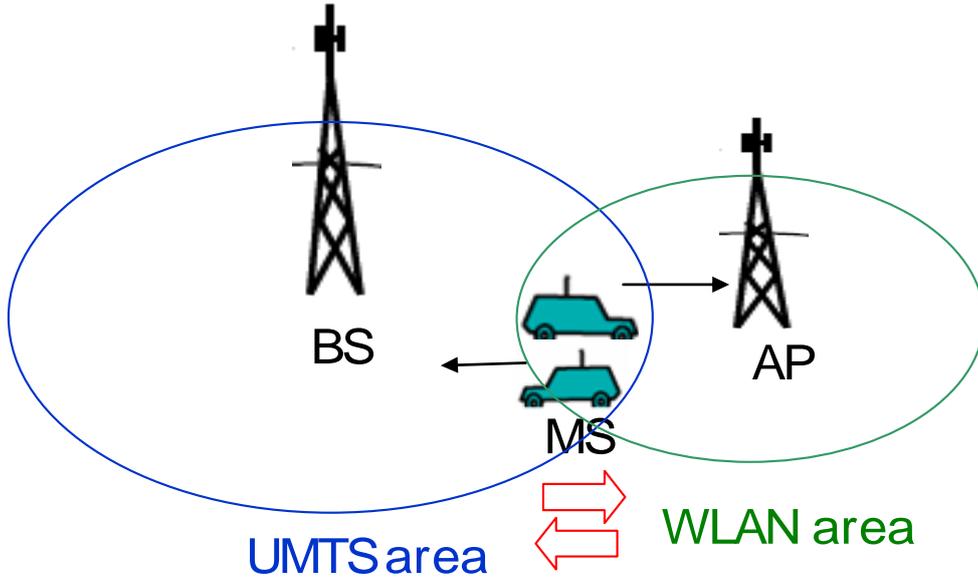


Figure 6.4 System model

Each network has its own users which are uniformly distributed among the coverage area. The wireless mobile users (MS) can move freely between both networks.

The position of a MS is defined with  $r$  and  $\phi$  coordinates (indirectly  $x,y$  coordinates), where  $r$  is the distance from the center of the area and  $\phi$  is the angle with the horizontal axis. The power distribution function (pdf) for the user density in the area is given by:

$$f_r(r) = \begin{cases} 2r/R^2, & \dots\dots\dots 0 \leq r \leq R \\ 0, & \dots\dots\dots r > R. \end{cases} \quad (6.4)$$

Also, the pdf for  $\phi$  is given by:

$$f_\phi(\phi) = 1/2\pi, \dots\dots\dots 0 \leq \phi \leq 2\pi \quad (6.5)$$

In this model, the movement direction and the magnitude of the velocity,  $v$  of the users are assumed to remain constant within one simulation time step; these are allowed to change at handover to the other area. The pdf for  $\theta$  is given by:

$$f_{\theta}(\theta) = 1/2\pi, \dots, 0 \leq \theta \leq 2\pi \quad (6.6)$$

The pdf for the velocity is given by:

$$f_v(v) = \begin{cases} k \frac{1}{\sqrt{2\pi}o} e^{-\frac{(v-m)^2}{2o^2}}, & \dots, v \geq 0 \\ 0, & \dots, v < 0 \end{cases} \quad (6.6)$$

$m$  is the average velocity of the user

$o$  is the standard deviation

$$k = \frac{1}{\frac{1}{2} + \frac{1}{\sqrt{\pi}} \int_0^{\frac{m}{\sqrt{2}o}} e^{-x^2} dx} \text{ is constant}$$

Thus, in this system model the following assumptions are made:

- The users are uniformly distributed within each area.
- The initial location of each user is defined by  $r$  and  $\phi$  coordinates (indirectly  $x, y$  coordinates).
- The angles of the direction of movement,  $\theta$ , are uniformly distributed.
- The users are allowed to move in any direction from the starting location.
- The velocity of each user is constant during the simulation time step.
- The users can freely move among both areas.
- Calls from different users are independent.

## 6.4.2 Simulation Approach

The simulation is based on a program code developed in MATLAB. It runs for a certain number of iterations as specified by the simulation parameters which are set at the beginning of the simulation. Figure 6.5 summarizes the simulation approach.

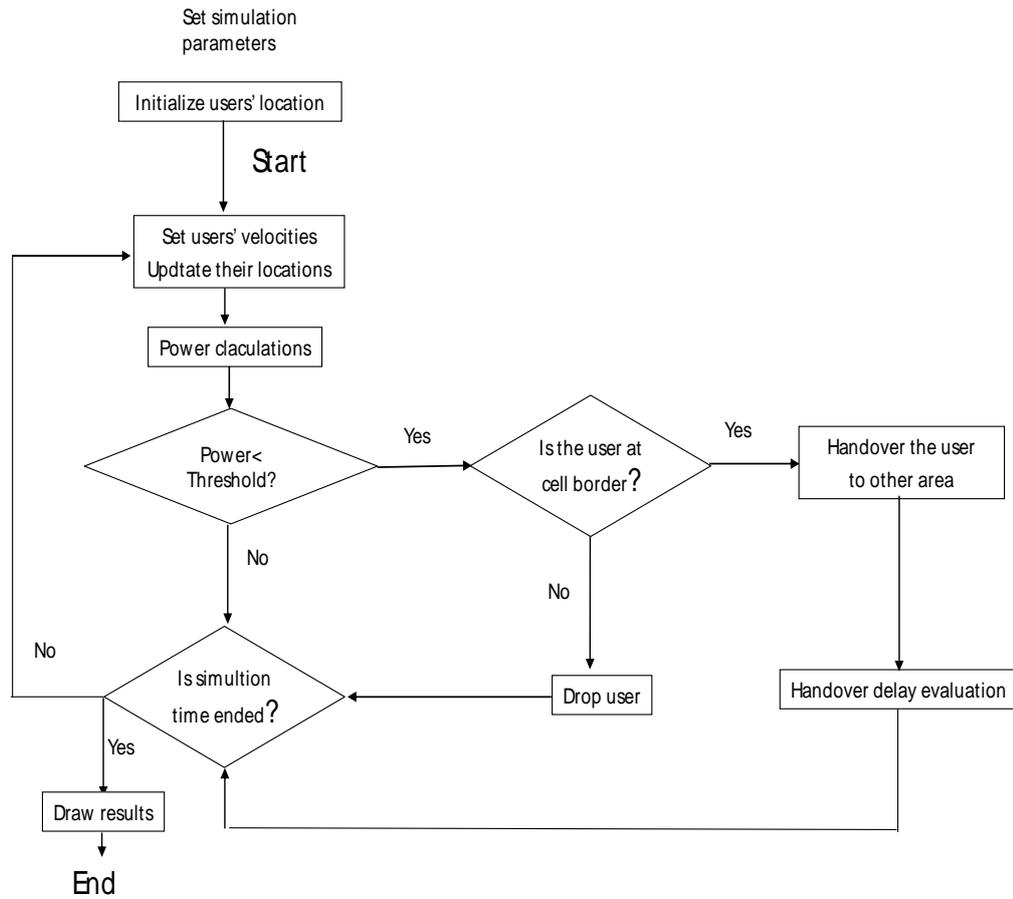


Figure 6.5 Simulation approach

First, the simulation parameters are set; so the simulation will run according to the specified simulation time and each iteration lasts according to the specified time step. The number of iterations equals to the simulation time divided by the time step.

In every iteration, the mobility of user is set by setting their velocities' magnitude and their direction of movements. Based on that, the users' locations are updated. Hence, the power of the signal is calculated for each user and compared to a certain predefined threshold. If the power of the signal is less than the predefined threshold; then this means the user should handover to the other area. However, the handover occurs if the power of the signal is less than the predefined threshold and if the user moves towards the next area (in the simulation this is done when the user is at the area border or the direction of movement,  $\theta$  is within  $0 \leq \theta \leq \pi/2$ , or  $3\pi/2 \leq \theta \leq 2\pi$ ).

In the same iteration, the handover delay for each interworking method is calculated. At the end of the simulation, three figures are generated. The first figure illustrates the distribution of users among UMTS-WLAN areas at the beginning of the simulation. The second figure illustrates the number of handovers in UMTS and WLAN areas which occurred during the simulation. The third figure illustrates the handover delay for each

interworking method: the mobile IP method, the gateway method, and the emulator method.

The simulation is an interactive tool that interacts with user and enables him to set the parameters and to observe the simulation progress. The simulation code, parameters, instructions, details are described in the appendix.

### 6.4.3 Simulation Results

When the simulation is completed, the following figures are shown:

- ❖ Distribution of users: it shows the UMTS coverage area and the WLAN coverage area and the initial users' locations and their distribution among their coverage areas. Each user group is located initially at its own coverage area as shown in Figure 6.6.

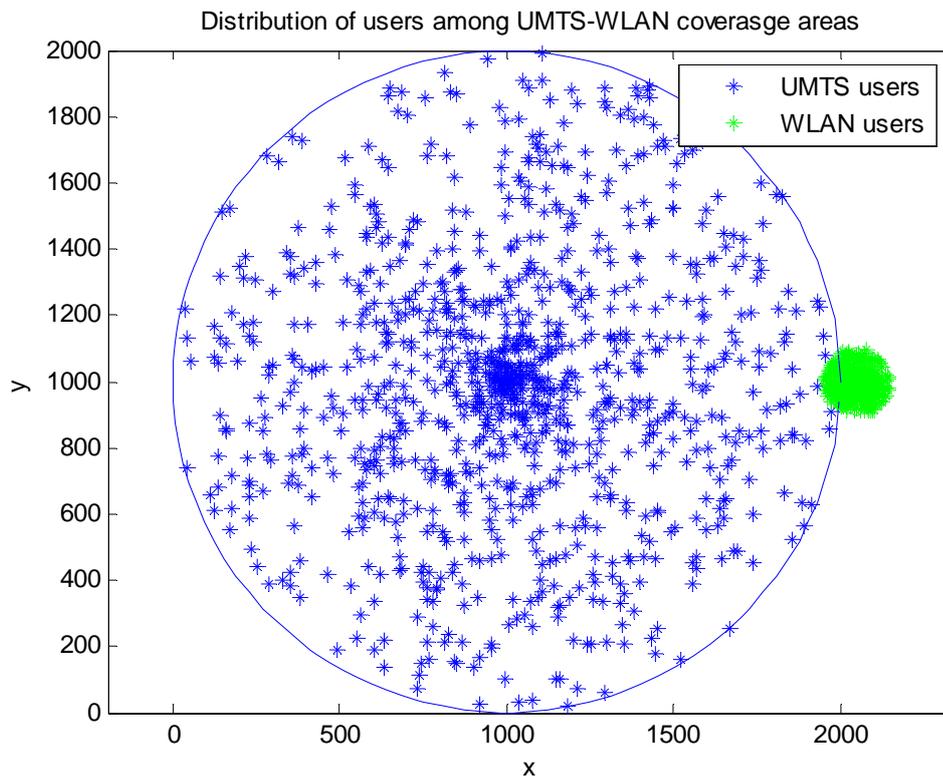


Figure 6.6 System Model: Distribution of users among WLAN-UMTS area

- ❖ Number of UMTS-WLAN handover users: It shows the number of users which performed handover to the other area during each time step. Thus, the number of UMTS handover users and the number of WLAN handover users are shown in Figure 6.8.

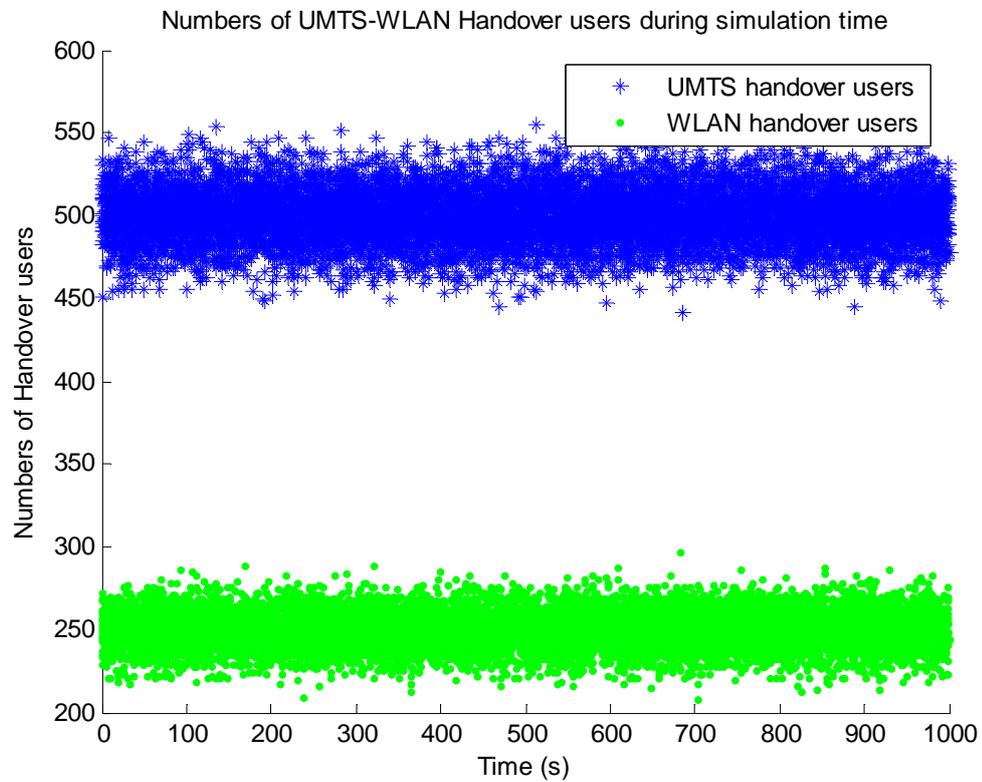


Figure 6.7 Number of WLAN-UMTS Handover users

- ❖ Number of UMTS-WLAN dropped users: It shows the number of users which dropped in each area during each time step. Thus, the number of UMTS dropped users and the number of WLAN dropped users are shown in Figure 6.8.

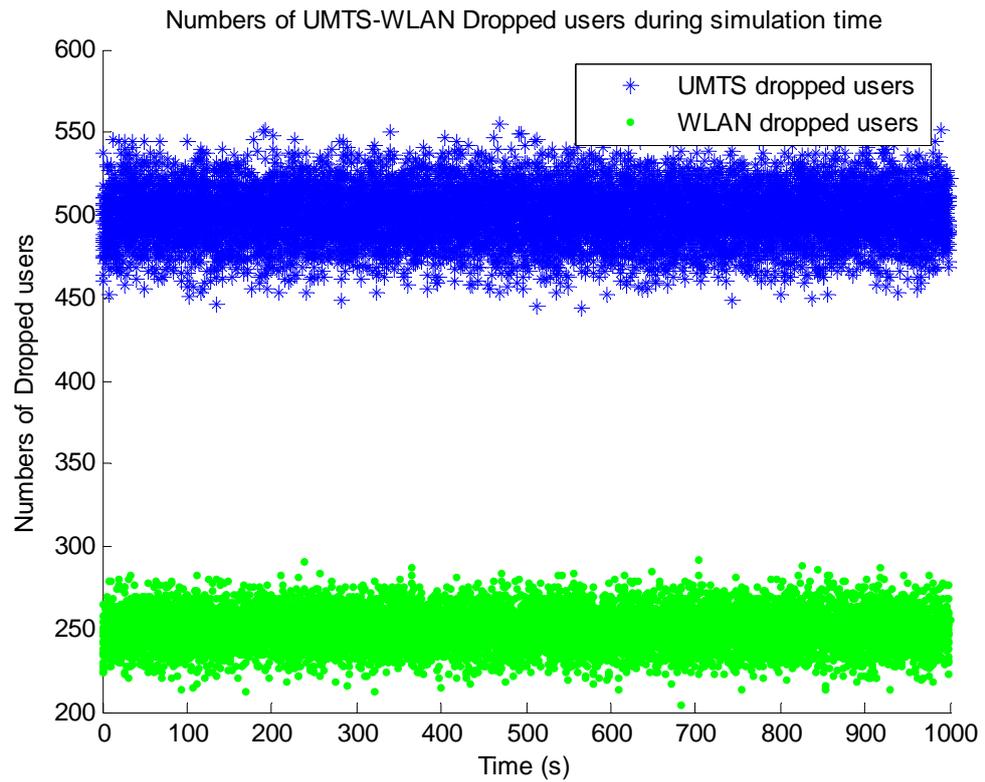


Figure 6.8 Number of WLAN-UMTS Dropped users

- ❖ Handover delay: it shows the handover delay for each interworking method: the mobile IP method, the gateway method, and the emulator method as shown in Figure 6.9.

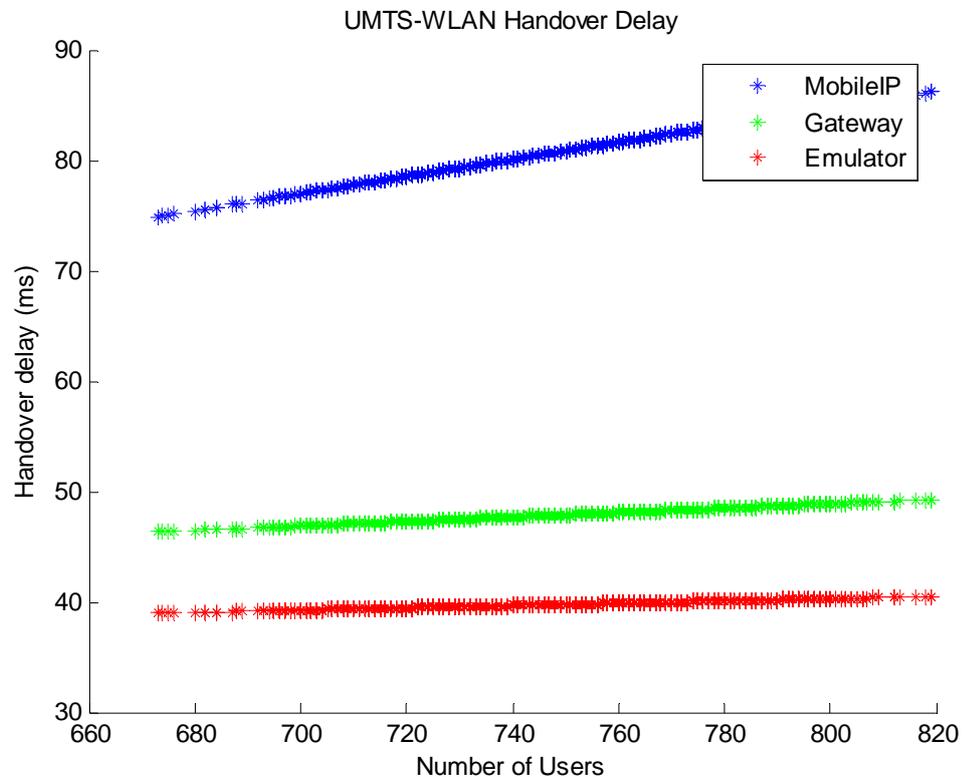


Figure 6.9 Handover delay for different WLAN-UMTS Interworking methods

#### 6.4.4 Discussion

From the simulation results in the previous section, the performance of the interworking methods is clear from Figure 6.10. The mobile IP method has the highest handover delay, while the gateway method has lower delay and the emulator method has the lowest. This result confirms the expected result that was obtained analytically earlier in section 6.3.2 and section 6.3.3.

The mobile IP method suffers from high handover delay since the handover occurs among two networks. The usage of the gateway in the gateway method fastens the handover. However, in the emulator method, the handover occurs in the single UMTS network since WLAN is treated as any normal UMTS cell.

The used simulation model is not that much accurate but it gives an approximate estimation about the performance of the interworking methods. However, some further modification worth to be done in order to get more accurate results but this left as future work.

## 6.5 Summary

The performance of UMTS-WLAN interworking methods (the mobile IP method, the gateway method, and the emulator method) has been illustrated analytically and using simulation throughout this chapter.

# 7. SUMMARY & CONCLUSIONS

In the previous chapters, the question of UMTS-WLAN interworking has been demonstrated. The focus is on the features, architecture, and evaluation of these internetworking technologies.

The importance of UMTS-WLAN interworking comes to supply the need for public wireless access: to cover the demand for high data-intensive applications and to enable smooth online access to corporate data services in hot spots. This is done by integrating both UMTS and WLAN together to utilize high mobility and high data rate key features together.

Different UMTS-WLAN interworking architecture methodologies are introduced and studied. The main interworking methods are: the mobile IP method, the gateway method, and the emulator method. The performance of the interworking methods can be evaluated using several performance metrics. The metric used here is the handover delay. These methods have been evaluated analytically and via simulation; based on handover delay.

As a comparison, based on consequences of the analytical and simulated models, the mobile IP method has the highest handover delay, while the gateway method has lower handover delay and the emulator method has the lowest. Mobile IP method suffers from high handover delay since the handover occurs between two networks. The usage of gateway in the gateway method fastens the handover. However, in the emulator method, the handover occurs in the single UMTS network since WLAN is treated as any normal UMTS cell. These results are confirmed based on literature studies which show the same results for the interworking methods

This research provides an analytical model and a simulated model which can be used for evaluating the performance of UMTS-WLAN interworking method: mobile IP method, the gateway method, and emulator method.

The used simulation model is not that much accurate but it gives an approximate estimation about the direction of the performance of the interworking methods. However, some further modification worth to be done in order to get more accurate results but this left as future work. There are still some open questions, which may be considered in future work since the subject of UMTS-WLAN interworking is still under study. For instance, one future task is to simulate the actual UMTS-WLAN interworking method architectures: protocol, traffic model, hot spots etc in order to study the performance of the different interworking methods more accurately and from different aspects rather than only handover delay.

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## APPENDIX

Here, the simulation which was developed in MATLAB will be described. This includes: simulation parameters, instructions, and code.

The simulation parameters are summarized in Table A.1. These parameters need to be set before starting the simulation.

Table A.1 Simulations Parameters

Parameter	UMTS	WLAN
Cell Radius (m)	1000	100
Centre coordinates (x,y) (m)	(1000,1000)	(2050,1000)
Power of access point (dB)	80	40
Gain of access point (dBi)	100	50
Gain of MS antenna (dBi)	10	5
Frequency (MHz)	2000	2400
Target Threshold (dBm)	-120	-100
Path loss exponent	3.5	3.5
Standard deviation for shadowing	6.5	6.5
Number of users	1000	500
Speed of user (m/s)	20	5
Simulation time (s)	1000	
Time step (s)	0.1	

To start the simulation, first, browse to the project directory that has the simulation program, second, run the *main* command in MATLAB prompt, then enter the suitable values for the simulations parameters- If no values are entered then the default values between brackets will be set automatically. Finally, wait until the simulation ends and the result figures are drawn. This is illustrated as shown bellow:

```
>> cd C:\MATLAB7\work\project
```

>> main

Please enter the simulation parameters [default value in brackets]...

Range/radius of BS cell in meter [1000]?

Range/radius of AP cell in meter[100]?

BS location

Center of BS area

x position for BS [Similar to BS range]?

y position for BS [Similar to BS range]?

AP location

Center of AP area

x position for AP [ $x_{bs}+R_{bs}+R_{ap}/2$ ]?

y position for AP [Similar to BS]?

Power of umts BS in dB [80]?

Gain of umts BS [100]?

Gain of umts user antenna [10]?

Power of wlan AP in dB [40]?

Gain of wlan AP in dBi [50]?

Gain of wlan user antenna [5]?

UMTS operating frequency band in MHz [2000]?

WLAN operating frequency band in MHz [2400]?

Target Power Threshold for umts user handover in dBm [-120]?

Target Power Threshold for wlan user handover in dBm [-100]?

Path loss exponent [3.5]?

Standard deviation of shadowing [6.5]?

Number of umts users [1000]?

Number of wlan users [500]?

Speed of umts user m/s [20]?

Speed of wlan user m/s [5]?

Simulation Time in seconds [1000]?

Time step in seconds [0.01]?

-----  
Simulation starts...

-----  
-----

Iteration number: 1

-----

Number of umts handover users: 495

Number of wlan handover users: 238

Number of umts dropped users: 499

Number of wlan dropped users: 242

Handover delay using MobileIP: 7.952800e+001

Handover delay using Gateway : 4.752820e+001

Handover delay using Emulator: 3.958780e+001

-----

Iteration number: 2

-----

Number of umts handover users: 512

Number of wlan handover users: 231

Number of umts dropped users: 483

Number of wlan dropped users: 251

Handover delay using MobileIP: 8.030100e+001

Handover delay using Gateway : 4.772920e+001

Handover delay using Emulator: 3.968980e+001

-----

.....

....

.

The simulation code is shown bellow:

```

% Simulation: "Evaluation of UMTS-WLAN Interworking methods: the mobile IP,
% the gateway, and the emulator"

% Programmed by Mohammad Abualreesh

%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%      Setting      Simulation      parameters
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

clear;

disp('Please enter the simulation parameters [default value in brackets]...');

R_bs=input('Range/radius of BS cell in meter [1000]? ');

if length(R_bs)==0

    R_bs=1000;

end

R_ap=input('Range/radius of AP cell in meter[100]? ');

if length(R_ap)==0

    R_ap=100;

end

disp('BS location');

disp('Center of BS area');

x_bs=input('x position for BS [Similar to BS range]?');

if length(x_bs)==0

    x_bs=R_bs;

end

y_bs=input('y position for BS [Similar to BS range]?');

if length(y_bs)==0

    y_bs=R_bs;

end

disp('AP location');

disp('Center of AP area');

x_ap=input('x position for AP [x_bs+R_bs+R_ap/2]?');

if length(x_ap)==0

    x_ap=x_bs+R_bs+R_ap/2;

end

```

```
y_ap=input('y position for AP [Similar to BS]?');
if length(y_ap)==0
    y_ap=y_bs;
end
p_bs=input('Power of umts BS in dB [80]? ');
if length(p_bs)==0
    p_bs=80;
end
g_bs=input('Gain of umts BS [100]? ');
if length(g_bs)==0
    g_bs=100;
end
g_umts=input('Gain of umts user antenna [10]? ');
if length(g_umts)==0
    g_umts=10;
end
p_ap=input('Power of wlan AP in dB [40]? ');
if length(p_ap)==0
    p_ap=40;
end
g_ap=input('Gain of wlan AP in dBi [50]? ');
if length(g_ap)==0
    g_ap=50;
end
g_wlan=input('Gain of wlan user antenna [5]? ');
if length(g_wlan)==0
    g_wlan=5;
end
frequency_umts=input('UMTS operating frequency band in MHz [2000]?');
if length(frequency_umts)==0
    frequency_umts=2000;
```

```
end

frequency_wlan=input('WLAN operating frequency band in MHz [2400]?');

if length(frequency_wlan)==0
    frequency_wlan=2400;
end

umts_threshold=input('Target Power Threshold for umts user handover in dBm [-120]? ');

if length(umts_threshold)==0
    umts_threshold=-120;
end

wlan_threshold=input('Target Power Threshold for wlan user handover in dBm [-100]? ');

if length(wlan_threshold)==0
    wlan_threshold=-100;
end

alpha=input('Path loss exponent [3.5]?');

if length(alpha)==0
    alpha=3.5;
end

sigma=input('Standard deviation of shadowing [6.5]?');

if length(sigma)==0
    sigma=6.5;
end

N_umts=input('Number of umts users [1000]? ');

if length(N_umts)==0
    N_umts=1000;
end

N_wlan=input('Number of wlan users [500]? ');

if length(N_wlan)==0
    N_wlan=500;
end

speed_umts=input('Speed of umts user m/s [20]? ');

if length(speed_umts)==0
```

```

    speed_umts=20;

end

speed_wlan=input('Speed of wlan user m/s [5]? ');
if length(speed_wlan)==0
    speed_wlan=5;
end

simulation_time=input('Simulation Time in seconds [1000]?');
if length(simulation_time)==0
    simulation_time=1000;
end

time_step=input('Time step in seconds [0.01]? ');
if length(time_step)==0
    time_step=0.01;
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%add set available resources in AP/BS

%set umts users locations
r_umts_user=rand(1,N_umts);
phi_umts_user=2*pi*rand(1,N_umts);
% scale by BS radius to get the exact location
for i=1:N_umts
    x_umts_user(i)=R_bs*r_umts_user(i)*cos(phi_umts_user(i))+0.01+x_bs; % 0.01 to avoid user
    at exact location of BS
    y_umts_user(i)=R_bs*r_umts_user(i)*sin(phi_umts_user(i))+0.01+y_bs;
end

%set wlan users locations
r_wlan_user=rand(1,N_wlan);
phi_wlan_user=2*pi*rand(1,N_wlan);
% scale by AP radius to get the exact location
for i=1:N_wlan
    x_wlan_user(i)=R_ap*r_wlan_user(i)*cos(phi_wlan_user(i))+0.01+x_ap; % 0.01 to avoid user at
    exact location of AP

```

```

y_wlan_user(i)=R_ap*r_wlan_user(i)*sin(phi_wlan_user(i))+0.01+y_ap;

end

% Plot AP/BS with their users

plot(x_umts_user,y_umts_user, 'b*');

hold on;

plot(x_wlan_user,y_wlan_user, 'g*');

legend('UMTS users','WLAN users');

xlabel('x');

ylabel('y');

axis equal;

%axis([0 x_ap+R_ap+20 0 y_ap+R_ap+20]);

title('Distribution of users among UMTS-WLAN coverasge areas');

hold on;

phi=0:2*pi/100:2*pi;

for i=1:100

x_umts_bs(i)=R_bs*cos(phi(i))+x_bs;

y_umts_bs(i)=R_bs*sin(phi(i))+y_bs;

end

for i=1:100

x_wlan_ap(i)=R_ap*cos(phi(i))+x_ap;

y_wlan_ap(i)=R_ap*sin(phi(i))+y_ap;

end

plot(x_umts_bs,y_umts_bs, 'b-');

hold on;

plot(x_wlan_ap,y_wlan_ap, 'g-');

hold on;

p('-----');

disp('Simulation starts...');

disp('-----');

Handover_umts_user_number=[];

```

```

Handover_wlan_user_number=[];
Dropped_umts_user_number=[];
Dropped_wlan_user_number=[];
k=1;
for t=0:time_step:simulation_time

    Handover_umts_user_number(k)=0;
    Dropped_umts_user_number(k)=0;
    Handover_wlan_user_number(k)=0;
    Dropped_wlan_user_number(k)=0;

    %set wlan users speed

    v_wlan_user=speed_wlan*rand(1,N_wlan);
    phi_v_wlan_user=2*pi*rand(1,N_wlan);

    %calculate power level for wlan user

    for i=1:N_wlan

        dist(i)=sqrt((x_ap-x_wlan_user(i)+v_wlan_user(i)*t*cos(phi_v_wlan_user(i)))^2+(y_ap-
        y_wlan_user(i)+v_wlan_user(i)*t*sin(phi_v_wlan_user(i)))^2);

        p_wlan_user(i)=p_ap+g_ap+g_wlan+alpha*10*log(300./(frequency_wlan*4*pi*dist(i)))+shadow(
        sigma);

        if (p_wlan_user(i) < wlan_threshold)

            if (phi_v_wlan_user(i)<=pi/2 | phi_v_wlan_user(i)>= 3*pi/2)
                Handover_wlan_user_number(k)=Handover_wlan_user_number(k)+1;
            else
                Dropped_wlan_user_number(k)=Dropped_wlan_user_number(k)+1;
            end
        end
    end
end

```

```

        end

    end

end

%set umts users speed
v_umts_user=speed_umts*rand(1,N_umts);
phi_v_umts_user=2*pi*rand(1,N_umts);

%calculate power level for umts user

for i=1:N_umts

    dist(i)=sqrt((x_bs-x_umts_user(i)+v_umts_user(i)*t*cos(phi_v_umts_user(i)))^2+(y_bs-
y_umts_user(i)+v_umts_user(i)*t*sin(phi_v_umts_user(i)))^2);

p_umts_user(i)=p_ap+g_ap+g_umts+alpha*10*log(300./(frequency_umts*4*pi*dist(i)))+shadow(
sigma);

    if (p_umts_user(i) < umts_threshold)

        if (phi_v_umts_user(i)<=pi/2 | phi_v_umts_user(i)>= 3*pi/2)

            Handover_umts_user_number(k)=Handover_umts_user_number(k)+1;

        else

            Dropped_umts_user_number(k)=Dropped_umts_user_number(k)+1;

        end

    end

end

end

hand-
over_delay_mobileIP(k)=handover_delay('mobileIP',Handover_umts_user_number(k)+Handove
r_wlan_user_number(k));

```

```

    handover_delay_gateway(k)
=handover_delay('gateway',Handover_umts_user_number(k)+Handover_wlan_user_number(k)
);

    hand-
over_delay_emulator(k)=handover_delay('emulator',Handover_umts_user_number(k)+Handove
r_wlan_user_number(k));

    disp('-----');
    fprintf('Iteration number: %d\n',k);
    disp('-----');
    fprintf('Number of umts handover users: %d\n',Handover_umts_user_number(k));
    fprintf('Number of wlan handover users: %d\n',Handover_wlan_user_number(k));
    fprintf('Number of umts dropped users: %d\n',Dropped_umts_user_number(k));
    fprintf('Number of wlan dropped users: %d\n',Dropped_wlan_user_number(k));

    fprintf('Handover delay using MobileIP: %d\n', handover_delay_mobileIP(k));
    fprintf('Handover delay using Gateway : %d\n', handover_delay_gateway(k));
    fprintf('Handover delay using Emulator: %d\n', handover_delay_emulator(k));

    k=k+1;

end

% Draw Numbers of UMTS-WLAN Handover users during simulation time
t=0:time_step:simulation_time;
figure;
hold on;
plot(t,Handover_umts_user_number, 'b*');
hold on;
plot(t,Handover_wlan_user_number, 'g. ');
legend('UMTS handover users','WLAN handover users');
ylabel('Numbers of Handover users');
xlabel('Time (s)');

```

```

title('Numbers of UMTS-WLAN Handover users during simulation time');

hold on;

% Draw Numbers of UMTS-WLAN Dropped users during simulation time

t=0:time_step:simulation_time;

figure;

hold on;

plot(t,Dropped_umts_user_number, 'b*');

hold on;

plot(t,Dropped_wlan_user_number, 'g. ');

legend('UMTS dropped users','WLAN dropped users');

ylabel('Numbers of Dropped users');

xlabel('Time (s)');

title('Numbers of UMTS-WLAN Dropped users during simulation time');

hold on;

% Draw UMTS-WLAN Handover Delay

figure;

hold on;

total_handover=Handover_umts_user_number+Handover_wlan_user_number;

plot(total_handover,handover_delay_mobileIP, 'b*');

hold on;

plot(total_handover,handover_delay_gateway, 'g*');

hold on;

plot(total_handover,handover_delay_emulator, 'r*');

legend('MobileIP','Gateway','Emulator');

ylabel('Handover delay (ms)');

xlabel('Number of Users');

title('UMTS-WLAN Handover Delay');

hold on;

%***** end of main file *****

%%%%%%%%%%

```

```

% This function calculates the distance      between two points: (x1,y1)&(x2,y2)
function d = distance(x1,y1,x2,y2)
d = sqrt((x2-x1)^2+(y2-y1)^2);
%***** end of distance file *****

% shadow.m

%% This function generates attenuation of shadowing
%
%
function [x] = shadow(sigma)
r = randn;
x = sigma * r;
%***** end of shadow file *****

%
% This function is used to evaluate an approximate relation using polynomial fitting in
% the simulation data from [20]
% handover delay D vs no. of users N
% Mobile IP: D1=22.8671+0.0773N
% Gateway: D2=32.7949+0.0201N
% Emulator: D3=32.1112+0.0102N
%
function params = polyFitting(x,y,n)
psi=[];
X=x';
Y=y';
for j=1:n+1
    psi(:,j)=X.^(j-1);
end
params=inv(psi'*psi)*psi'*Y;
%***** end of polyFitting file *****

%Simulation data used in polynomial fitting from [20]

```

Number of Users	Handover Delay (ms)		
	Mobile Ip	Gateway	Emulator
10	21.875	31.25	28.125
110	31.25	34.375	31.25
210	40.625	37.5	34.375
310	46.875	39.0625	34.375
410	56.25	40.625	37.5
510	59.375	42.1875	37.5
610	68.75	43.75	40.625
710	78.125	46.875	40.625
810	84.375	50	42.1875
910	90.625	53.125	42.1875
1010	100	53.125	43.75
1110	103.125	54.6875	43.75
1210	115.625	56.25	45.3125
1310	125	59.375	45.3125
1410	131.25	60.9375	48.4375
1510	137.5	62.5	48.4375
1610	150	65.625	50
1710	153.125	67.1875	50
1810	165.625	70.3125	50
1910	171.875	71.875	51.5625
2010	181.25	73.4375	51.5625
2110	187.5	75	53.125
2210	190.625	78.125	53.125
2310	200	79.6875	54.6875
2410	209.375	81.25	54.6875
2510	215.625	84.375	56.25
2610	225	87.5	56.25
2710	231.25	89.0625	60.9375
2810	240.625	92.1875	60.9375
2910	246.875	93.75	62.5
3010	281.25	93.75	62.5
3110	256.25	95.3125	64.0625
3210	271.875	96.875	64.0625
3310	281.25	98.4375	67.1875
3410	284.375	100	67.1875
3510	309.375	101.5625	68.75
3610	300	103.125	68.75
3710	306.25	107.8125	70.3125
3810	315.625	109.375	70.3125
3910	321.875	110.9375	70.3125
4010	331.25	112.5	73.4375
4110	337.5	114.0625	73.4375
4210	346.875	117.1875	75
4310	353.125	118.75	75
4410	365.625	121.875	78.125
4510	368.75	125	78.125
4610	378.125	126.5625	79.6875
4710	387.5	128.125	79.6875
4810	390.625	129.6875	82.8125
4910	400	131.25	82.8125