

Next Generation Mobile Wireless Hybrid Network Interworking Architecture

**A thesis submitted in fulfilment of
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Dedicated to my parents

Preface

Abstract

It is a universally stated design requirement that next generation mobile systems will be compatible and interoperable with IPv6 and with various access technologies such as IEEE 802.11x. Discussion in the literature is currently as to whether the recently developed High Speed Packet Access (HSPA) or the developing Long Term Evaluation (LTE) technology is appropriate for the next generation mobile wireless system. However, the HSPA and the LTE technologies are not sufficient in their current form to provide ubiquitous data services. The third-generation mobile wireless network (3G) provides a highly developed global service to customers through either circuit switched or packet switched networks; new mobile multimedia services (e.g. streaming/mobile TV, location base services, downloads, multiuser games and other applications) that provide greater flexibility for the operator to introduce new services to its portfolio and from the user point of view, more services to select and a variety of higher, on-demand data rates compared with 2.5-2.75G mobile wireless system. However cellular networks suffer from a limited data rate and expensive deployment. In contrast, wireless local area networks (WLAN) are deployed widely in small areas or hotspots, because of their cost-effectiveness, ease of deployment and high data rates in an unlicensed frequency band. On the other hand, WLAN (IEEE 802.11x) cannot provide wide coverage cost-efficiently and is therefore at a disadvantage to 3G in the provision of wide coverage. In order to provide more services at high data rates in the hotspots and campus-wide areas, 3G service providers regard WLAN as a technology that compliments the 3G mobile wireless system. The recent evolution and successful deployment of WLANs worldwide has yielded demand to integrate WLANs with 3G mobile wireless technologies seamlessly. The key goal of this integration is to develop heterogeneous mobile data networks, capable of supporting ubiquitous data services with high data rates in hotspots. The effort to develop heterogeneous networks – also referred to fourth-generation (4G) mobile wireless data networks – is linked with many technical challenges including seamless vertical handovers across WLAN and 3G radio technologies, security, common

authentication, unified accounting & billing, WLAN sharing (by several mobile wireless networks – different operators), consistent QoS and service provisioning, etc.

This research included modelling a hybrid UMTS/WLAN network with two competent couplings: Tight Coupling and Loose Coupling. The coupling techniques were used in conjunction with EAP-AKA for authentication and Mobile IP for mobility management. The research provides an analysis of the coupling techniques and highlights the advantages and disadvantages of the coupling techniques. A large matrix of performance figures were generated for each of the coupling techniques using Opnet Modeller, a network simulation tool.

Declaration

This is to certify that to the best of my knowledge and belief, the work presented in this thesis, except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program; and, any editorial work, paid or unpaid, carried out by a third party is acknowledged; and, ethics procedures and guidelines have been followed.

Signature: _____

Abu Sayed Chowdhury

Date: 30/03/20010

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List of Abbreviations

1G	First Generation
2G	Second Generation
3G	Third Generations
3GPP	Third generation partnership project
4G	Fourth Generations
AAA	Authentication, Authorisation and Accounting
AKA	Authentication and Key Agreement
AMPS	Analogue Mobile Phone System
AP	Access Point
ARP	Address Resolution Protocol
ATM	Asynchronous Transfer Mode
AUC	Authentication Centre
BTS	Base Transceiver station
BSC	Base Station Controller
BSS	Basic Service Set
CDMA	Code Division Multiple Access
CN	Core Network
COA	Care of Address
CON	Correspondent Node
CSMA	Carrier Sense Multiple Access
CA	Collision avoidance
DCF	Distributed Coordination Function
DCS	Digital communication System
EAP	Extensible Authentication Protocol
EIR	Equipment Identify Registers
EDGE	Enhanced Data for Global Evaluation
ESS	Extended Service Set
FA	Foreign Agents
FTP	File Transfer Protocol
FDMA	Frequency Division Multiple Access
GGSN	Gateway GPRS Supporting Node
GPRS	General Packet Radio services

GTP	GPRS Tunnelling Protocol
GSM	Global System Mobile Communication
HLR	Home Location Register
HSPA	High Speed Packet Access
HTTP	Hypertext Transfer Protocol
HTML	Hypertext Markup Language
IFS	Inter Frame Space
IMS	IP Multimedia Services
IMEI	International Mobile Equipment Identity
IMSI	International Mobile Subscriber Identity
ITU	International Telecommunications Union
LTE	Long Term Evaluation
ME	Mobile Equipment
MS	Mobile Station
MSC	Mobile Switching Centre
MAC	Medium Access Control
NMT	Nordic Mobile Telephone
NSS	Network Switching Subsystem
OFDM	Orthogonal Frequency Division Multiplexing
OSPF	Open Shortest Path First
PDC	Pacific Digital Cellular
PDCCP	Packet Data Convergence Protocol
PLMN	Public Land Mobile Network
PS	Packet Switched
PCF	Point Coordination Function
RAB	Radio Access Bearer
RB	Radio Bearer
RIP	Routing Information Protocol
RL	Radio Link
RRC	Radio Resource Control
RNC	Radio Network Controller
RSS	Received Signal Strength
SGSN	Serving GPRS Supporting Node

TDMA	Time Division Multiple Access
TMSI	Temporary Mobile Subscriber Identity
UMTS	Universal Mobile Telecommunication System
UTRAN	UMTS Terrestrial Radio Access Network
UE	User Equipment
USIM	Universal Subscriber Identity Mobile
VoIP	Voice over Internet Protocol
VLR	Visitor Location Register
WLAN	Wireless Local Area Network
WWAN	Wireless Wide Area Networks
WMAN	Wireless Metropolitan Area Networks
WPAN	Wireless Personal Area Networks
WAP	Wireless application Protocol
WCDMA	Wideband Code Division Multiple Access

1 Introduction

In recent years, there has been a dramatic growth in mobile wireless communications providing customers with telephony and data services. New systems are constantly under development to support enhanced mobile telephony and data services. Wireless networking technologies are categorised according to the network coverage area: Wireless Wide Area Networks (WWAN), Wireless Metropolitan Area Networks (WMAN), Wireless Personal Area Networks (WPAN) and Wireless Local Area Networks (WLAN). Wireless networks may be used to complement or replace wired networks in some situations, such as in low consumer density areas where the cost of providing cabling would not be warranted. Mobile wireless communication systems have been differentiated from each other by the word ‘generation’, and can be categorised by ‘first-generation’ (1G), second-generation (2G) and third-generation (3G), which has been quite appropriate due to the generation gap between the technologies used in each system. For the next generation mobile system users anticipate another generational leap in the provision of wider access at faster rates which will make more applications available.

UMTS (Universal Mobile Telecommunication System) is a technology that is widely used in mobile wireless systems and may also in some instances be referred to as the third generation mobile wireless system - 3G. There are several advantages of UMTS over previous systems such as accurate mobility support and due to increased data rates new mobile multimedia services have been made available to users. However, as time has moved on UMTS is now seen to be deficient in data rates and the provision of a range of new services available for customers. WLAN (IEEE 802.11x) may be used to enhance the provision of network data services by providing a high data rate capability and a low deployment cost when compared to UMTS network implementations. In terms of data rate, UMTS can provide 2 Mbps with full mobility where as the latest variation of WLAN (IEEE 802.11n) can provide a data rate of 144 Mbps. One of the goals for a next generation wireless system is to be ubiquitous and to provide data rates at a speed of 100 Mbps or more. One option for next generation wireless systems is to integrate technologies so as to provide wide coverage and higher data rates in targeted high user density locations. The resulting

hybrid network should improve the customer experience through the provision of higher data rates and access to a wider range of applications.

1.1 Scope

The UMTS-WLAN model is currently being studied within the 3GPP (Third generation partnership project) [TS 23.234 2006]. To identify the UMTS-WLAN interworking capabilities, 3GPP has defined six benchmark scenarios. The following six scenarios defined by 3GPP focus on the type and quality of the services offered to the user.

Scenario 1 – Common billing and customer care

The first scenario, which is the simplest scheme, provides basic integration by providing a common billing system and customer care to the subscriber but no real interworking between WLAN and 3G public land mobile network (PLMN). The independent security of the two systems may be applied.

Scenario 2 – 3GPP system based access control and charging

This scenario requires a common authentication, authorization and accounting which are provided by the 3GPP system. The security system for 3G subscribers in WLAN is to be applied by their 3GPP system. It also includes the features of Scenario 1.

Scenario 3 – Access to 3G packet switched services

The aim of this scenario is to extend subscriber access to 3G packet switched services in the WLAN environment. In conjunction, to select the Packet Switched (PS) based service to connect an IP service selection method is used. These services may include IP multimedia services, location-based services, instant messaging services, presented-based services and multimedia messaging services.

Scenario 4 – Access to 3G packet switched-based services with service continuity

The goal of this scenario is to maintain service continuity across the 3G and WLAN radio access technologies in addition to the PS service described in Scenario 3. For example, a user can start a Wireless application Protocol (WAP) session from WLAN and will be able to continue to utilize this session after moving to a UMTS region and vice versa.

Scenario 5 – Access to 3G packet switched-based services with seamless service continuity

This scenario moves another step further by introducing seamless service continuity between the 3G and WLAN radio access technologies. That is, PS-based services should be utilized across the 3G and WLAN radio access technologies in a seamless manner, i.e. without the user noticing any significant differences.

Scenario 6 – Access to 3G circuit switched-based services with seamless mobility

The purpose of this scenario is to grant access to 3G circuit switched-based services (e.g. normal digital voice calls) from the WLAN system. Seamless mobility for these services should be provided.

Note that from Scenario 1 to Scenario 6 the progression of the WLAN and 3G network integration increases and hence more and more demanding interworking requirements exist. However, Scenario 5 and Scenario 6 are not considered for this research as it is beyond the scope of the current goals.

The research outcome was to design an architecture which will satisfy the requirements of Scenario 1 to Scenario 4. The scope of this research included:

- A literature review of current research on the integration of 3G and WLAN
- An initial investigation of UMTS and WLAN network concepts and technology used.
- Detailed research and investigation of UMTS-WLAN integration including:
 - Mobility Management
 - Authentication
- Implementation of a simulation model using Opnet Modeller Version 15
 - To design a Tight Coupling scenario
 - To design a Loose Coupling scenario
 - To design EAP-AKA protocol for Authentication
 - To design Mobile IP for mobility management

-
- Application configuration for VoIP, FTP, HTTP, and EMAIL
 - Data collection
 - Data analysis
 - Comparison of simulation results with prior research
 - Comparison of simulation results for several applications operated over the tight coupling and loose coupling architectures

1.2 Purpose

The purpose of this thesis is to provide a record of the research carried out and the results achieved which include an integrated mobility methodology with two different kinds of integration - tight coupling and loose coupling. The purpose of this research was not limited to analysing the coupling architecture; it also included implementing the integration method with authentication and mobility management. EAP-AKA was used for authentication and Mobile IP was used for mobility management. The research purpose included:

- To identify whether the tight coupling or loose coupling architectures provided better performance for various typical internet applications.
- To implement the EAP-AKA protocol for authentication.
- To execute the Mobile IP technology for mobility management where handover delay can be controlled.
- To measure several application performance parameters including jitter and voice over internet protocol (VoIP) end-to-end delay.
- To measure the file transfer protocol (ftp) response time when a file is downloaded and then uploaded over the network.
- To measure hypertext transfer protocol (http) response times in two cases: the first is the response time to download a http object and the second is the response time to download a http page.

-
- To measure performance for web services using an example such as to upload or download an email and to identify which architecture takes the longest time to get a response.

1.3 Thesis Outline

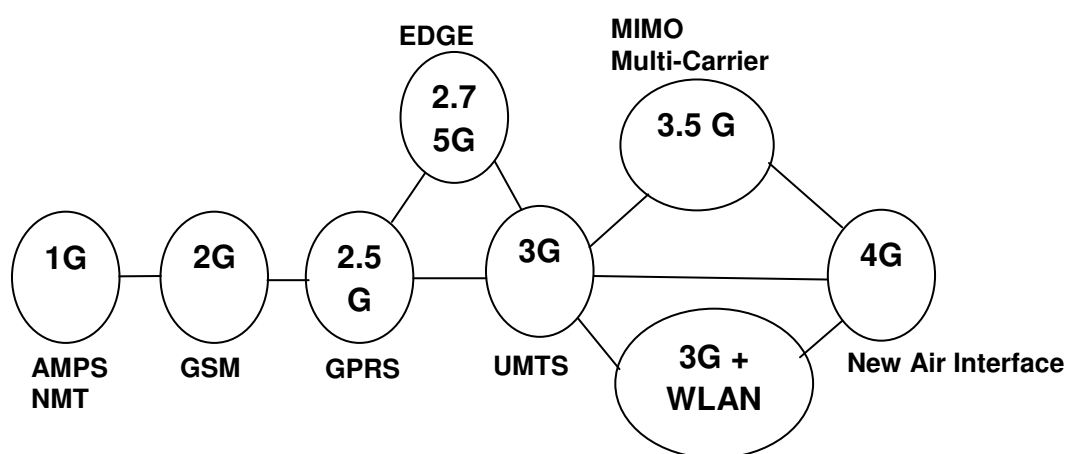
The rest of the thesis is organized as follows. A literature review and discussion on the state of 3G and WLAN systems is provided in Chapter 2. The research objectives, assumptions and limitations are provided in Chapter 3. The research process and work carried out is presented in Chapter 4. An analysis and discussion of the research results is provided in Chapter 5 and this is followed in Chapter 6 with the conclusion. Finally, possible future research opportunities are identified in Chapter 7.

2 Background

This chapter provides background and a literature review in the area of cellular and wireless technologies. It begins with a description of cellular systems including the three generations of mobile wireless communications: first generation (1G), second generation (2G), and third generation (3G) and some key attributes of UMTS and WLAN. This chapter also illustrates the proposed architectures for interworking between UMTS and WLAN.

2.1 Evaluation of Mobile Communication

Electromagnetic waves were first discovered as a communication medium at the end of the 19th century. In the late 1960's and early 1970's a number of different countries believed in the opportunity of cellular communication. In Japan, a nationwide cellular system operating at 800 MHz was proposed by Nippon Telegraph and Telephone Company and a patent proposal was submitted by Bell Telephone laboratories in the USA in 1970. In Bahrain during May 1978 the first commercially developed cellular telephone system was started. It was very simple with 250 subscribers and consisted of two cells. The early cellular wireless systems were severely affected by restricted mobility, low capacity, limited services, and poor speech quality. In late 1978, the Advance Mobile Phone System became operational in Chicago. Nordic Mobile Telephone (NMT) launched the first commercially available mobile phone system operating at 450 MHz [THEODORE S. 2002]. A brief overview the mobile wireless generations is shown in Figure 2-1.



2.2 First Generation

The first mobile phone system launched was based on analogue technology. At that time, there was no worldwide coordination for the development of technical standards for mobile wireless telephone systems. The equipment was heavy, bulky, expensive and susceptible to interference. The increasing necessity for a system catering for mobile communication needs, and offering more capability, resulted in the development of the 2G mobile wireless system. The 2G mobile wireless system performance was limited, the headsets were large and cumbersome, the coverage was poor and the phone handsets were expensive. However, the 2G mobile wireless systems marked a major milestone in the telecommunications industry. As time passed numerous different standards were introduced. Roaming was not possible and the frequency spectrum was not used efficiently. The three main systems launched were AMPS (Analog Mobile Phone System) also known by the specification number IS-41, TACS (Total Access Communication System) and NMT (Nordic Mobile Telephone). All of these mobile wireless systems used FM modulation for the voice channel. The channel spacing was 30KHz, 25KHz, and 25KHz respectively for AMPS, TACS and NMT. The frequency used by this system was generally 900KHz, while NMT System used 450 MHz [IAN 2006].

2.3 Second Generation

In the mid-1980's the European commission started a series of activities to liberalise the communications sector, including mobile communications. This resulted in the creation of a digital communications technology called the Global System for Mobile Communication (GSM). Second generation technologies used the digital modulation technique TDMA/FDD and CDMA/FDD unlike the first generation systems that used FDMA/FDD analogue FM. There were three TDMA (Time Division Multiple Access) standards and one CDMA (Code Division Multiple Access) standard [IAN 2006]:

- (1) GSM supports eight time slotted users with an allocation of 200 KHz for each user.
- (2) Interim standard 136 (IS-136) supports three time slotted users with an allocation of a 30 kHz radio channel for each user which was mostly used in North America, South America and Australia.

(3) Pacific Digital Cellular (PDC) was the Japanese TDMA standard.

(4) CDMA or Interim Standard 95 Code Division Multiple Access (IS-95) which supports 64 users on separate 1.25 MHz channels.

2.3.1 Global System Mobile Communication (GSM)

The aim of the GSM is to get provide customers with telephone and data services using an efficient and secure communications medium. GSM operates at 900MHz and the also at other bands including 1800MHz also known as DCS1800 (Digital communication System) and 1900MHz also known as PCS1900 (Personal Communication System) [SAAD 2007]. The main elements of the GSM system are the Base Transceiver Station (BTS), Base Station Controller (BSC) and the NSS (Network Switching Subsystem), in which there is the Mobile Switching Centre (MSC); VLR (Visitor Location Register); HLR (Home Location Register); Authentication and Registration area. This network is capable of providing all of the basic services such as speech and data services up to 9.6 kbps. The GSM architecture is shown in Figure 2-2.

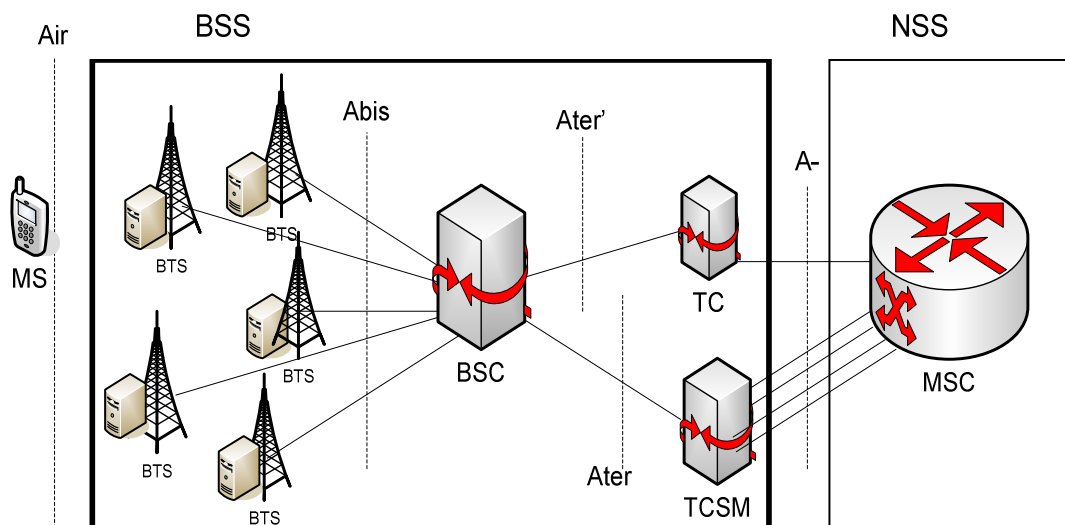


Figure 2-2 GSM Architecture

2.3.1.1 Base Station Subsystem (BSS)

The BSS consists of the BTS, BSC and a transcoder sub-multiplexer (TCSM). The latter is sometimes physically located at the MSC. Hence the BSC also has three standardized interfaces to the fixed network, namely Abis, A and X.25.

Base Transceiver Station

The BTS manages the interface between the network and the mobile station. Hence, it performs the important function of acting as a hub for the whole of the network infrastructure. Mobile terminals are linked to the BTS through the air-interface. Transmission and reception at the BTS with the mobile is done via Omni directional or directional antennas (usually having 120-degree sectors). The major functions of the base station are transmission of signals in the desired format, coding and decoding of the signals, countering the effects of multi-path transmission by using equalisation algorithms, encryption of the data streams, measurements of quality and received signal power, and operation and management of the base station itself [ETOH 2005].

Base Station Controller

The BSC controls the radio subsystem, especially the base station. The major functions of the BSC include management of the radio resources and handover. The BSC is also responsible for control of the power transmitted per channel, and it deals with the O&M and signalling, security configurations and alarms.

2.3.1.2 Network Subsystem (NSS)

The network subsystem acts as an interface between the GSM network and the public networks including PSTN/ISDN. The main components of the NSS are the MSC, HLR, VLR, AUC, and EIR.

Mobile Switching Centre

The MSC (or switch as it is generally called) is the single most important element of the NSS as it is responsible for the switching functions that are necessary for interconnections between mobile users and other mobile and fixed network users. For this purpose, MSC makes use of the three major components of the NSS, namely the HLR, VLR and AUC.

Home Location Register

The HLR contains the information related to each mobile subscriber, such as the type of subscription, services that the user can use the subscriber's current location and

the mobile equipment status. The database in the HLR remains intact and unchanged until the termination of the subscription.

Visitor Location Register

The VLR comes into action once the subscriber enters the coverage region. Unlike the HLR, the VLR is dynamic in nature and interacts with the HLR when recoding the data of a particular mobile subscriber. When the subscriber moves to another region, the subscriber session database is also shifted to the VLR of the new region.

Authentication Centre

The AUC (or AC) is responsible for policing actions in the network. This has all the data required to protect the network against false subscribers and to protect the calls of its regular subscribers. There are two major keys in the GSM standards: the encryption of communication between mobile users, and the authentication of users. The encryption keys are held both in the mobile equipment and the AUC thus protecting the information against unauthorized access.

Equipment Identify Registers

Each item of mobile equipment has its own personal identification, which is denoted by a number – the International Mobile Equipment Identity (IMEI). The number is installed during the manufacture of the equipment and states its confirmation to the GSM standards. Whenever a call is made, the network checks the identity number; if this number is not found on the approved list of authorized equipment, access is denied. The EIR contains this list of authorized numbers and allows the IMEI to be verified.

2.3.2 General Packet Radio Services (GPRS)

GPRS is a packet based data network that supports multiuser network resource sharing of individual radio channels and time slots. GPRS is different to HSCSD which dedicates a circuit switched channel to a specific user. GPRS retains the modulation formats specified in the 2G TDMA. GPRS subscribers are automatically tuned to dedicated GPRS radio channels and particular time slots for “always on” access to the network. GPRS can transfer data immediately at high speed typically 32-48kbps [SAAD 2007]. GPRS has additional benefits which include compatibility between data transfer and voice calls.

2.3.2.1 GPRS Network Structure

To archive packet-based services the core network structure has been upgraded from that of GSM. The network between BTS and BSC is similar as to GSM. The two main functional elements in a GPRS network are the Serving GPRS Node (SGSN) and the Gateway GPRS Support Node (GGSN). A brief description of GPRS architecture is provided in Figure 2-3.

Serving GPRS Supporting Node (SGSN)

To establish GPRS over a GSM network the BSC is upgraded. Data from the BSC is routed through the SGSN to the mobile user within the coverage area of the service. The SGSN provides a number of functions for mobile data services, including authentication. The SGSN also tracks the location of the mobile station within the GPRS network and ensures the required quality of service, mobility management (location management) and billing [AJAY R. 2004].

Gateway GPRS Support Node (GGSN)

The GPRS backbone network and external packet data network (Radio network and IP network) are connected through a GGSN. The GGSN converts GPRS packets which come from SGSN into the appropriate packet data protocol (PDP) format (IP or X.25) and then send the packets to an outside packet data network. In the other direction, the incoming data packet addresses are analyzed and converted to the GSM address of the designated mobile user. The packets are sent to the responsible SGSN for the mobile user. The SGSN address of the user and the user's profile in the SGSN's location register are stored in the GGSN. The GGSN assigns an IP address and serves as a default router for the connected user equipment. The mobile equipment must attach itself to a SGSN and activate its PDP address. This is the address supplied by GGSN, which is associated with SGSN and the mobile device. The mobile can attach to only one SGSN at a time although once an address is assigned to it can communicate with multiple GGSN using multiple PDP addresses [AJAY R. 2004].

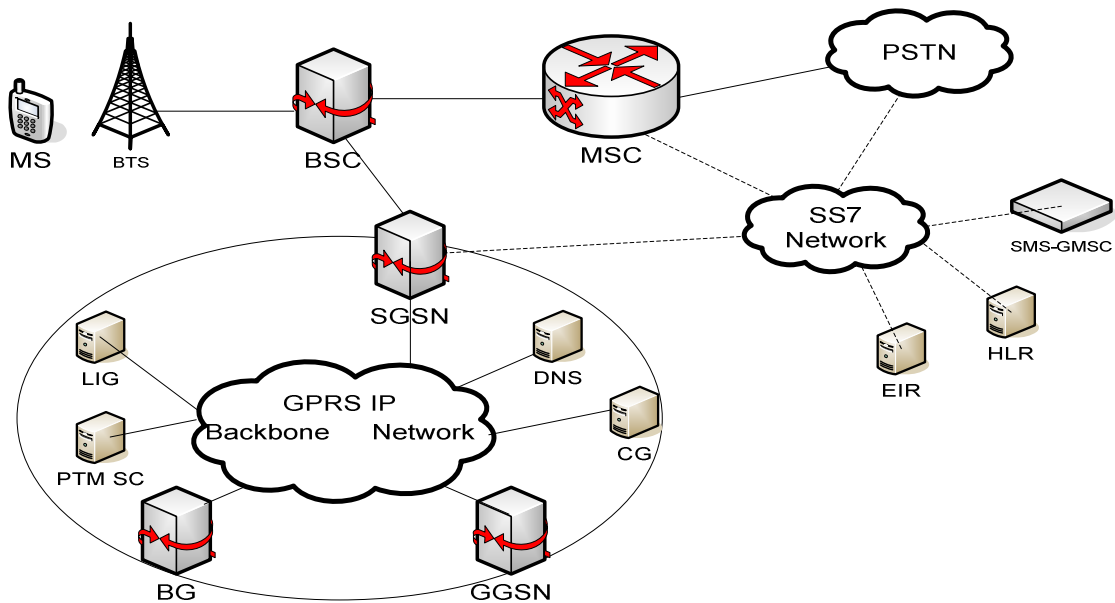


Figure 2-3 GPRS Architecture

GPRS Mobiles

GPRS mobiles are classified according to their capabilities, such as connection types and data rates supported.

Class A: Class A mobile devices can be connected at the same time to GPRS and GSM services.

Class B: Class B mobile devices can use either GPRS or GSM at one time, but can be attached to both services.

Class C: Class C mobile devices can be attached to either to GSM or GPRS services, but the mobile user needs to switch manually between the two different types of services.

GPRS Coding

The GPRS coding scheme depends upon radio frequency signal conditions and the data rate being provided.

CS-1: It is the highest level of error correction and detection scheme. It is used in conditions where the signal level is low or interference level is high. It results in a data throughput of 9.05 kbps.

CS-2: It is a better channel error correction and coding scheme. It uses the 2/3 encoder. This results in a data throughput of 13.4 kbps. It also includes RLC/MAC header and other features.

CS-3: The 3/4 encoder results in data throughput of 15.6 kbps.

CS-4: CS-4 is used when interference is low and signal strength is high. It is the least robust but fastest encoder available and is normally most used when a mobile device is near a base station. If all the time slots are used the data throughput is 171.2 kbps [IAN. 2006].

2.3.2.2 GPRS network interfaces

As GPRS developed and extra network elements were added there was a need for new interface types. The new interfaces are known as G-interfaces. Brief descriptions of the G-interfaces are: [IAN. 2006].

- Gb interface. This lies between BSS and SGSN. It carries the traffic and signaling information between the BSS (of GSM) and the GPRS networks, thus easily making it the most important interface in network planning.
- Gn interface. This is present between the SGSN and SGSN/GGSN of the same network. It provides data and signaling for intra-system functioning.
- Gd interface. It is present between the SMS-GSMC/SMS-IW MSC and SGSN, providing the better use of SMS services.
- Gp interface. It lies between the SGSN and the GGSN of other public land mobile networks. Therefore it is an interface between the two GPRS networks. This interface is highly important considering its strategic location and functions that include security routing etc.
- Gs interface. This is present between the SGSN and MSC/VLR. Location data handling and paging requests through the MSC are handled via the interface.
- Gr interface. As this is an interface between the SGSN and HLR, all the subscriber information can be assessed by the SGSN and the HLR.
- Gf interface. This interface gives the SGSN the equipment information that is available in the EIR.
- Gi interface. This lies between the GGSN and external networks. This is not a standard interface, as the specification will depend on the type of interface that will be connected to the GPRS network.

2.3.2.3 GPRS network protocol structure

The GPRS protocol structure is quite different from GSM, as illustrated in Figure 2-4.

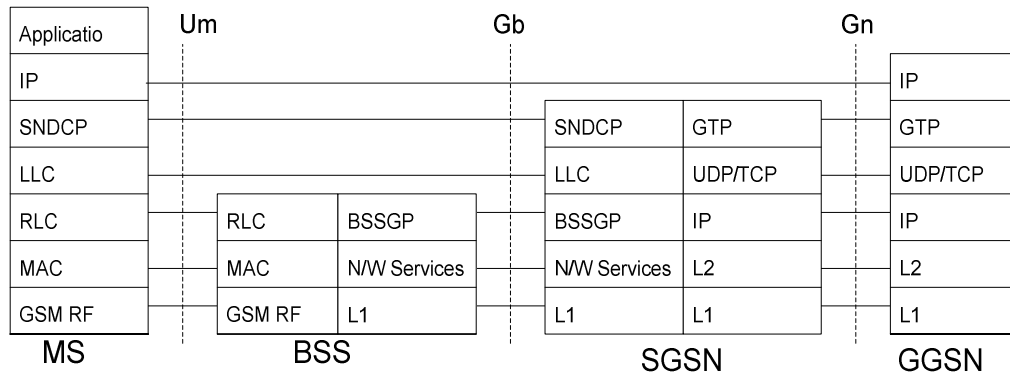


Figure 2-4 GPRS Protocol Stack

2.3.2.4 Physical Channel

GPRS is transmitted over the physical channel using modulation and frame structures common to GSM voice services. The BSC assign slots dynamically to GPRS according to the demand of the remaining slots that are used by GSM voice traffic. The new channel packet data channel (PDCH) has the same overall structure as that of GSM. A common packet profile and timing advance attribute is used to identify the signal travel time from the mobile device to the base station.

2.3.3 EDGE Enhanced Data for Global Evaluation

EDGE stands for Enhanced Data for GSM. It is a further evolution of the GSM network that provided higher data rates. The core network remained the same while radio transmission changes were implemented to facilitate faster data transmission rates to mobile devices. The EDGE architecture is shown in Figure 2-5. The EDGE implementation uses a higher order modulation format known as 8PSK (Frequency Shift Keying) to achieve a higher data rate transmission, which makes EDGE different from GSM, which uses GMSK. The pay load per slot was upgraded from 116 bits to 464 bits. The upgrade in the BTS hardware enabled it to transmit and receive 8PSK modulation. The EDGE capable mobile devices can be used by both circuit switched voice and packet switched data services and were backwards compatible with GPRS networks. The mobile device would use the high

data rate 8PSK when conditions were favorable, otherwise, GMSK / GPRS was used. Mobile devices are grouped in the following classes: [THEODORE S. 2002].

- **Class A.** GSM voice, GPRS/EDGE data are supported at the same time.
- **Class B.** GSM voice, GPRS/EDGE data is supported but one at a time not simultaneously.
- **Class C.** This equipment can support GPRS/EDGE data but does not support voice services.

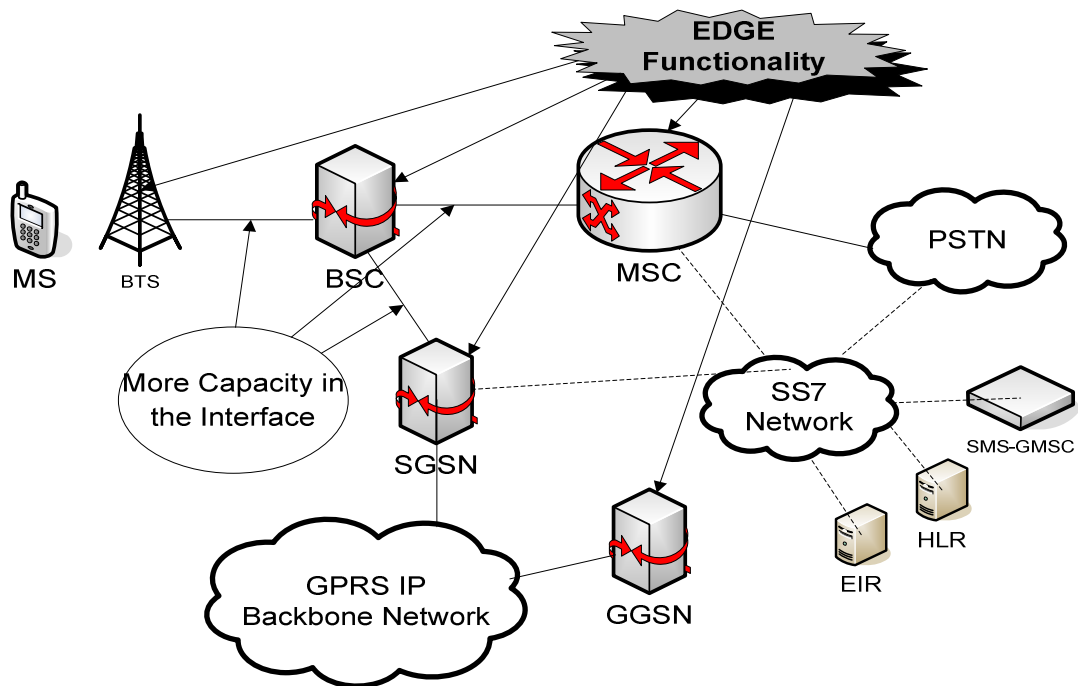


Figure 2-5 EDGE Architecture

2.3.3.1 Time slots

The primary requirement for the evolutionary technologies is that they are all able to operate on the same network, which ensures that services are offered to present users having older phones with those who pay additional rates for premium EDGE services. In traffic frames different time slots are needed that will support different types of packet structures and different types of modulation, which depends upon what phones are being used, the calls being made and the prevailing conditions. It is possible that multiple time slots could be delivering GSM, GPRS data and providing an EDGE connection using 8PSK [IAN. 2006].

2.3.3.2 EDGE Operation

The overall operation of EDGE is the same as for GPRS; it has the same core network as GPRS. The differences occur at the air interface. GSM, GPRS and EDGE calls can be made simultaneously. New hardware at the base station is required which enables transmission of 8PSK as well as GMSK modulation [IAN. 2006].

	GPRS (Using GMSK)	EDGE (Using 8PSK)
Overall Payload per slot	116	462
Overall Payload per block	338	1392

Table 2-1 Comparison of GPRS and EDGE data pay load

2.4 Third Generation

The Third Generation Partnership Project (3GPP) was created by several standards development organizations to define the evolution of the 2G system to 3G. This grouping came up with a radio access technology called wideband code-division multiple accesses (WCDMA) that met the 3G wireless systems requirements set by the International Telecommunications Union (ITU). WCDMA is mainly used in Europe in the context of migration from 2G to the Universal Mobile Telecommunication System (UMTS). 3G (UMTS) refers to the interconnection of a new type of radio access network, the UMTS Terrestrial Radio Access Network (UTRAN), to the adapted pre-release 99 GSM/GPRS core network infrastructure. Release 99 was the first 3GPP release to introduce WCDMA and it was functionally frozen in December 1999 [JAVIER 2007]. 3G devices generally have greater transmission abilities, both in terms of speed and capacity, than their predecessors. The ITU defines 3G as any device that can transmit or receive data at 144 kbps or better. In practice, 3G devices can transfer data at up to 384 kbps in wide coverage area, and 2 Mbps in local coverage area [HOLMA 2000 & JAVIER 2007].

2.4.1 Network Architecture

A UMTS 3G network consists of three interacting parts: User Equipment (UE), the UMTS Terrestrial Radio Access Network (UTRAN), and the Core Network (CN).

UTRAN has two nodes: Node B and the Radio Network Controller (RNC). The packet switch CN has two nodes: Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN). The GGSN connects UMTS network to the network core. A typical UMTS 3G network is shown in Figure 2-6.

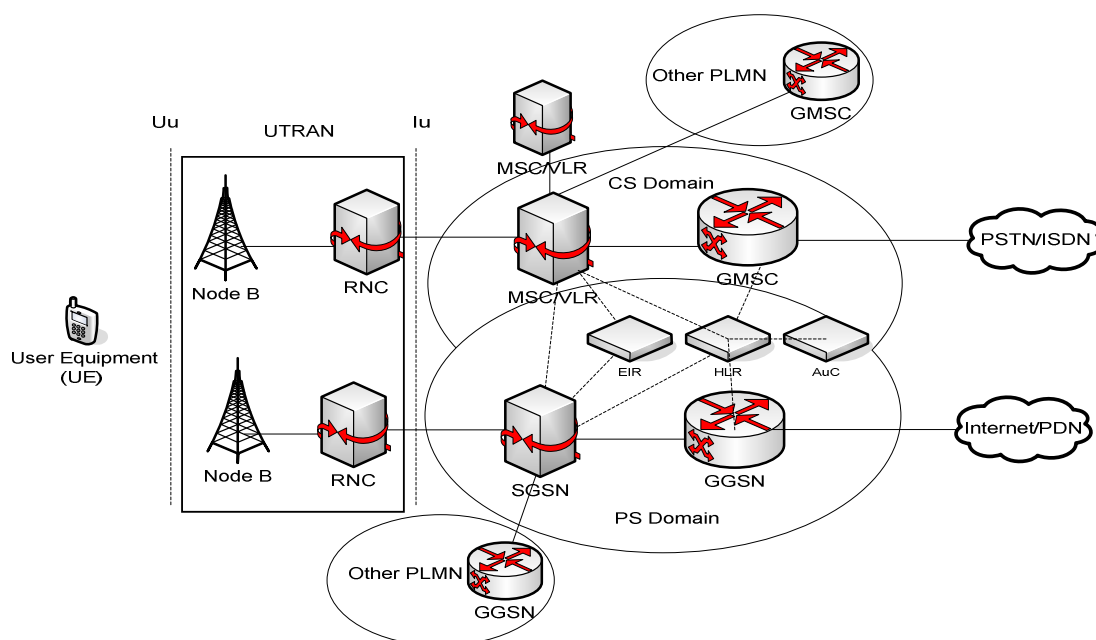


Figure 2-6 UMTS Architecture

User Equipment

UE is the name given to a mobile terminal within a UMTS network (similar to a mobile station in GSM/GPRS terminology). This is the vector enabling a subscriber to access UMTS services through the radio interface Uu. From a functional point of view, the UE is composed of two parts, the mobile equipment (ME) and the universal subscriber identity mobile (USIM).

UTRAN

The UTRAN provides the user with the physical resources to access the core network. It is responsible for radio resource, data and signalling traffic exchange between UE and CN and handle withdrawal and allocation of radio bearers required for traffic support and control. To some extent UE mobility and network access technology is based on WCDMA. The UTRAN interfaces and their GSM equivalent are shown in Table 2-2.

Interface	Location	Equivalent in GSM
Uu	UE ↔ UTRAN	Um
Iu	UTRAN ↔ CN Iu-CS: RNC ↔ MSC	A
	UTRAN ↔ CN Iu-PS: RNC ↔ GSN	Gb
Iur	RNC ↔ RNC	None
Iub	Node B ↔ RNC	Abis

Table 2-2 UTRAN Interfaces

Core Network

The core network is responsible for the management of telecommunication services for each UMTS subscriber. This includes: the establishment, termination and modification of circuit and packet UE-terminated and UE originated calls; the mechanisms for UE authentication; interconnection with external mobile and fixed networks; user charging; and other activities.

2.4.2 Protocols

The UMTS protocol stack is shown in Figure 2-7. There are a number of UMTS interfaces based upon the protocol stack [ETOH 2005]. The application layer creates and interprets the UMTS signalling messages and also manipulates data streams, while the transport layer is responsible for transferring the data stream from one network component to another. The three planes for the protocol stack are: (1) the user plane which carries information from the user such as data packets or voice packets; (2) signalling messages are carried by the control plane; and (3) the transport control plane will carry internal signalling messages if the data is transported using Asynchronous Transfer Mode (ATM). In the application layer the control plane contains signalling protocols used by the network elements to communicate with each other. The user plane protocol manipulates the data (compression, decompression). The transport layer represents standard transport technology that has been selected to be used for UTRAN, but without any UTRAN specific requirements [JAVIER 2007].

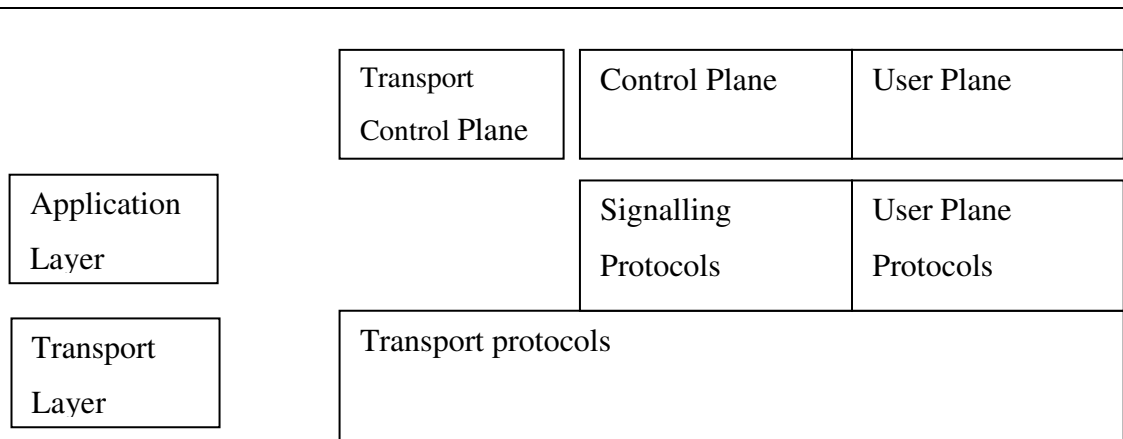


Figure 2-7 UMTS Protocol Stack

2.4.3 Interfaces

The main open interfaces are specified as follows [JAVIER 2007]:

- Cu interface: This is the electrical interface between the USIM smartcard and the ME. The interface follows a standard format for smartcards.
- Uu interface: This is the WCDMA radio interface, which is the subject of the main part of this book. The Uu is the interface through which the UE accesses the fixed part of the system, and is therefore probably the most important open interface in UMTS. There are likely to be many more UE manufacturers than manufacturers of fixed network elements.
- Iu interface: Similarly to the corresponding interfaces in GSM, A (Circuit Switched) and Gb (Packet Switched), the open Iu interface gives UMTS operators the possibility of acquiring UTRAN and CN from different manufacturers. The enabled competition in this area has been one of the success factors of GSM.
- Iur interface: The open Iur interface allows soft handover between RNCs from different manufacturers, and therefore complements the open Iu interface.
- Iub interface: The Iub connects a Node B and an RNC. UMTS is the first commercial mobile telephony system where the Controller–Base Station interface is standardised as a fully open interface. Like the other open interfaces, open Iub is expected to further motivate competition between manufacturers in this area. It is likely that new manufacturers concentrating exclusively on Node Bs will enter the market.

2.4.3.1 QoS in UMTS

There are different classes of QoS in UMTS characterized by different types and integrity requirements as shown in Table 2-3. UMTS applications can be sorted into one of these classes.

QoS Class (Traffic class)	Conversational Class	Streaming Class	Interactive class	Background Class
Fundamental Characteristics	Stringent and low delay. Preserve time relation (jitter) between information entities.	Preserve time relation (jitter) between information entities. Buffering at receiver to reduce jitter.	Request and respond pattern. Preserve data integrity (bit error).	Modest time requirement on data arrival. Preserve data integrity (bit error).
Typical Applications	Voice, Video, online games.	Streaming multimedia (Audio/video)	Web browsing, Games , file download,	Background download, Mail, SMS

Table 2-3 UMTS traffic classes

2.4.4 Packet switch and Circuit switch connection

When a wire line user wants to call a mobile user on the UMTS network, the user will dial the UMTS number; the call will be routed through the telephone network to the UMTS network switching node (SMSC). The switching node will identify the called user data in the HLR database. The HLR database maintains the user state and is used to identify the location of the called user and will send query for a roaming number to the VLR which is responsible for the area containing the user. The VLR will respond with the appropriate number and the HLR will supply this number indicating the destination-switching node. Through the VLR the MSC knows the responsible RNC for the called user's current location and will request the RNC to setup a channel to the mobile station. When the users want to access internet services, the RNC must first activate the PDP context; the PDP in the GGSN is data structure and contains subscriber session information when a subscriber is active. The data in the PDP includes the UE IP address,

IMSI, Tunnel end point ID (TEID) at the GGSN and SGSN. A PDP context is a range of settings that defines which packet data network a user may use for exchanging data. The permitted PDP contexts are stored in the HLR, for example a possible context could be access to the internet. Another context is access to an intranet. Each user can use several contexts and activate them simultaneously. To activate the PDP a user first establishes connection over the RNC to SGSN and sends the message that the user would like to access the internet. The SGSN will forward the query to the responsible GGSN. A query to the HLR checks the user's authorization for access to an external network. If the reply is positive then the GGSN activates the context and informs the mobile equipment accordingly. Through this process the mobile station is allocated a temporary IP address that allows the user to be identified on the UMTS network from the outside. The context activation process creates an IP tunnel through the network to the external interface. The incoming data packets from the Internet are sent to the tunnel by the GGSN and over the SGSN to the RNC. The RNC unpacks the packets and forwards them over a second tunnel to the mobile equipment. This procedure separates the traffic within the UMTS network from the user traffic. The tunnel is active for the session duration which ends when the MS deactivates the context. During this time the SGSN is constantly informed of the current location of the MS (micro mobility management). If the user changes location, the route in the GGSN is shifted to the new SGSN. In case of longer periods of inactivity the MS timer runs out and the context may be closed if the inactivity reaches a set timeout point. However the logical connection between GGSN and mobile station is maintained continuously. The tunnel is not released until the context is deactivated or the mobile station disconnects from the SGSN. Afterwards the IP address can be used for another connection [JAVIER 2007].

2.4.5 Authentication

UMTS AKA is a security mechanism used to accomplish the authentication features and all of the key agreement features for network access security. The UMTS AKA protocol comprises two stages: Distribution of authentication vectors from the home environment (HE) to the service network (SN), and authenticated key

establishment. The steps of AKA protocol are shown in Figure 2-8 and described as [ARKKO 2004]:

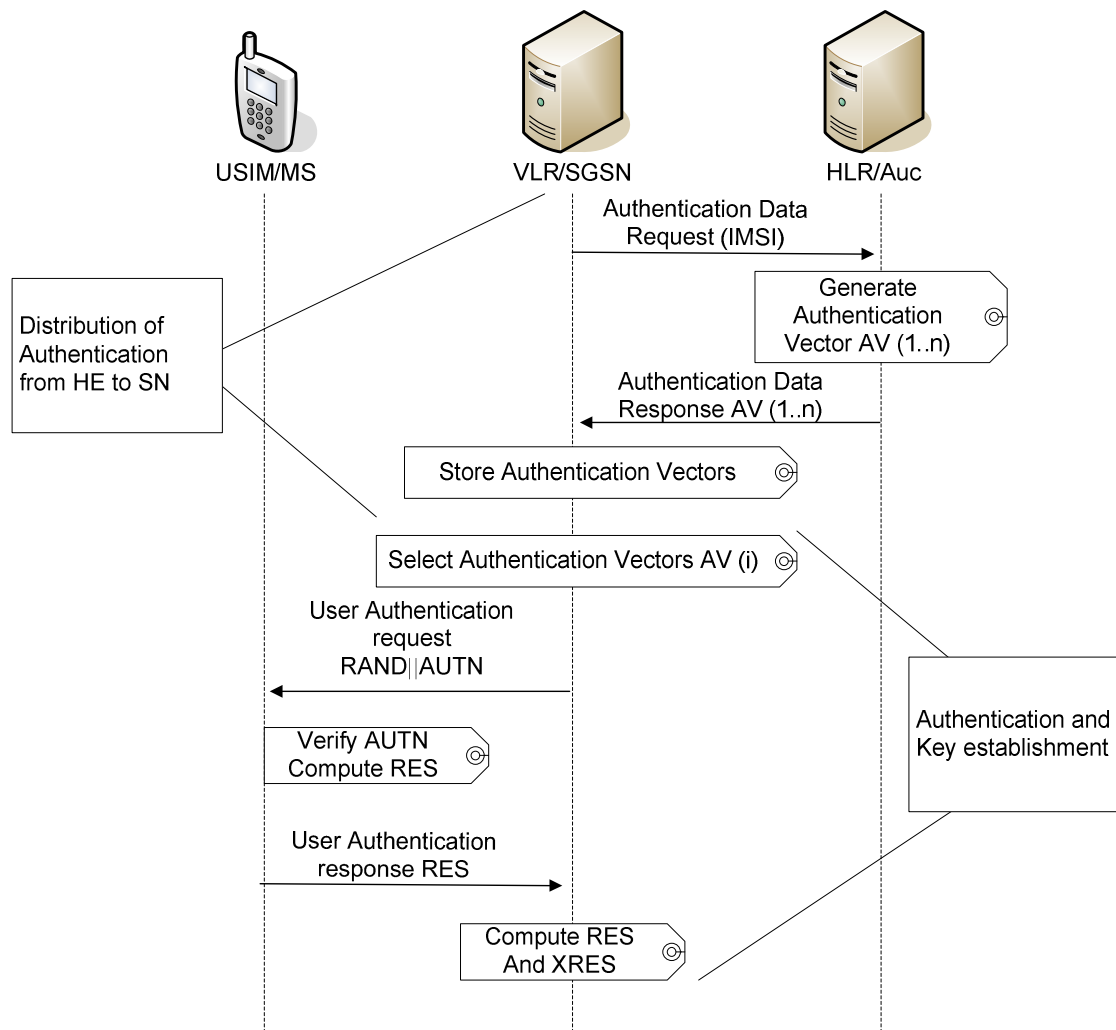


Figure 2-8 UMTS AKA

- The VLR/SGSN forwards the request to the MS's HLR/AuC to attain an Authentication Vector (AV) following a request from the MS. The request includes the MS's International Mobile subscriber Identity (IMSI).
- HLR/AuC uses the MS's IMSI to obtain the shared secret key K and generates an ordered array of n authentication vectors after receiving the request from the VLR/SGSN. Each authentication vector includes the following components: a random number $RAND$, an expected response $XRES$, a cipher key CK , an integrity key IK and an authentication token $AUTN$. The generation of AV is 1-n.

As a final point, the HLR/AUC sends a response with authentication vectors back to the VLR/SGSN.

- The VLR/SGSN stores the AVs which are received from HLR/AuC, and will select an AV from the vectors on a random basis, to execute the second stage of the AKA procedure later. At the time of instigating the second stage it sends the parameter RAND and AUTN of the selected AV to the MS.
- The MS performs the following step, after receiving the *RAND* and *AUTN*:
 - The MS computes the anonymity key $AK = f5_k(RAND)$ using the shared key K and regains the SQN from AUTN, where f5 is a key generating function. The MS then verifies the freshness of the SQN to confirm whether the AV has been used or not. The MS compute the $XMAC = f1_k(SQN || RAND || AMF)$ and compares it with the *MAC* received from the VLR/SGSN, where *f1* is a message authentication function.
 - If both verifications were successful, the MS is assured of the authentication of the HLR/AuC. It calculates the $RES = f2_k(RAND)$, $CK = f3_k(RAND)$ and $IK = f4_k(RAND)$ where f3 and f4 are the key generating functions. Lastly, the MS sends the *RES* back to the VLR/SGSN.
- When the VLR/SGSN receives the RES from MS, the XRES of the selected AV is compared with RES. If they match, the VLR/SGSN is assured that the MS is a legal subscriber and the AKA exchange is successful. Therefore, the CK and IK will be used in the following communiqué between the MS and the VLR/SGSN to provide confidentiality and reliability.

2.5 WLAN

The wireless Local Area Network (WLAN) industry has become one of the fastest growing segments of the communications industry. WLANs are envisioned as an alternative to wired LANs, which have high installation and maintenance cost. In public

locations known as hotspots, customer premise and homes, WLAN provides high speed access to the Internet while maintaining an optimal trade off between range and data rates. In addition, WLAN can also act as a complement to the 3G cellular network. The IEEE 802.11x standard for WLAN has an emphasis on the physical layer and medium access control (MAC) layer for ad-hoc and access point (AP) based networks. Initially WLAN standards supported only three protocols for physical layer Infrared (IR), direct sequence spread spectrum, frequency hopping spread spectrum. The IEEE 802.11b standard is an extension of the original 802.11 standard and includes data rates of 1, 2, 5.5 and 11 Mbps and uses direct sequence spectrum (DSSS) at the physical layer. Extensions IEEE 802.11a and IEEE 802.11g provide data rates ranging from 6 to 54 Mbps in the 2.4 GHz and 5 GHz bands and use orthogonal frequency division multiplexing (OFDM) at the physical layer. All of the WLAN standards have similar protocols at the MAC layer which uses the carrier sense multiple access/collision avoidance (CSMA/CA) scheme [SAAD Z. 2007].

2.5.1 MAC Technologies:

The MAC protocols provide two functions, the main distributed coordination function (DCF) and the optional point coordination function (PCF), which can be used to determine when a station has access to the wireless medium.

- Each station can apply the DCF individually to determine when to access the medium, thus distributing the decision-making process among stations.
- The PCF is used during a contention-free period to poll stations. The polled station can access the wireless medium exclusively, without any contention.

The distributed coordination function (DCF) is the contention-based function of the IEEE 802.11 MAC. In the DCF, when the channel changes from a busy state to an idle state, it does the following:

1. Wait a specific IFS (inter frame space) time period.
2. If the channel is still idle, then wait a random back off time.
3. If the channel is still idle, then transmits the frame.

In contrast, the MAC layer point coordination function (PCF) is based on a contention-free mechanism. The point coordinator uses PCF inter frame space (PIFS) when issuing polls. and can cease the DCF asynchronous communication when the PIFS becomes smaller than the DCF Inter Frame Space (DIFS) while issuing polls. The point

coordinator issues polls in a round robin fashion to stations which are a part of the PCF. Because PIFS is smaller than DIFS the point coordinator can seize the DCF operation so the PCF is a contention free service while the DCF has the possibility of contentions occurring.

2.5.2 Network Architecture

Movement of the mobile node inside WLAN is transparent to the upper layer protocols; for example the LLC layer and TCP layer. The AP and mobile stations, which are part of WLAN infrastructure, have built-in protocols for the physical layer and the MAC layer. All the 802.11 functions are physically built-in into the radio network interface card (NIC). IEEE 802.11 has been designed to support two topologies which are:

- Extended service set network.
- Independent basic service set network.

All the users inside the basic service set (BSS) remain fully connected and can move about but cannot communicate directly to each other if the mobile device moves outside the BSS, so many BSS provide an extended service set (ESS). This type of interconnection is known as a multiple BSS distribution system; all of the ESS and BSS networks are transparent to the LLC layer. A logical point called a portal is used for data to enter or leave if the data frames travel between a non IEEE 802.11 LAN and IEEE 802.11x. So a portal provides a logical integration between wired LAN and WLAN.

2.5.2.1 Basic Service Set

BSS is a basic building block of IEEE 802.11x where the MS are controlled by a coordination function; either the DCF or the PCF. The BSS is shown in Figure 2-9. The MS can communicate with each other inside the BSS. If the BSS is not connected to any infrastructure network then the MS within the BSS area can communicate with each other directly and this is known as an ad-hoc IEEE 802.11 network. An independent BSS (IBSS) may form an ad-hoc network in which each individual node can communicate or initialize a session to any other node and there is no centralized controlling device. MS follow the following procedure when participating with an IBSS:

- One station is selected to initialize the communication and it is given service set ID SSID it is known as initializing station.

-
- Initially selected station send beacon frames.
 - Other stations in the IBSS try to get access on the medium for service with SSID that matches their desired ID, so in this way other station get further information to communicate.
 - More than one station could be configured as the start point.

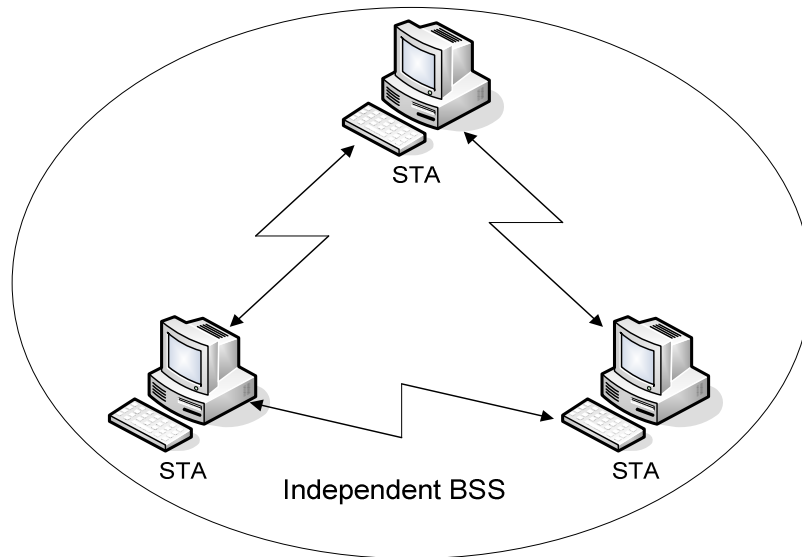


Figure 2-9 Independent BSS

2.5.2.2 Extended Service Set

Wireless users in an infrastructure network are provided with special services and range extension, which is not the case in an ad-hoc network. Infrastructure networks are designed using multiple AP. The AP behaves like a base station in cellular networks and also connects multiple BSS with the result that coverage can be increased. This facility is formed into an ESS region. The ESS is comprised of multiple BSS as explained before and the BSS are integrated together by a common distribution system (DS). The DS works like a backbone network and transfers data at the MAC level and that is why DS can incorporate non IEEE802.11 interfaces and standards like IEEE 802.3 Ethernet LAN, IEEE 802.4 token ring, and basic IEEE 802.11, and other appropriate standards. The ESS architecture is shown in Figure 2-10. AP are connected to each other through wired networks called backbone networks. A procedure to commence ESS operations includes the following steps:

- Extended service set is used to identify infrastructure network.

-
- AP will adapt to this ESSID.
 - After power up, MS send requests and find the AP to which the MS has to associate.

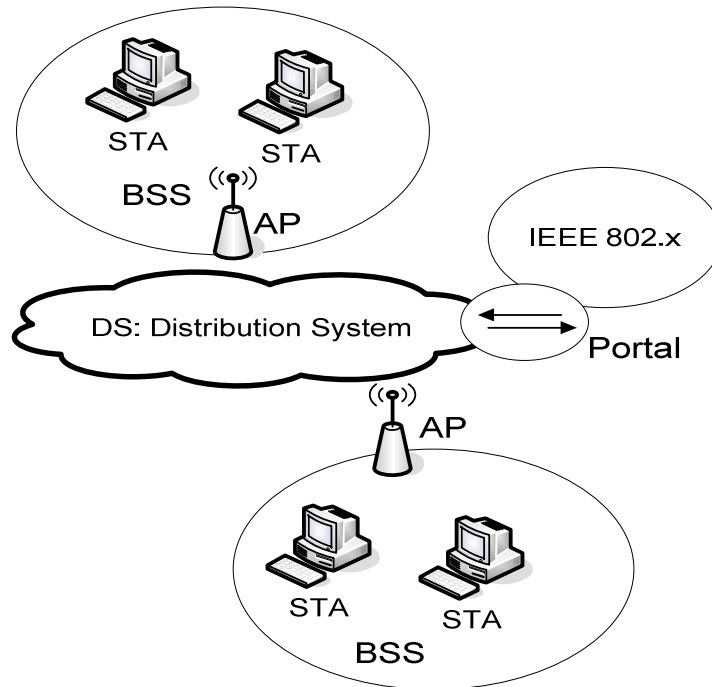


Figure 2-10 Extended Service Set (ESS)

2.5.3 Overview of Current WLAN Standard

The international WLAN specification is developed by the IEEE 802.11 WG, which was established in May 1989 and is composed of volunteers from industry and academia [ETOH 2005]. The IEEE 802.11 standards are summarised in Table 2-4.

Standard	802.11	802.11a	802.11b	802.11g	802.11n

Standard Approved	July 1997	October 1999	October 1999	July 2003	November 2009
Frequency	2.4-2.4835 GH	5.15-5.35 GH	2.4-2.4835 GH	2.4-2.4835 GH	5 GH and/or 2.4 GH
Throughput	1 mbit/s	27 mbit/s	5 mbit/s	22 mbit/s	144 mbit/s
Data Rate	2 Mbps	54	11	54	600
Modulation	DSSS	OFDM	DSSS	OFDM	OFDM

Table 2-4 IEEE 802.11 standards

2.5.4 WLAN Authentication

The WLAN (IEEE 802.11x) system employs the Extensible Authentication Protocol (EAP) [ABOBA 2004] to provide a flexible authentication framework. Other authentication mechanisms may be used however EAP was selected for WLAN based on its characteristics and suitability. A typical authentication process using EAP is shown in Figure 2-11. There are four types of EAP messages: EAP Request, EAP Response, EAP Success and EAP Failure. EAP can route authentication traffic encapsulated within EAP Request/Response messages to a centralized authentication server rather than having AP make independent authentication decisions. The EAP messages do not have an addressing mechanism and are encapsulated using the EAP over LAN (EAPOL) protocol. Currently, there are several state-of-the-art authentication protocols encapsulated in the EAP protocol suite including EAP-SRP [CARLSON 2001], EAP-TLS [RFC 2716], PEAP [PALKER 2004] and EAP-TTLS [FUNK 2004].

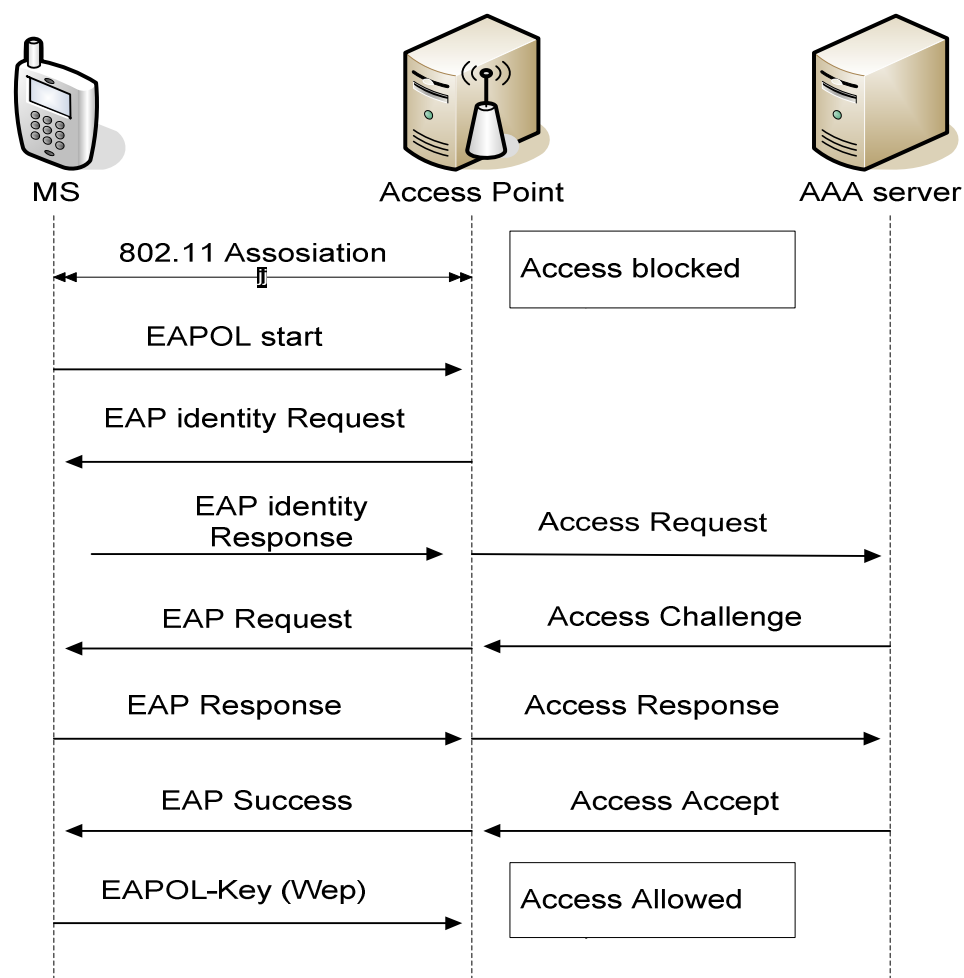


Figure 2-11 Authentication flow of WLAN (IEEE 802.11x)

2.6 3G-WLAN Interworking

With the move towards 4G systems that provide feature sets including seamless roaming between heterogeneous networks it is anticipated that a number of new standards will coexist for a period before a dominant 4G solution emerges. As a step in the development process towards a 4G mobile wireless network integration of WLANs and the 3G mobile wireless data network is an important outcome. Facilitating this outcome will provide knowledge that can be used in the next generation mobile wireless network. Six possible service integration scenarios have been identified and are shown in Table 2-5 [TS 23.234 2006].

Scenario	Features
1	Common billing and Customer Care
2	Scenario 1 + Common Authentication

3	Scenario 2 + Access to 3G packet-switch based services
4	Scenario 3 + Service Continuity
5	Scenario 4 + Seamless service continuity
6	Scenario 5 + Access 3G circuit-switch based services with seamless mobility

Table 2-5 Interworking Scenarios and features

UMTS and WLAN interworking is regarded as an important working item for future mobile wireless systems. From the literature review it was found that there are several alternatives to interconnect the two networks. The integration architectures between UMTS and 802.11x networks can be broadly divided into four categories:

- open coupling
- loose coupling
- tight coupling
- very tight coupling

A description of the coupling architectures is provided in the following sections.

2.6.1 Open Coupling

In an open coupling scheme WLAN and UMTS use their own separate access and transport networks and billing and user management occurs through different authentication mechanisms. This is the simplest coupling architecture for 3G-WLAN interworking.

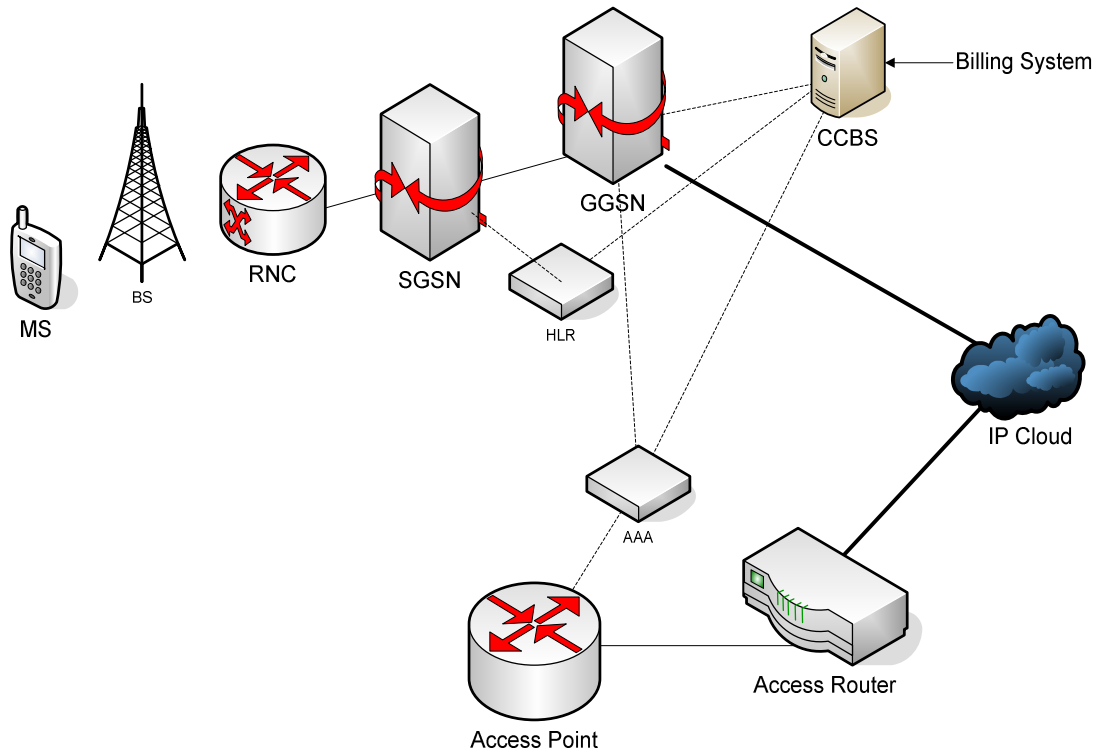


Figure 2-12 Open Coupling

The open coupling architecture connection between 3G and WLAN is through the customer relationship as shown in Figure 2-12. The customer receives one bill from the mobile operator for the usage of both 3G and WLAN services. Integrated Customer Care allows for a simplified service offering from both the operator and the subscriber's perspective. The security level of the two systems is independent. A large handover delay may arise due to authentication traffic between the authentication, authorisation and accounting (AAA) server and the HLR [MARWAN 2008]. Due to handover delay many researchers have not considered this coupling architecture for interworking 3G and WLAN and although open coupling meets the requirement of the 3GPP Scenario 1, open coupling was not selected for this study.

2.6.2 Loose Coupling

In a loose coupling architecture the use of a common authentication mechanism provides a link between the AAA server in the WLAN network and the HLR in the UMTS network. In other words, loose coupling provides the subscribers with access to the 3G based packet services without making any changes to the WLAN and UMTS protocols. The key element to support mobility management in this architecture is the

use of mobile IP [VARMA 2003]. However, there are other variants to this coupling, which may involve the user data traffic being routed to the UMTS Core Network (CN) [APOSTOLIS& SALKINTZIS, 2004]. The data traffic is routed directly via an IP network which is an advantage of this method. That is why it is also called the mobile IP approach. The loose coupling architecture is shown in Figure 2-13.

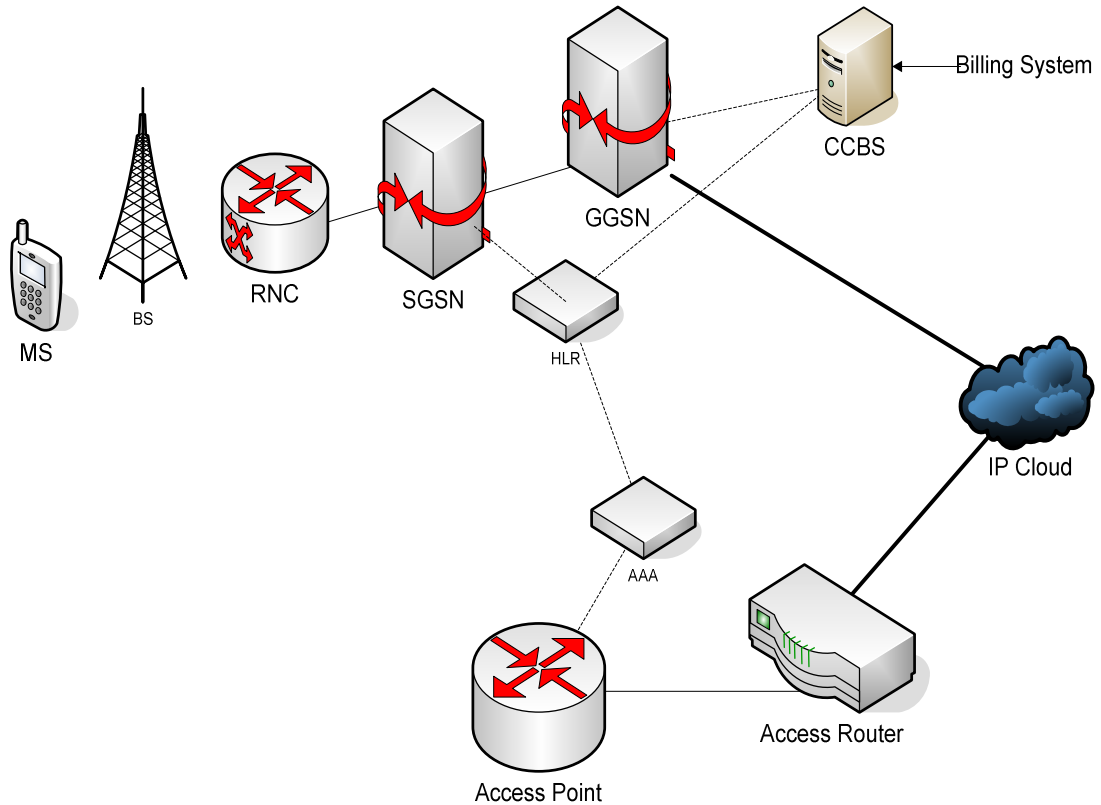


Figure 2-13 Loose Coupling

2.6.3 Tight Coupling

As shown in Figure 2-14, the tight coupling architecture integrates two networks at the CN level where a WLAN AP is connected as a RNC to the UMTS SGSN to support the handover between WLAN and UMTS networks. In other words, tight coupling makes two different radio access technologies work together with a single core network. The key functional element in the system is the handover between the WLAN

and the UMTS networks and this may be likened to the handover occurring between two individual wireless network cells. The tight coupling integration scheme includes the reuse of UMTS AAA mechanisms, usage of common subscriber databases and billing systems, and increased security features (since the UMTS security mechanisms are reused). Tight coupling provides for the possibility of continuous sessions as users move across the two networks, since the handoff in this case is very similar to an intra-UMTS handoff as the WLAN AP appears as another RNC to the SGSN node [RUGGERI 2004]. An obvious benefit of this approach is that the UMTS mobility management techniques can be directly applied.

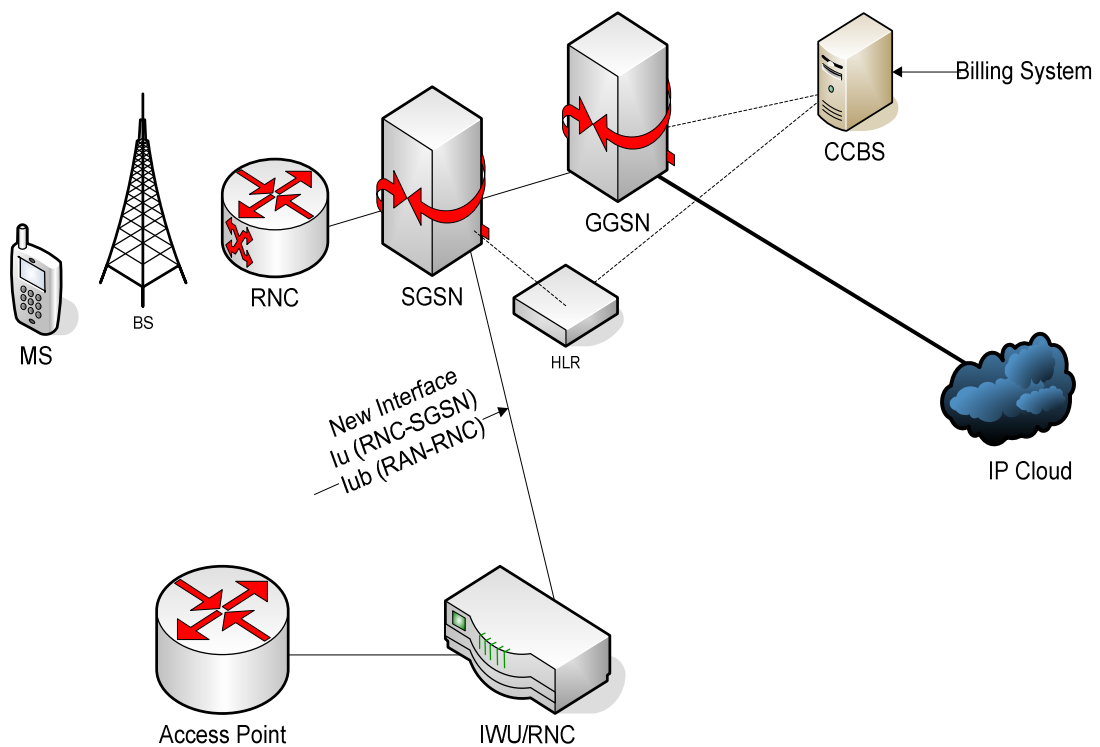


Figure 2-14 Tight Coupling

2.6.4 Very Tight Coupling

The very tight coupling approach is the same as that in the tight coupling scheme with the addition that the WLAN AP is connected to the RNC as shown in Figure 2-15. The access point connects to the RNC through the Iub interface, presenting itself as a node B (Base Station) [GEORGE 2005]. Using very tight coupling enables the collection of information relating to air interface conditions and network capacity. However, it is considered quite complicated and only few solutions have been proposed in this area. The reason very tight coupling is regarded as complex interworking scheme are:

- It needs to implement the new interface for RNC-WLAN, where WLAN is seen as cell management at the RNC.
- AP also need to implement the 3G protocol stack [TS 22.934 2002].
- Modifications mainly affect RNC and more specifically Radio Resource Control (RRC).
- The decision for selecting the proper radio interface, in the WLAN management, and to control the handover RRC state model should be changed.

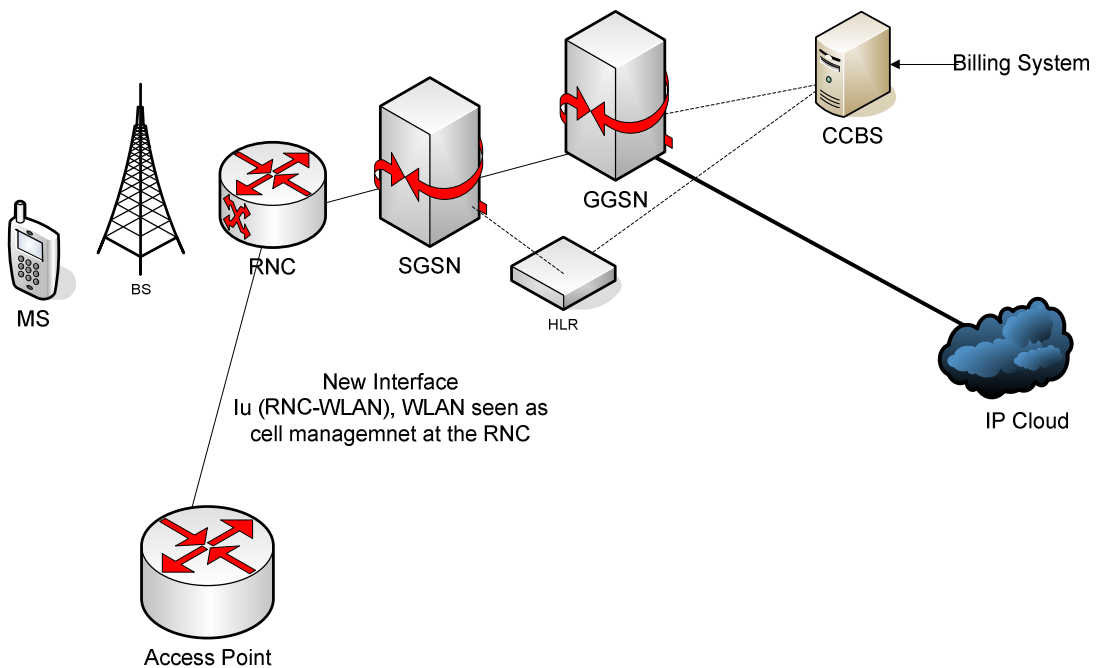


Figure 2-15Very tight Coupling

2.7 Related work

The concept of integrating two or more access networks to provide ubiquitous service to mobile users has been a research focus for some time with interworking WLAN and UMTS networks being a focus of attention [LI 2002, JASEEMUDDIN 2003, APOSTOLIS K. 2004, SALKINTZIS 2004, and LIU 2005]. A valuable reference is provided by Salkintzis, et al. [SALKINTZIS 2002] although the focus is the 2.5G GPRS cellular system, where a new network element, called the GPRS interworking function (GIF) was proposed to pass user data traffic. In heterogeneous network literature, a terminal with a double communication capability allows the user to switch connections from one radio access network to another without packet loss [SIDDQUE

2005 and ASHRAF 2008]. The literature review found very few studies on the performance of these hybrid networks for various internet applications. For example, Song and Jamalipour focus on the performance of a network selection algorithm rather than traffic sessions [SONG 2005]. The performance of a loose coupling architecture with regard to the continuity of real-time video traffic for UMTS connections has been measured by Salkintzis et al. [SALKINTZIS 2005]. Another attempt to re-use AAA procedures and offer access to 3GPP PS services from WLAN is proposed by Salkintzis [A.K. 2004]. The main advance is the use of UMTS instead of GPRS, but no solution for session continuity is given. Munasinghe and Jamalipour [KUMUDI 2008] have proposed an IMS based integration where the proposed system can manage the real time sessions with the use of the IMS as a unified session controller. Salkintzis [Salkintzis 2004] proposed architectures which enable 3G subscribers to benefit from high throughput IP connectivity in strategic hotspot locations. Kaloxylos et al. proposed policy-based scheme is not based on the IETF Policy Framework [A. KALOXYLOS 2006], as was proposed by Barbaresi et al. [A. Barbaresi 2005]. Moreover, the interoperability between different providers' network is not specified. The approach proposed by Kaloxylos et al. proposes the connection of WLAN with UMTS through an interworking unit (referred to as ERNC). This unit is directly connected to SGSN as proposed in [SALKINTZIS 2002]. The main advantage of this proposal compared to the work by Barbaresi et al. [A. BARBARESI 2005] is that it incorporates policy-based decision entities (similar to PDPs) both at the RNC and the mobile terminal. In this way, the mobile terminal manages to handover its data or voice connections according to different parameters such as user, terminal, and service profiles, as well as the availability of alternative networks. This results in more flexible and efficient use of their sources for both the WLAN and the cellular network. Since, the architecture is similar to that of one proposed by Salkintzis et al. [SALKINTZIS 2002], most of the UMTS infrastructure is reused, thus at least service continuity is provided. The study by Welling et al. showed that WLANs are economically profitable as a complementary, rather than competing solution for 3G wireless data network operators [Welling 2003]. The authors also discussed the AAA signalling for interworking 3G/WLAN rather than the analysing performance.

Finally, the study by Abu-Amara et al. measures the performance of loose coupling and open coupling with two mobility schemes [Marwan 2008]. The authors found that in open coupling, a large handover may arise due to authentication traffic between the AAA

server and the HLR. On the other hand, very tight coupling is considered as a complex coupling architecture due to the need for extensive hardware and system modification. The literature review provides motivation for a performance analysis between tight coupling and loose coupling with various internet applications.

3 Objectives

The objective of UMTS/WLAN integration is to provide flexibility, reliable low cost and high quality services across two network types. The aim of this thesis is to present research outcomes including an analysis of UMTS/WLAN integration and the performance of common applications. The research included the development of a model and simulation environment that could be used to gain results suitable for analysis. Specific attention was paid to design tight coupling and loose coupling architectures where EAP-AKA was used for common authentication and mobile IP was used as a mobility management scheme.

The research has made a significant technical contribution to the body of knowledge by analysing coupling architectures for a 3G/WLAN hybrid network and providing simulation results for an analysis of four service applications utilising the different coupling architectures.

The direction taken with the research was to identify an architecture that can provide better overall performance and flexible interworking. The research has also focused on:

- The requirements for interworking between WLAN and UMTS
- The objectives of the next generation mobile system
- To identify the suitable coupling for the 3GPP proposed Scenario 1 to Scenario 4
- The design on the 3GPP proposed scenarios for supporting authentication and access control
- Utilize mobile IP as the common service interface for handover in order to guarantee the handover from the underlying radio access network
- Minimize the number of changes to the existing UMTS protocol
- Minimize the number of changes to the existing WLAN protocol
- Implement VoIP codec over UMTS network
- Implement VoIP codec over WLAN network

Research was first carried out to gain an understanding of UMTS and WLAN networks and the suitability of both networks for simulation and associated network management and control protocols.

Investigation of a satisfactory technique for authentication was performed using the EAP-AKA protocol and the most appropriate method for mobility management was investigated by using Mobile IP.

3.1 Research Limitations

The research presents an analysis to identify an appropriate architecture for the next generation mobile wireless system dependent on various kinds of Internet applications. The experimental data, used in the analysis, was collected from simulation models run using Opnet Modeller. A necessary number of assumptions were made to ensure that reasonable results can be generated within the research time-frame. Moreover, many challenges have been faced during the network model developments and simulation which can be summarized in the following points:

- Opnet Modeller v15 provided several base models that were adapted and the base models do not include a AAA server to provide security for either UMTS or WLAN.
- In Opnet Modeller v15 there is no model which can act as a HLR database that contains all the information related to the mobile user for UMTS technology.
- The Opnet Modeller v15 UMTS model does not support Mobile IP.
- Opnet Modeller v15 model nodes required modification to support both WLAN and UMTS.
- The EAP-AKA protocol which was used for authentication in both coupling scenarios was not included in Opnet Modeller v15 and needed to be added by building a functional element that could be incorporated with the model nodes.
- As Opnet Modeller v15 is used to simulate the hybrid UMTS network the data collected and analysed would be slightly different from results collected using a real system. Opnet Modeller v15 is one of the leading simulation software

applications available today and for this reason the limitations associated with its use are considered acceptable.

The limitations associated with the tools to be used during the research were overcome and the research focused on the architectures, nodes and protocol behaviours that reflected the UMTS and WLAN networks.

3.2 Assumption

A necessary number of assumptions were made to keep the simulation complexity manageable, while still meeting the research goals. This section describes assumptions made in modelling both the UMTS and WLAN data networks, as well as the interworking of these two technologies.

- The network models provided and used within the Opnet Modeller simulation application were considered to be reasonable and suitable for the research. References to other research using Opnet Modeller and the network models have been provided.
- The protocols (EAP-AKA) provided and used within the Opnet Modeller simulation were considered to be acceptable and suitable for the research.
- The different type of codec's used to analyse the voice application was considered to be reasonable and suitable for the research.
- For mobility, the users will start moving from the home network (i.e. UMTS) to a foreign network (i.e. WLAN) after five minutes from starting the simulation. This provided a reasonable delay so that traffic would be established and consistent prior to migration from UMTS to WLAN.
- The UMTS user will move to the WLAN network.
- The authentication process has been simulated using a custom model application:
 - UMTS authentication was implemented as part of a user application and it is communicating with the 3G AAA and HLR during this process.
 - WLAN uses AAA.

4 **Architecture for Next Generation Mobile Wireless System**

The IEEE 802.11 WLANs, which are also known as Wi-Fi, have been rapidly gaining popularity to provide high-speed wireless access for indoor networks, enterprise networks, and public hotspots. Particularly, public hotspots including airports, coffee houses, convention centres hotels, school and university campuses, and libraries which have a high demand for wireless data services. However, the most important shortcoming in WLANs is the range; they cannot provide an end to end service for mobility over a wide area. On the other hand, UMTS can provide mobility over a large coverage area with relatively low data rates. Therefore, integrated UMTS and WLAN networks benefit users with both high speed connectivity as well as widespread coverage. The key goal of this integration is to develop heterogeneous mobile data networks, capable of supporting ubiquitous data services with high data rates in hotspots. The effort to develop such heterogeneous networks – also referred to as the Next Generation Mobile System (NGMS) – is linked with many technical challenges including seamless vertical handovers across WLAN and 3G radio technologies, security, common authentication, unified accounting and billing, WLAN sharing (by several 3G networks), consistent QoS and service provisioning.

This chapter presents the goals of the NGMS and present the steps used to achieve the research objectives including the development of the models to be used in the simulation environment and the development of the authentication protocol and adapting mobility management within the simulation models.

This chapter is organised as follows. The goals for the 4G NGMS are presented in Section 4.1. The details of the two coupling schemes including the simulation set up are shown in Section 4.2. The mobility management for the integrated 3G/WLAN system is presented in Section 4.3. The EAP-AKA protocol used authentication in the integration model is presented in Section 4.4. Finally, a summary is provided in Section 4.5.

4.1 The Goal of Next Generation Mobile System

The evolving next generation mobile systems are expected to solve still-remaining problems of the third generation (3G) systems and to provide a wide variety of new services, from high-quality voice to high-definition video with high data rate wireless channels. The term NGMS is used broadly to include several types of broadband wireless access communication systems, not only cellular telephone systems. One of the terms used to describe NGMS is MAGIC—Mobile multimedia, Anytime anywhere, Global mobility support, Integrated wireless solution, and Customized personal service. The NGMS will not only support the next generation of mobile service, but also support the fixed wireless networks. The next generation mobile systems are about seamlessly integrating terminals, networks, and applications to satisfy increasing user demands. The continuous expansion of mobile communication and wireless networks shows evidence of exceptional growth in the areas of mobile subscriber, wireless network access, mobile services, and applications. The goals of the NGMS include:

- **Ubiquitous** — any service at any place and any time via any network to any person on any device.
- **Convergent** — portability, seamless handover and service continuity
- **Providing bandwidth** — 100 Mbps or more
- **Supporting for Multiple Applications and Services** — Efficient support for unicast, multicast and broadcast services and the applications that rely on them.

4.2 Simulation Setup

This research project has used Opnet Modeller 15.0 to create the network configuration for the NGMS and the selected Internet based applications running over the network. This section describes the simulation model and the applications used to evaluate the performance of the tight and loose coupling architectures. Opnet is a very flexible simulation tool which provides drag and drop facilities for the communication devices like (routers, user equipments, and servers), interconnecting models (ATM link, fibre optics, both wired and wireless LAN and PPP links) and multiple protocols. However, Opnet does not provide some of the major components needed in the network

such as AAA, HLR, 3GAAA, Mobile IP under a UMTS model and the EAP-AKA protocol. All of the additional components have been developed during the research program and the outcomes will be presented here. The Mobile IP configuration and EAP-AKA protocol implementation are discussed later on in this chapter. Two different network models were developed and the first included a tight coupling scheme and the second included a loose coupling scheme. Twelve scenarios were developed for various kinds of Internet applications. Six scenarios were made for voice applications where three codecs were used with the two different coupling schemes and the rest of the scenarios were made for the ftp, http and web applications with the two different coupling schemes. A 3G model was combined with an 802.11g model using Opnet Modeller to evaluate network, integration and application performance. The network configuration process can be divided into 5 steps that are:

1. All of the required communication devices were added into the Opnet Modeller scenario.
2. The communication devices were interconnected using fixed link models excluding the user device model which includes a wireless mobile node. When the connections were established an inbuilt test mechanism was used to verify the links.
3. The test applications were configured using scenario application definitions. As shown in Appendix A.
4. Then the Opnet scenario profile was configured for the user device and a profile definition was added. To identify the applications for each user the profile was configured as shown in Appendix A.
5. Mobile IP was implemented to work with UMTS and the EAP-AKA authentication protocol was added to the Opnet scenarios as shown in Appendix A.

Before running each simulation the desired statistics were selected. After each simulation the results were collated and analysed.

4.2.1 Tight Coupling

The tight coupling scheme, described in Chapter 2, integrates two networks at the CN level where WLAN AP are connected as an RNC to the UMTS SGSN through a SGSN Emulator to support the handover between WLAN and UMTS networks. In other words, it makes two different radio access technologies work together with a single core network. The key functional element in the system is the handover between a WLAN and a UMTS network which can be considered as a handover between two individual cells. In this integration scheme including the reuse of UMTS AAA mechanisms, usage of common subscriber databases and billing systems, increased security features (since the UMTS security mechanisms are reused), as well as the possibility of having continuous sessions as users move across the two networks, since the handoff in this case is very similar to an intra-UMTS handoff as the WLAN AP appears as another RNC to the SGSN node. An obvious benefit of this approach is that the UMTS mobility management techniques can be directly applied.

In a tight-coupled network, it is possible to support a user's IP mobility using tunneling protocols without using Mobile IP. On the other hand, Mobile IP can also be applied in a tightly coupled network [Young 2006], but even in that case, handover between the different access networks (i.e. the UMTS and the WLAN) does not need to change the Foreign Agents (FA) since those access networks belong to the same FA (GGSN). So, the vertical handover between UMTS and WLAN is an intra-FA handover, as are other inter-RNC handover or inter-AP (SGSN emulator) handovers, which does not need to change the user's IP address and to register to an FA or the HA. The scenario created within Opnet Modeller for tight coupling is shown in Figure 4-1.

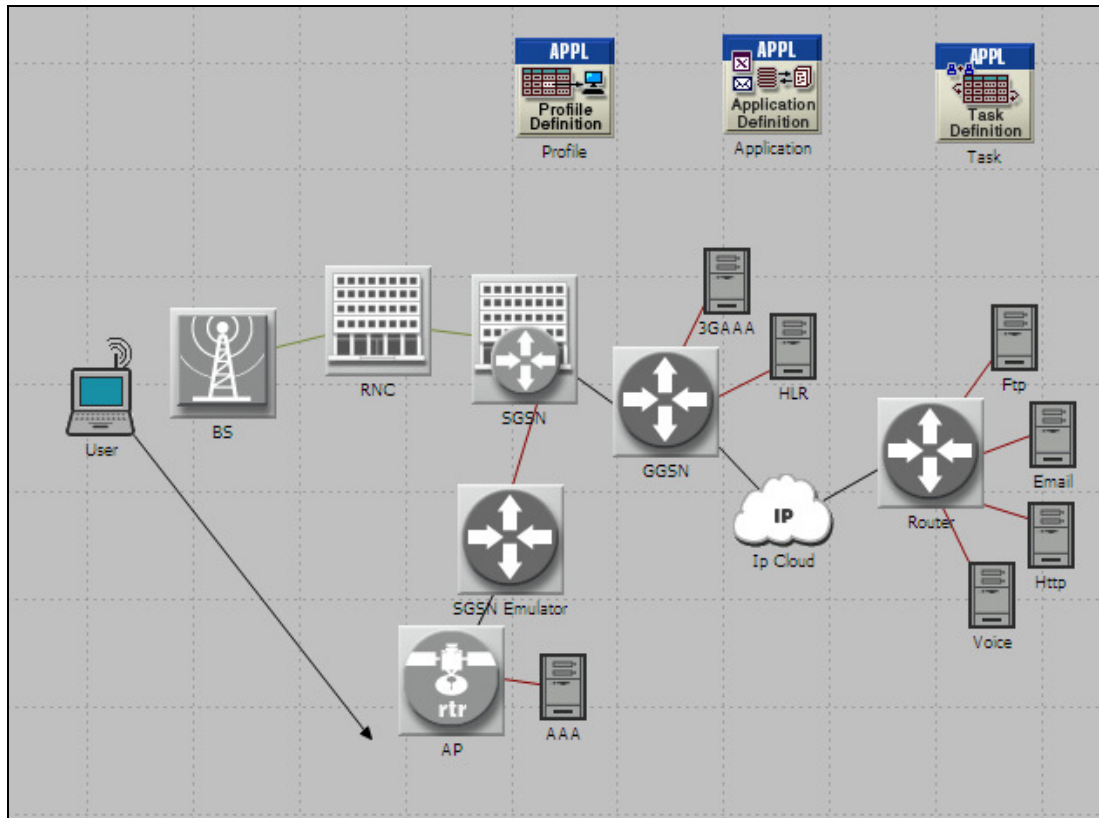


Figure 4-1 Tight Coupling Scenario

4.2.1.1 Handover to the WLAN

The RNC decides whether or not to start handover based on the measurement results from the UE, and if required, it sends a relocation required message to the SGSN. Then, the SGSN sends handover messages to the appropriate SGSN Emulator. The UE is associated with an AP, and the SGSN requests the SGSN emulator to begin the radio access bearer setup procedure. After completing the bearer setup procedure, the SGSN requests the GGSN to update the PDP context to the UE. The complete handover process is shown in Figure 4-2 [Young 2006].

4.2.1.2 Handover to the UMTS

Handover to the UMTS network is similar to handover to the WLAN network. After deciding upon handover to UMTS, the SGSN Emulator sends a relocation required message to the SGSN to start relocation procedures. After a successful setup of a PDP context, which means RRC connections and radio access bearer (RAB) - including a Radio Bearer (RB), (Radio Links) (RL), an Iu bearer are set up successfully, the UE and

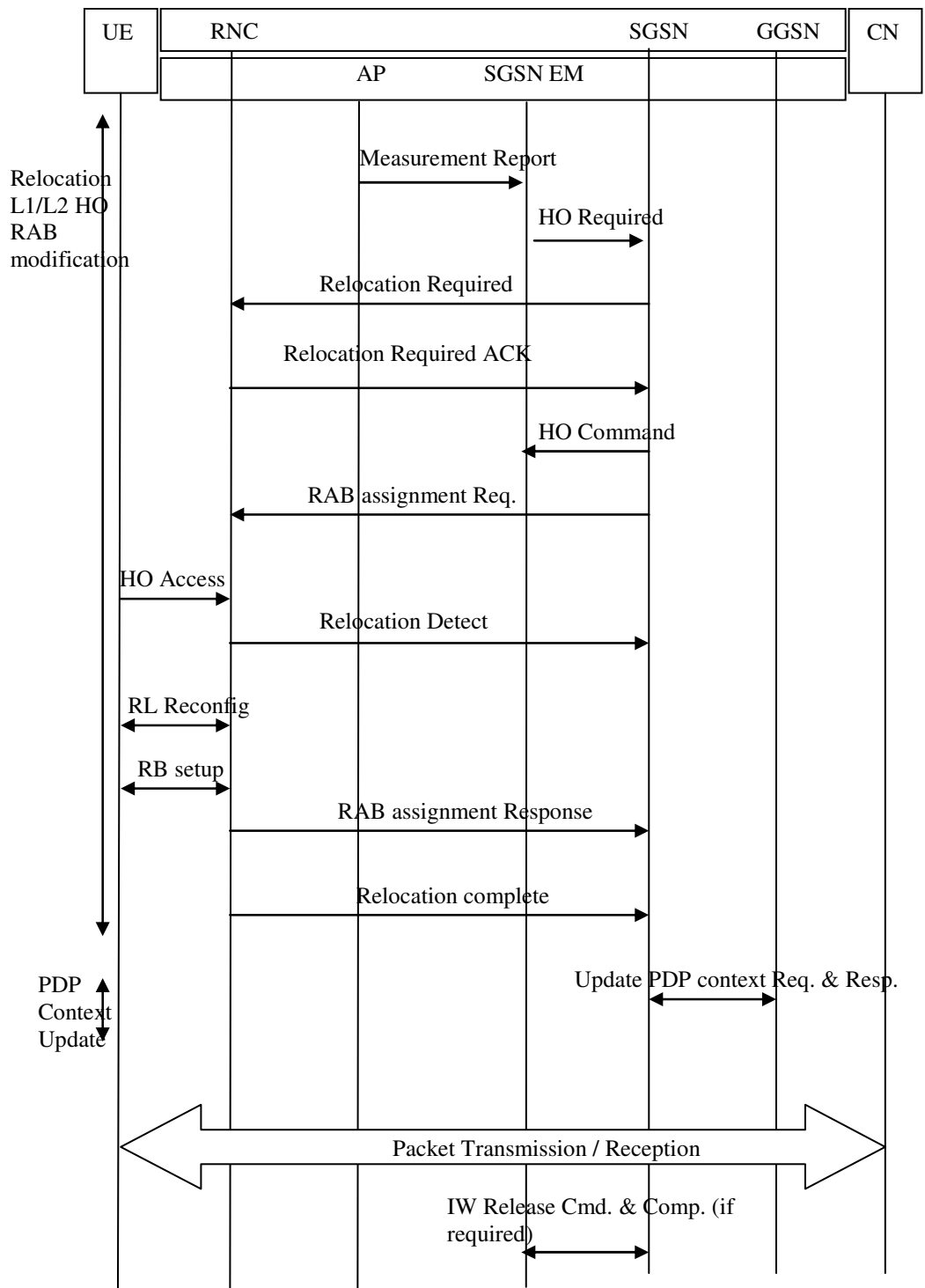


Figure 4-3 Handover to UMTS for a tight coupling scenario

4.2.2 Loose Coupling

The second scenario is loose coupling as described in Chapter 2, which enables the use of common authentication mechanisms by providing a link between the AAA server in the WLAN network and the HLR in the UMTS network as shown in Figure 4-4. In the loose coupling scenario two networks are connected through an IP cloud. From the IP cloud to connect to a WLAN network a SGSN emulator was used. The key element to support mobility management in this architecture is Mobile IP [VARMA 2003]. However, there are other variants to this coupling, which may involve the user data traffic being routed to the UMTS CN [APOSTOLIS 2004, SALKINTZIS 2004]. The data traffic is routed directly via an IP network (or the Internet) which is advantageous of this method and besides a potential traffic bottleneck can easily be avoided.

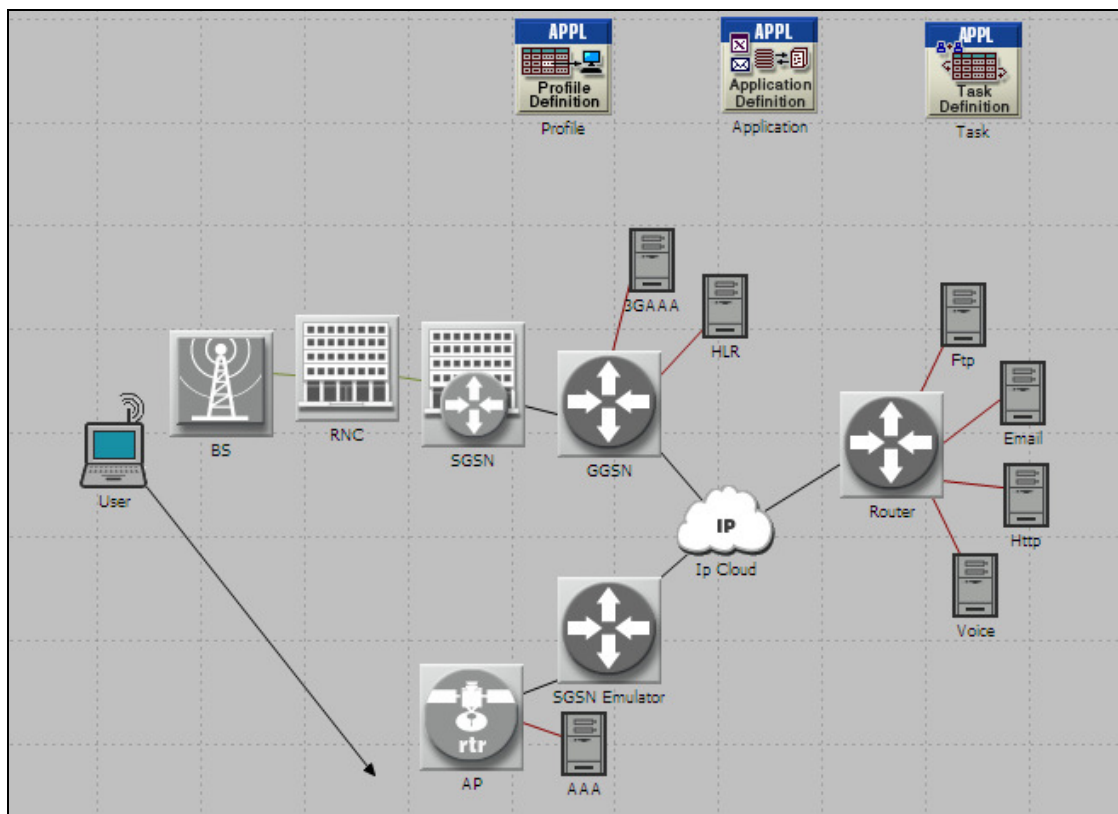


Figure 4-4 Loose Coupling Scenario

To support IP-level mobility in a loose-coupled network, it is assumed that the Mobile IP (MIP) is applied and that the WLAN and the UMTS networks have their own FAs. (A GGSN acts as an FA in UMTS, and the HA and the Correspondent Nodes

(CON) are located in the external IP networks.) The handover procedures to/from WLAN from/to UMTS are shown in Figures 4-5 and 4-6 [YOUNG 2006].

4.2.2.1 Handover to the WLAN network

A UE turns its power on, and is associated with an AP. In our simulation UE represents the user. Then, the UE and the AP start the 802.1x authentication procedure. After completing authentication successfully, an IP address is assigned to the UE by AAA for MIP registration. Using this IP address, the UE registers to the FA in the WLAN and restarts transmitting and receiving packets.

4.2.2.2 Handover to the UMTS network

First, a UE sets up a RRC connection with an RNC and starts authentication and ciphering. After the successful setup of the RRC connection, the UE starts the GPRS attach procedure and requests the activation of a PDP context. Then, an SGSN starts to set up an Iu bearer to the RNC, and requests that the RNC assigns a RAB and that the GGSN creates a PDP context with the UE. The RNC initiates the setup of a RB and additional RL for the PDP context. With the IP address assigned by the GGSN, the SGSN sends back an activate PDP context message to the UE. Now, the UE can transmit IP packets using the new PDP context with the assigned IP address. To receive packets from the home network, the UE sends a registration request message using Mobile IP, then the FA (GGSN) performs Mobile IP registration to the HA of the UE. Thereafter, the UE can receive IP packets forwarded by the HA. When the UE leaves the UMTS network and moves to the WLAN, it is possible for the PDP context or the signaling connections to remain active and to enable a return to the UMTS upon completion of the high rate data transmission in the WLAN. This operation could save signaling costs, since the UE can skip long and complicated setup procedures. So, it is also expected that handover latency and packet loss would decrease [Young 2006].

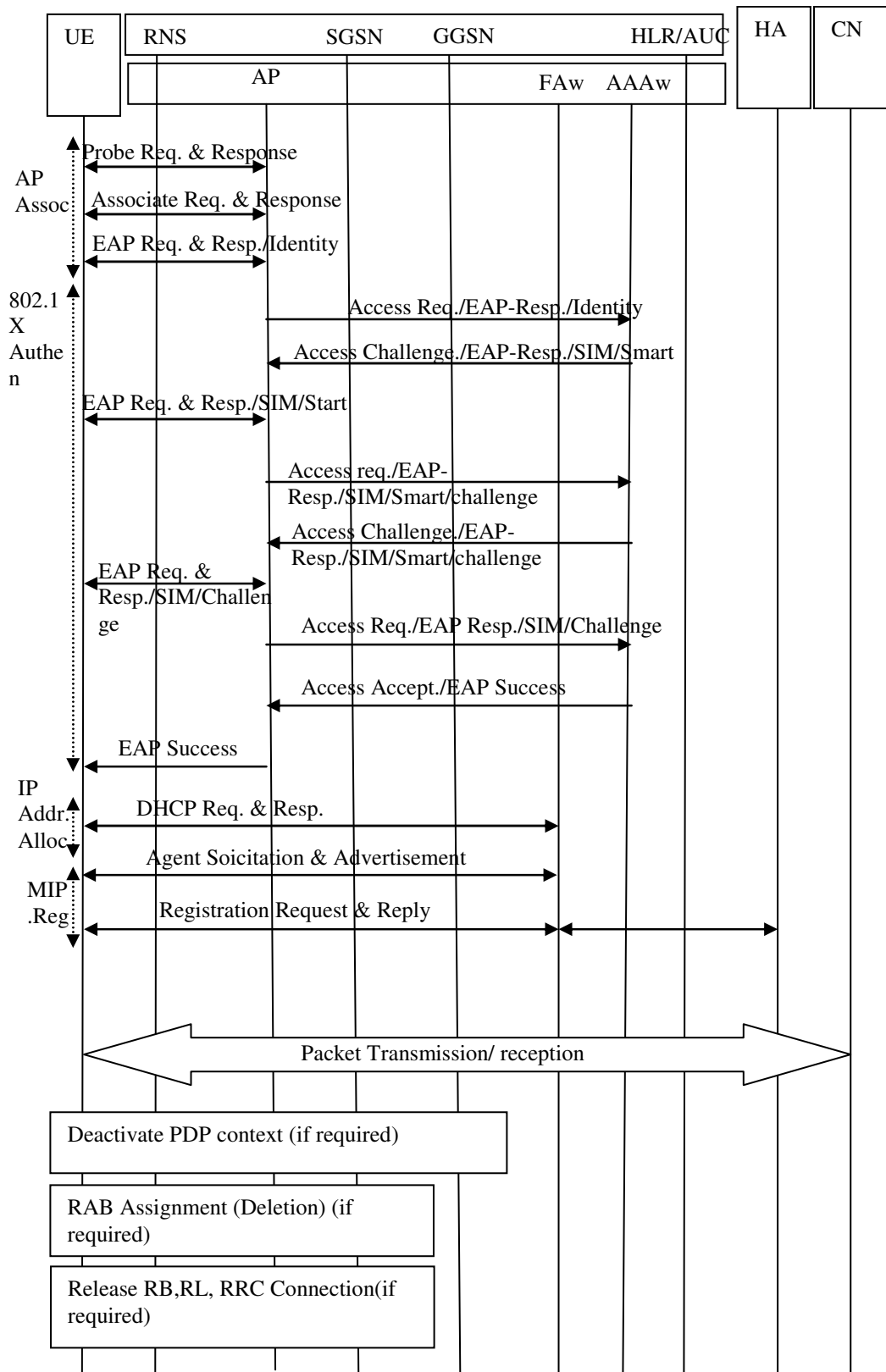


Figure 4-5 Handover to WLAN for a loose coupling scenario

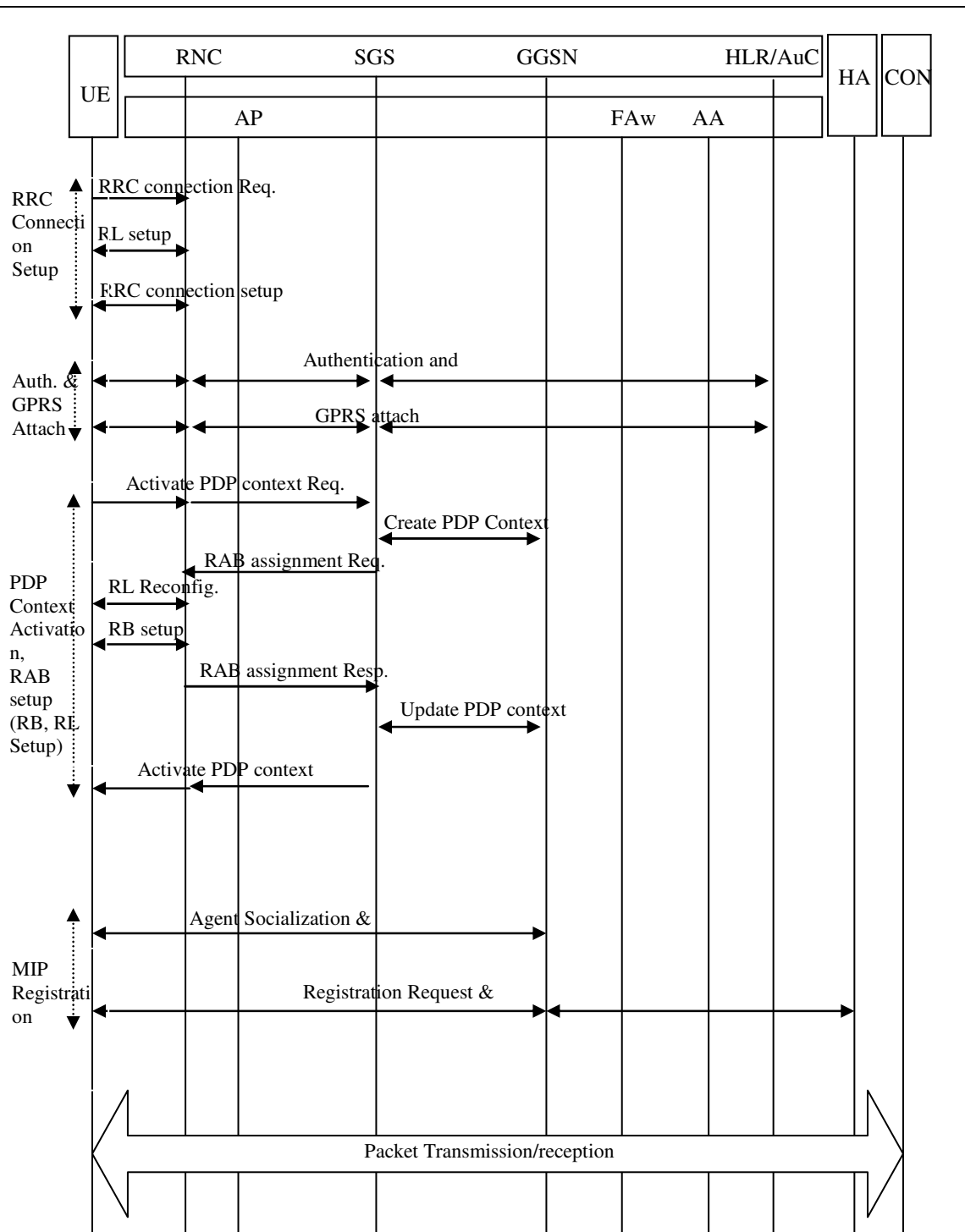


Figure 4-6 Handover to UMTS for a loose coupling scenario

4.3 Mobility Management

Mobile IP is one of the most popular network layer solutions for IP network mobility management and it fulfils the requirement to maintain Internet connectivity throughout user sessions [I.F. 1999, 2004]. Mobile IP is employed to restructure the connections when a MS moves from one network to another, e.g. from UMTS to WLAN. Outside of the UMTS network, the MS is identified by a COA associated with its point of attachment to the UMTS network. Encapsulation and packet delivery is managed by a collocated foreign agent [VARMA 2003]. In this study both coupling scheme network scenarios utilise Mobile IP to support mobility management.

4.3.1 Handover management between WLAN and UMTS

Handoff management is the process by which a MS keeps its connection active when it moves from one AP to another. It is necessary for a MS to employ various points of attachment to maintain connectivity to the network at all times. There is a clear difference between the two types of handover which are known as horizontal handover and vertical handover. Horizontal handover refers to handover between node B and APs that are using the same kind of network interface. Vertical handover refers to handover between a node B and APs (or vice versa) that are employing different wireless technologies. In the case of a vertical handover, two distinctions are made:

- Upward vertical handover, which occurs from IEEE 802.11 WLAN access points with small coverage to an UMTS node B with wider coverage;
- A downward vertical handover, which occurs in the reverse direction.

A downward vertical handover has to take place when a network with a smaller coverage, such as a WLAN network, becomes available when the user still has a connection to the UMTS network. An upward vertical handover takes place when a MS commences a move out of the WLAN network coverage area to the UMTS network and the user still has a connection to the WLAN network. In the case of upward vertical handovers, the MS decides that the current network is not reachable and hands over to the higher overlay UMTS network. The MS instructs the WLAN AP to stop forwarding packets and route this request via a Mobile IP registration procedure through the UMTS CN. When the MS is connected to the UMTS network, the MS listens primarily to the lower layer WLAN AP. If several beacons are identified successfully, the MS will

switch to the WLAN via the Mobile IP registration process. The vertical handover decisions are thus made on the basis of the presence or absence of the AP beacon packets.

4.3.2 Handover Based on Mobile IP

Handover is the mechanism by which the ongoing connection between MS and CN is transferred from one point of access to another point whilst maintaining connectivity. When a MS moves away from an AP or from a node B, the signal level degrades and there is a need to switch communications to another point of attachment that gives access to the existing IEEE 802.11x WLAN network or UMTS network. Handover mechanism in an overlay UMTS and underlay WLAN network could be performed so that the users attached to the UMTS network occasionally check for the availability of the underlay WLAN network. A good handover algorithm is needed to make an efficient decision when to make the handover. This section discusses the handover management procedure and the mechanism for a handover from WLAN to UMTS, and vice versa, based on the RSS metrics. This means that the handover initiation or the handover triggering is sensitive to signals from available access points. The handover management procedure from one network type to another is shown in Figure 4-7 [RAMJEE 2003].

An MS moving from WLAN network coverage may suddenly experience severe service degradation and will have to perform handover very fast to maintain the higher layer connection.

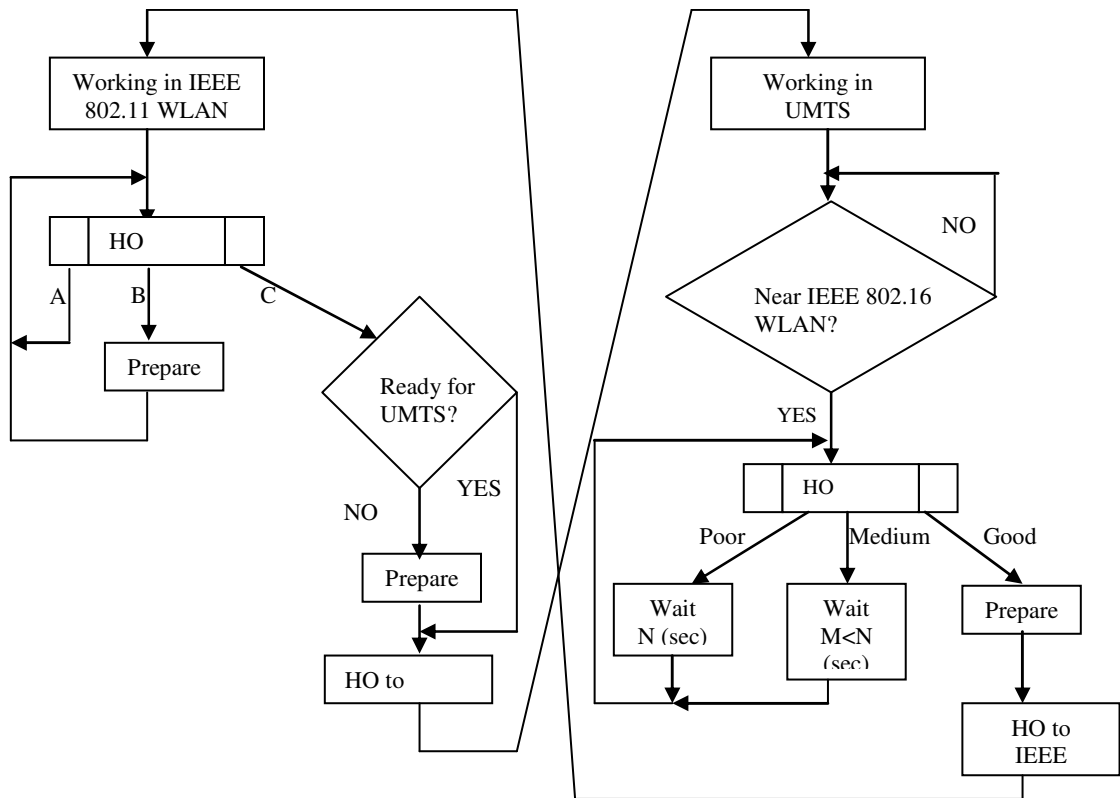


Figure 4-7 Handover management procedure between WLAN and UMTS

When a MS moves away from WLAN coverage within an area overlapped by UMTS coverage the following occurs [RAMJEE 2003]:

- The signals received by a MS from an AP in a WLAN network are initially strong and the MS is connected to the WLAN network, which is also the home network of the MS and the HA in this network.
- The signals from the AP become weaker when the MS moves away. The MS scans the air for another AP. If no AP is available, or if the signal strength from the available AP are not strong enough, the handover algorithm uses this information along with other variables to make a decision on handing over to the higher overlay UMTS network. Connection procedures commence to activate the UMTS USIM card.
- The handover algorithm in the MS decides to dissociate from the WLAN and associate with the UMTS network.

-
- The FA is activated and used by the MS dual USIM card and the Mobile IP protocol, and the MS gets a COA due to initially connecting to the UMTS network as a foreign network.
 - The HA in the WLAN is informed about the new IP address through a Mobile IP registration procedure, and using proxy Address Resolution Protocol (ARP) IP request datagram is received. The HA encapsulates the datagram and tunnels any packets arriving for the MS to the FA of the UMTS network. At the end of the delivery, the MS will receive and process the datagram.

In this case, the handover algorithm determines that there is no local coverage available via WLAN and a handover must be performed to the UMTS network, assuming that a UMTS service is available to the MS. Once the MS is attached to the UMTS, the MS constantly monitors the air at repeated intervals to see whether or not there is a high data rate. When a WLAN network becomes available the handover algorithm should initiate an association procedure to the newly discovered WLAN AP. The illustration of the handover management from WLAN to UMTS is explained in Figure 4-8 [RAMJEE 2003].

The procedure for handover management for a MS moving from a UMTS network to a WLAN network is as follows.

- The signal from the WLAN AP is initially not identified.
- The MS then detects a WLAN AP beacon, which indicates that the underlay WLAN network has become available.
- The handover algorithm decides to initiate a handover from UMTS to the WLAN network.
- The FA in the UMTS network is deactivated, the Mobile IP protocol is used to provide an IP update, and the home IP address is used.
- The HA in the WLAN network is instructed by the MS to no longer do a proxy ARP on its behalf through the Mobile IP protocol.

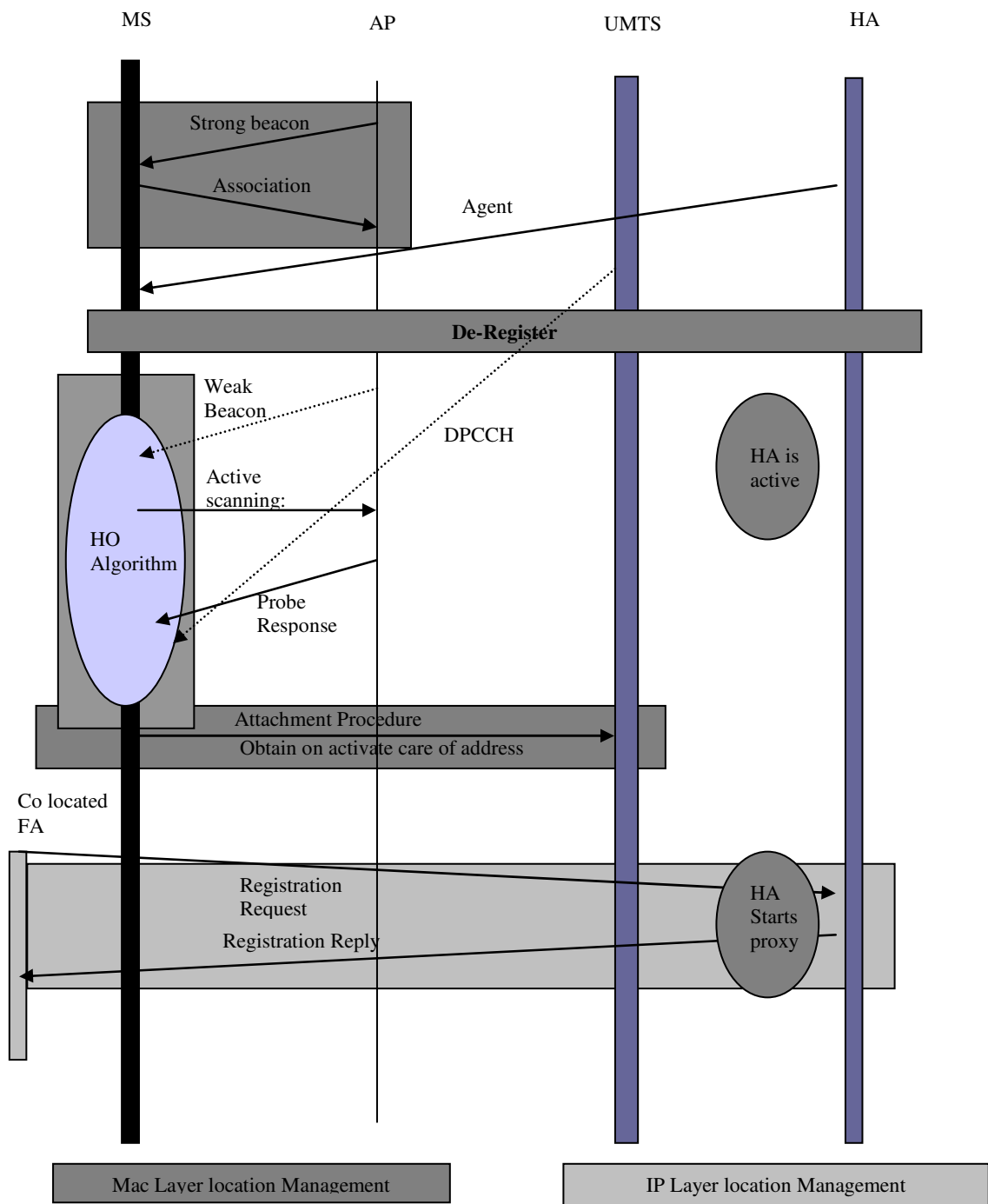


Figure 4-8 Message and signalling of the Handover management

4.3.2.1 Opnet Modeller Mobile IP configuration

Opnet Modeller does not provide Mobile IP support in the provided UMTS network items. It was necessary to design a movement scenario by configuring a task definition. To configure an activity to reflect the actions taken by Mobile IP it took 8 transactions to complete Mobile IP registration. After completing the two coupling network scenarios the Mobile IP task definition was added to the scenarios. The Mobile IP task was selected as shown in Figure 4-9. The following seven steps were taken to configure the Mobile IP task.

1. Opened the utilities object palette, and dragged a task config object into the scenario.
2. Right clicked on it and chose edit attributes.
3. Selected edit from the task specification drop=down menu.
4. Changed the rows value to 8 tasks in the task specification box.
5. Listed each task in the separate row of the table.
6. Entered a name for each phase in the phase name column of the manually configured table.
7. Completed the table by specifying values for each attribute.

	Phase Name	Start Phase After	Source	Destination	Source->Dest Traffic	Dest->Source Traffic
Transaction # 1	Transaction # 1	Application Starts	Originating Source	AAA	(...)	(...)
Transaction # 2	Transaction # 2	Previous Phase E...	AAA	Originating Source	(...)	(...)
Transaction # 3	Transaction # 3	Previous Phase E...	Originating Source	AAA	(...)	(...)
Transaction # 4	Transaction # 4	Previous Phase E...	AAA	HLR	(...)	(...)
Transaction # 5	Transaction # 5	Previous Phase E...	HLR	AAA	(...)	(...)
Transaction # 6	Transaction # 6	Previous Phase E...	AAA	Originating Source	(...)	(...)
Transaction # 7	Transaction # 7	Previous Phase E...	Originating Source	HLR	(...)	(...)
Transaction # 8	Transaction # 8	Previous Phase E...	HLR	Originating Source	(...)	(...)

Figure 4-9 Mobile IP task definition

In the Opnet Modeller simulation, the user MS was defined as an originating source by editing the user node attributes. After completing the Mobile IP task definition configuration manually, a profile was designed for the user node to identify the Mobile IP task definition from the associated user attributes. The user attributes were edited by first choosing a destination preference. In the same way the twelve scenarios were configured. All of the steps are broadly described in Appendix A.

4.4 Authentication

EAP-AKA was proposed by the 3GPP to provide access security for 3G/WLAN interworking. In the Opnet Modeller simulation, EAP-AKA was used as an authentication protocol. It is based on a UMTS AKA mechanism. Especially, in the EAP-AKA, the 3G home domain does not delegate the authentication responsibility to the visited WLAN for security and billing. A successful EAP-AKA procedure is illustrated in Figure 4-10 [ARKKO 2004]. At a minimum, EAP-AKA uses two roundtrips to support mutual authentication and generate session keys. In general, an identity request/response message pair is usually exchanged first. For full authentication the MS identity response is included in the user International Mobile Subscriber Identity (IMSI) or a temporary identity (TMSI). The EAP-AKA protocol authentication Opnet Modeller implementation is shown in Figure 4-11. The Mobile IP task was configured using the approach used for the EAP-AKA task, where 12 phases has defined to fulfil the EAP-AKA procedure. All of the steps are broadly described in the Appendix A.

After obtaining the MS identity, the AAA server of the 3G home domain requests and retrieves subscription data and authentication vectors from the HLR. It is important to notice that, several vectors may be obtained at a time and stored in AAA server for use at a later time; however they may not be reused. After that, the AAA server starts the actual AKA protocol by sending an EAP-request/AKA-Challenge message. The EAP-request/AKA-Challenge message contains a RAND random number and a network authentication token. The message optionally contains encrypted data, which is used to identity privacy requirements and for fast re-authentication.

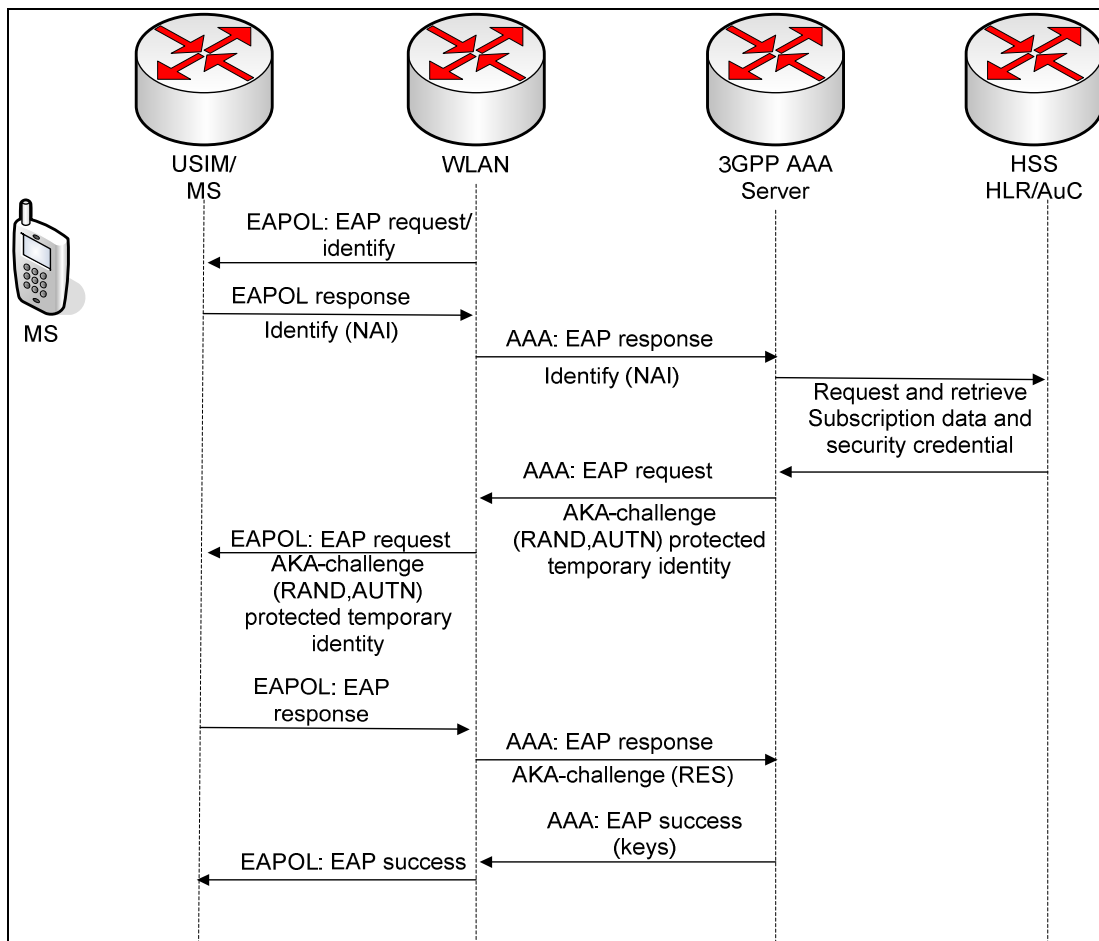


Figure 4-10 EAP-AKA Procedure

★ (Manual Configuration) Table				
	Phase Name	Start Phase After	Source	Destination
App starts	App starts	Application Starts	Originating Source	AAA
EAP req	EAP req	Previous Phase E...	AAA	Originating Source
EAP response	EAP response	Previous Phase E...	Originating Source	AAA
EAP response	EAP response	Previous Phase E...	AAA	3GAAA
Req Security	Req Security	Previous Phase E...	3GAAA	HLR
Retrieve security	Retrieve security	Previous Phase E...	HLR	3GAAA
EAP req	EAP req	Previous Phase E...	3GAAA	AAA
EAP req	EAP req	Previous Phase E...	AAA	Originating Source
EAP response	EAP response	Previous Phase E...	Originating Source	AAA
EAP response	EAP response	Previous Phase E...	AAA	3GAAA

12 Rows
Delete
Insert
Duplicate
Move Up
Move Down
Details
Promote
☒ Show row labels

Figure 4-11 EAP-AKA protocol in Opnet

Next, the MS runs the AKA algorithm (typically using a USIM) and verifies the authentication. If this is successful, then the MS is communicating to a valid AAA server and proceeds to send the EAP-Response/AKA-Challenge message. This message contains a result parameter, RES, which allows the AAA server in turn to authenticate the MS. Finally, the AAA server should also include a session key in the message sent to the WLAN AP. Since EAP authentication may be performed frequently in some environments, and the EAP-AKA full authentication procedure makes use of the UMTS AKA algorithms that require fresh authentication vectors from the HLR. Therefore, EAP-AKA optionally supports fast re-authentication. Some of the more advanced EAP-AKA features are not included in this research but may be an option for future work.

4.5 Summary

In this chapter, two possible coupling architectures were discussed in detail and the simulation platform was outlined. To interwork between UMTS and WLAN both technologies need a suitable authentication protocol for security and an appropriate mobility management system to control the handover correctly. In this research EAP-AKA was used for authentication and Mobile IP was used for mobility. Both Mobile IP and EAP-AKA were previously discussed and were successfully implemented through Opnet Modeller in the scenarios used for both simulating and analysing both coupling schemes.

Firstly, the goals of the NGMS were discussed to illustrate design demands and the advantage of UMTS/WLAN interworking. After that the simulation set up was discussed. Opnet Modeller scenarios for the two coupling schemes were designed, one for tight coupling and another for loose coupling. The handover procedure for both coupling schemes was discussed in detail. Within Section 4.3 mobility management was discussed and the features of Mobile IP were provided. To configure Mobile IP in Opnet Modeller the process was discussed and highlighted in Figure 4-9. The EAP-AKA protocol implementation within the Opnet Modeller scenarios was described in Section 4.4.

The simulation results and performance analysis will be presented and discussed in the next chapter.

5 Performance Analysis

The proposed coupling architectures were simulated and an analysis was carried out for various Internet applications. This chapter provides the simulation and analysis results. Comparison with other studies is made to complete the discussion of the NGMS performance based upon the results found during this reserach. The overall performance of the both coupling schemes was broadly investigated with four major applications: file transfer protocol (ftp), hypertext transfer protocol (http), web services and a voice application.

5.1 Network Entities and Functions

This section illustrates the functionality and configuration of each network node, the interconnecting models and profiles [OPNET 2009].

5.1.1 Application Configuration

Opnet Modeller provides definitions and attributes for the applications that are used by the MS for both of the network scenarios (ftp, http and email, voice). At first the attributes of the application servers was edited appropriately for use in the simulations. In the scenarios for this study, the user node was used to represent the MS or mobile node. The application parameters were set by editing the application description table as shown in Appendix A.

5.1.2 Profile Configuration

Six profiles were created for both coupling scheme scenarios. The applications to be used with the mobile node selected based upon a pre-defined profile. The four applications and two tasks associated with EAP-AKA and Mobile IP were selected as a profile for the mobile node as shown in Appendix A.

5.1.3 IP Cloud

The ip32_cloud node model was selected to represent the IP cloud and the ip32_cloud node model represents an IP cloud supporting up to 32 serial line interfaces at a selectable data rate through which IP traffic can be modelled. IP packets arriving on any cloud interface are routed to the appropriate output interface based on their

destination IP address. The Routing Information Protocol (RIP) or the Open Shortest Path First (OSPF) protocol may be used to automatically and dynamically create the cloud's routing tables and select routes in an adaptive manner. This cloud requires a fixed amount of time to route each packet, as determined by the "Packet Latency" attribute of the node. Packets are routed on a first-come-first-serve basis and may encounter queuing depending on the transmission rates of the corresponding output interfaces.

5.1.4 GGSN

The `umts_ggsn_atm8_ethernet8_slip8` node model was used as the GGSN and it supports 8 ATM interfaces, 8 Ethernet interfaces and up to 8 serial line interfaces at a selectable data rate. The various IP interfaces are used for connections with SGSN nodes via the UMTS core network as Gn interfaces. The GPRS Tunnelling Protocol GTP protocol runs within IP in order to handle the GTP tunnels set between this node and a GGSN node. GTP tunnels are used to transport the UMTS traffic crossing across the UMTS core network. This GGSN requires a fixed amount of time to route each packet, as determined by the "IP Forwarding Rate" attribute of the node. Packets are routed on a first-come-first-serve basis and may encounter queuing at the lower protocol layers, depending on the transmission rates of the corresponding output interfaces.

5.1.5 SGSN

The `umts_sgsn_ethernet_atm9_slip` node model was used as the SGSN. This node model represents a UMTS Serving SGSN node and it supports 9 ATM interfaces, 1 Ethernet interfaces and up to 1 serial line interfaces at a selectable data rate.

5.1.6 RNC

The `umts_rnc_ethernet_atm_slip` node model was used for the UMTS RNC. This model serves as an RNC of a UTRAN participating in a UMTS network. It has the ability to support and manage up to 8 Node-Bs. Each connection to a Node-B will run over an ATM stack. IP (PPP), where PPP refers to Point-to-Point Protocol. ATM and Ethernet interfaces are available for connectivity with the UMTS SGSN node. Packet Data Convergence Protocol (PDCP) compression is disabled, (handover parameters, channel configuration, admission control parameters) are set at default and addressed to auto assign.

5.1.7 BS

The `umts_node_b_adv` was used to serve as a Node-B node that handles the connection of the UEs in its own cell with RNC and the rest of the UMTS network. It was used to control the power and data and it also contains PDU which is used to send internet traffic over a radio channel. All parameters at default value and auto assigned (UMTS Node B) ID.

5.1.8 User

The `umts_wkstn_adv` node model was used for mobile user and it represents a workstation with client-server applications running over TCP/IP and UDP/IP. This workstation requires a fixed amount of time to route each packet, as determined by the "IP Forwarding Rate" attribute of the node. Packets are routed on a first-come-first-serve basis and may encounter queuing at the lower protocol layers, depending on the transmission rates of the corresponding output interfaces.

5.1.9 3G AAA

The `ethernet_server_adv` model was used for 3G AAA and it has all the data required to protect the network against false subscribers and to protect the calls of regular subscribers. The encryption keys are held both in the mobile equipment and the AUC and the information is protected against unauthorized access.

5.1.10 HLR

The `ethernet_server_adv` model was used for the HLR and it contains the information related to each mobile subscriber, such as the type of subscription, services that the user can use the subscriber's current location and the ME status.

5.1.11 Access point

The `wlan_ethernet_slip4_adv` node model was used for WLAN AP. This is a wireless LAN based router with one Ethernet and 4 Serial line interfaces. The multiple access schemes have been configured to DSSS and data rate was 54 mbps.

5.1.12 AAA

The ethernet_server_adv model was used for AAA and it was used for authentication in the WLAN.

5.1.13 Ftp

The ethernet_server_adv model was used for ftp server. It was configured to support all ftp services.

5.1.14 Email

The ethernet_server_adv model was used for email server. It was configured to support all email services.

5.1.15 Http

The ethernet_server_adv model was used for http server which has been configured to support all http services.

5.1.16 Voice

The ethernet_server_adv model was used for voice server. It was configured to support all voice services. Three different type of VoIP codecs were used to analyse the voice application which is described in the following section.

5.1.16.1 VOIP Codec

A codec converts analogue signals to a digital bit stream, and another identical codec is placed at the far end of the communication system to convert the digital bit stream back into an analogue signal. The quality of VoIP can be significantly improved by using proper codec. In a VoIP system, codecs are used to convert voice signals into digital data to be transmitted over the Internet or any IP based digital network supporting VoIP calls. Some codecs also support silence suppression, where silence is not encoded and transmitted. Details of the codecs used in the simulations are provided in Table 5-1 [SAMRAT 2008].

Codec	Algorithm	Bit rate (kbps)
ITU G.711	PCM (Pulse Code Modulation)	64
ITU G.729A	CS-ACELP (Conjugate Structure Algebraic-Code Excited Linear Prediction)	8
GSM FR	RPE-LTP (Regular Pulse Excitation Long-Term Prediction)	13

Table 5-1 VoIP codecs used in simulations

5.2 Results Analysis

The results found for each application are provided in the following four sections. Firstly, voice applications were discussed where loose coupling with G729A was found to provide better performance when considering overall QoS. Then ftp, email and http applications are discussed respectively.

5.2.1 Voice Applications

Three different codecs were used in this research as described in Table 5-1. For each codec, a 4ms frame size was used and two frames were included in a packet. In all, six simulations were carried out for two different architectures and three codecs used, and the statistical data was collected and is presented below.

The jitter for the three different VoIP codecs for both coupling schemes is shown in Figure 5-1. Jitter, the variation of packet or cell inter-arrival delay, is another factor which affects delay, especially during a handoff.

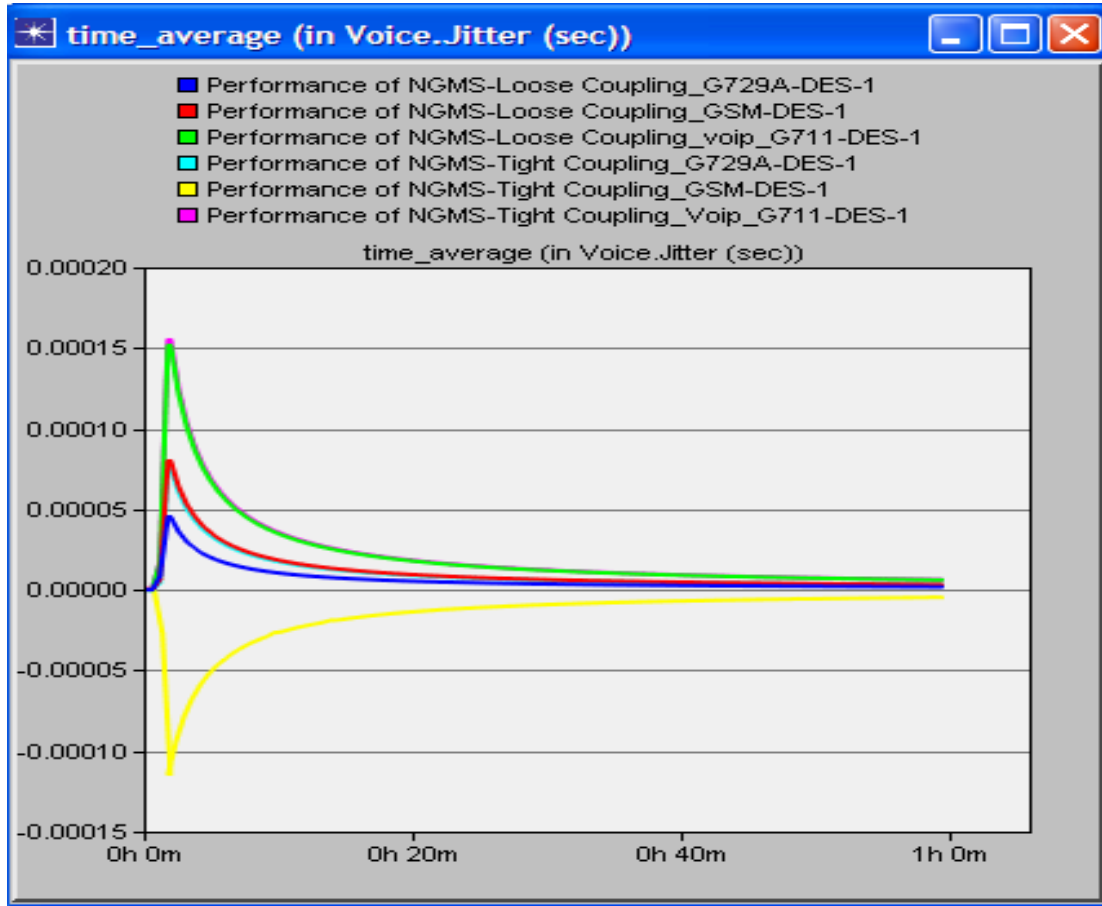


Figure 5-1 Jitter for Voice Applications

In this study the jitter was calculated, if two consecutive packets leave the source node with time stamps t_1 & t_2 and are played back at the destination node at time t_3 & t_4 , then:

$$\text{jitter} = (t_4 - t_3) - (t_2 - t_1)$$

Negative jitter indicates that the time difference between the packet arrival at the destination node was less than that at the source node.

It is evident from the simulation results that the voice capacity over a hybrid network is a function of the system parameters, voice packet payload length (depending on the codec used), and sampling period. In Figure 5-1, the horizontal axis shows the simulation time and the vertical axis shows the jitter average value over time. The G729A codec with loose coupling was found to provide better performance overall with less jitter. However, tight coupling with the GSM codec provides negative jitter when compared to the other codecs. At the beginning of the simulation, the jitter value was

noticeable different but as the simulation progressed, representing more traffic being sent in the stream, the average jitter value became similar for each codec.

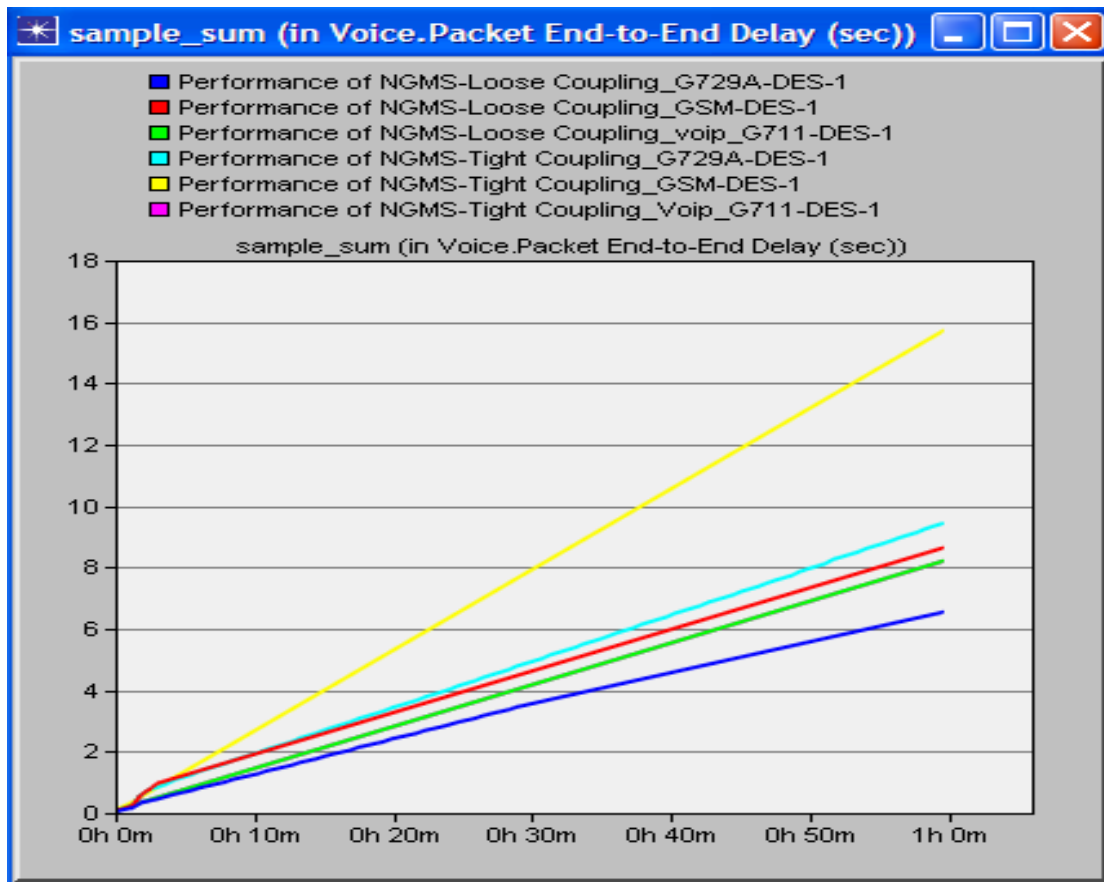


Figure 5-2 End-to-End Delay for voice applications

Figure 5-2 shows the End-to-End Delay for voice applications. End-to-End Delay was calculated as the total voice packet delay, called "analog-to-analog" or "mouth-to-ear" delay = network-delay + encoding-delay + decoding-delay + compression-delay + decompression-delay.

- Network delay is the time at which the sender node transmits the packet to RTP to the time the receiver receives it from RTP.
- Encoding delay (on the sender node) is computed from the encoder scheme.
- Decoding delay (on the receiver node) is assumed to be equal to the encoding delay.

-
- Compression and Decompression delays come from the corresponding attributes in the Voice application configuration. This statistic records data from all the nodes in the network.

In Figure 5-2, the horizontal axis shows the increasing simulation time from left to right and this corresponds to an increase in traffic and the vertical axis shows the End-to-End delay value. The G729A codec with loose coupling was found to provide better performance overall with less delay. At the beginning of the simulation the End-to-End delay was smaller and as the traffic increases End-to-End delay becomes more noticeable.

In Figure 5-3, the traffic received in both coupling scenarios for voice applications is shown. The horizontal axis shows the increasing simulation time from left to right representing increasing stream traffic and the vertical axis shows the amount of traffic received by the mobile user. The G729A codec with loose coupling was found to provide better performance by receiving more traffic to traffic received when using other codecs. This figure can also illustrate that the packet loss of the G729A codec is less than packet loss for other codecs.

The simulation results for tight coupling with GSM included negative jitter. However, considering the end-to-end delay and traffic received tight coupling with GSM was found to have greater delay and less traffic received when compared to loose coupling with G729A. From the results of Figure 5-1, Figure 5-2 and Figure 5-3, loose coupling with the G729A codec can be identified as the most appropriate scheme for the next generation heterogeneous networking framework.

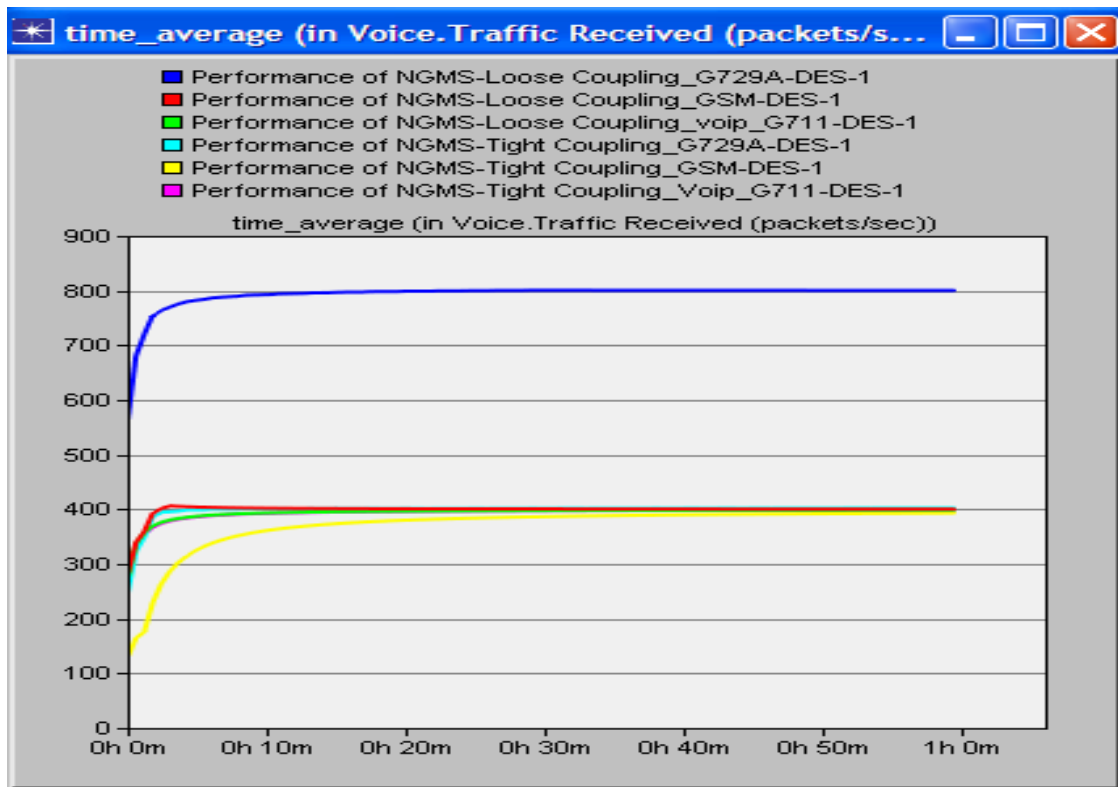


Figure 5-3 Traffic received for voice applications

5.2.2 FTP applications

Two different parameters were used to evaluate the performance of the FTP application.

- FTP upload response time and
- FTP download response time

For the FTP upload response time, the time elapsed between sending a file and receiving the response was measured. The response time for responses sent from a FTP server to the MS (user in this study) is included in the statistics presented.

For the FTP download response time, the time elapsed between sending a request and receiving the response packet was measured. The response time was measured from the time a client application (user in this study) sends a request to the ftp server to the time the MS receives a response packet. Every response packet sent from the ftp server to MS (user in this study) is included in this statistics presented.

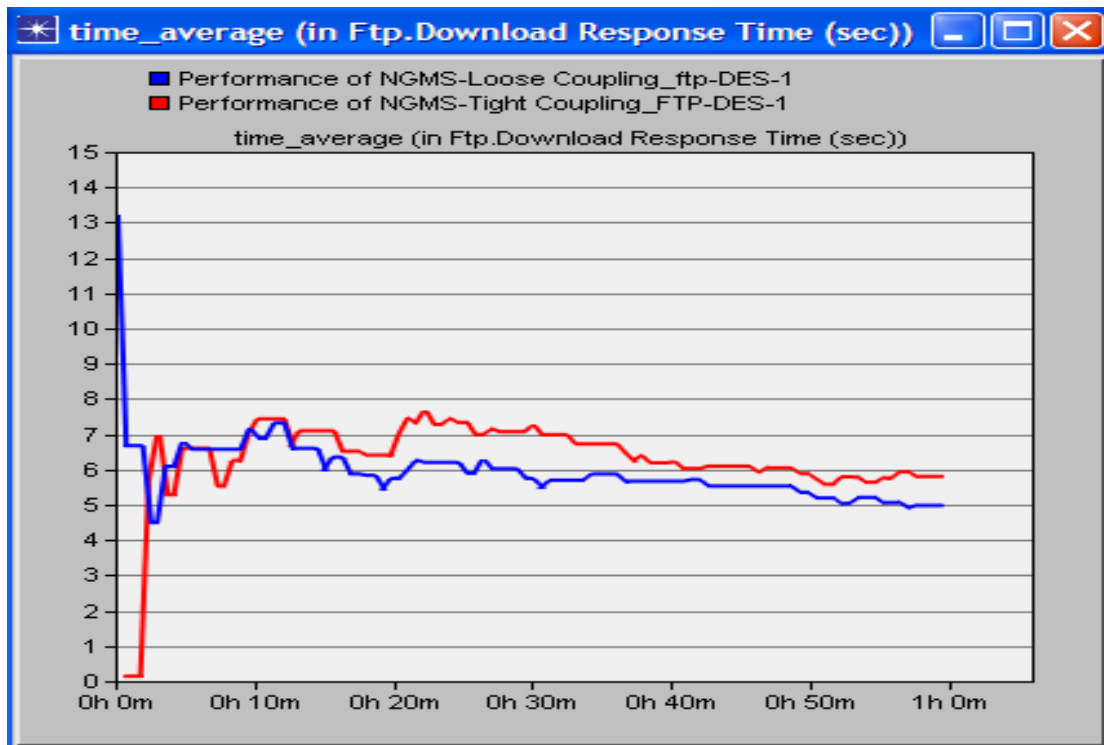


Figure 5-4 FTP response time to download

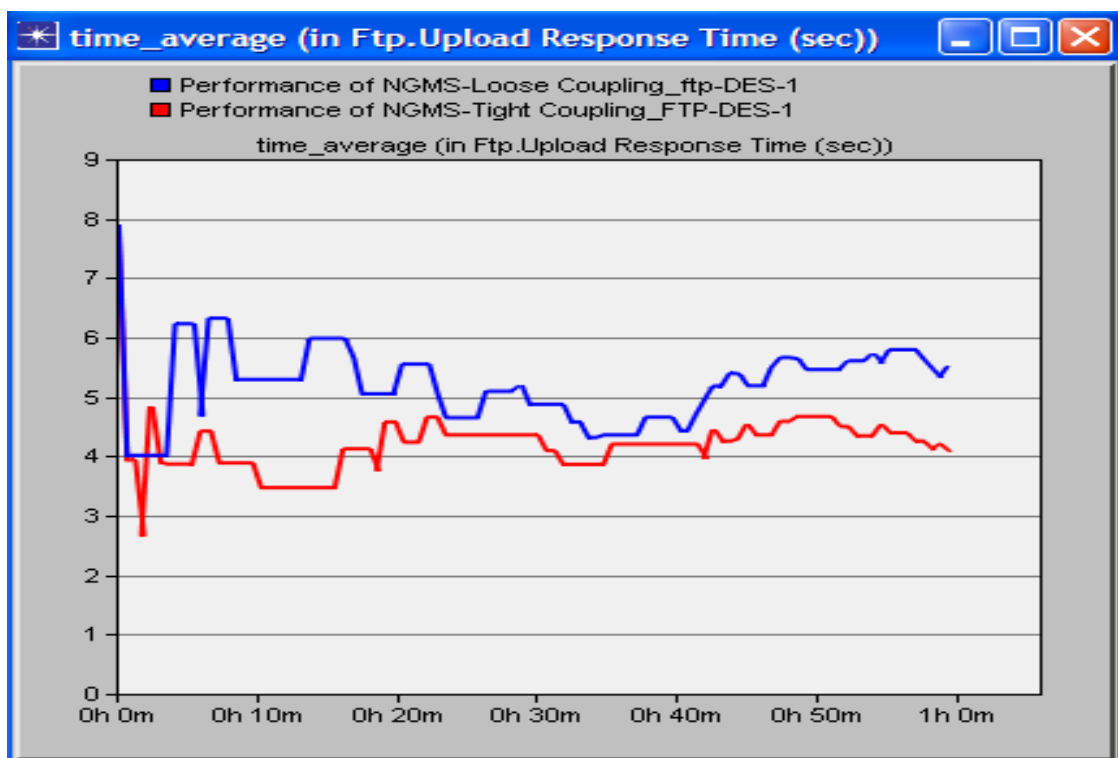


Figure 5-5 FTP response time to upload

In Figure 5-4, the graphs for the FTP response times are shown including the spike where the user sends the request to download the file from the ftp server. It is clear

from the graph that initially when there is less traffic the FTP download response time is low but as the simulation time passes more and more traffic is sent over the stream. The FTP transfer request which limits the networks resources is slower with more traffic and the response time increases. However if a comparison was made between the response times for the tight and loose coupling architectures then the loose coupling architecture is was found to have a lower FTP download response time. Figure 5-5 shows the FTP response time to upload a file and as the user load increases with time more traffic occurs and the loose coupling scheme is seen to take more time to get a response when requesting to send a file compared to tight coupling. As discussed in detail in Chapter 4 in the loose coupling architecture the AAA server and packet switched services of UMTS are a part of an IP cloud which explains why response time for downloading a file is less and to upload a file is greater when compared to the tight coupling architecture in which the AAA server is part of the RNC.

5.2.3 Email Applications

Two different parameters were used to evaluate the performance of the Email application.

- Email upload response time and
- Email download response time

For the Email upload response time the time elapsed between sending a request for email and receiving email from the email server is measured. This time includes a signalling delay for the connection setup.

For the Email download response time the time elapsed between sending email to the email server and receiving acknowledgments from the email server is measured. This time includes signalling delay for the connection setup.

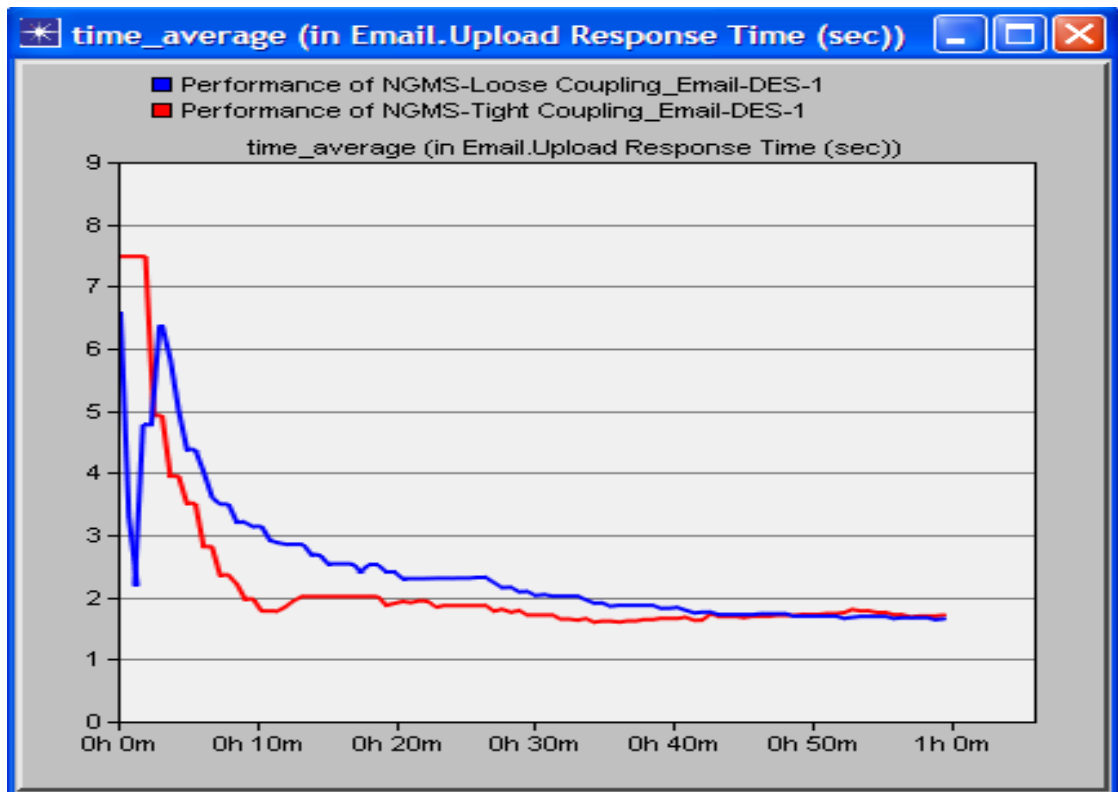


Figure 5-6 Email response time to upload

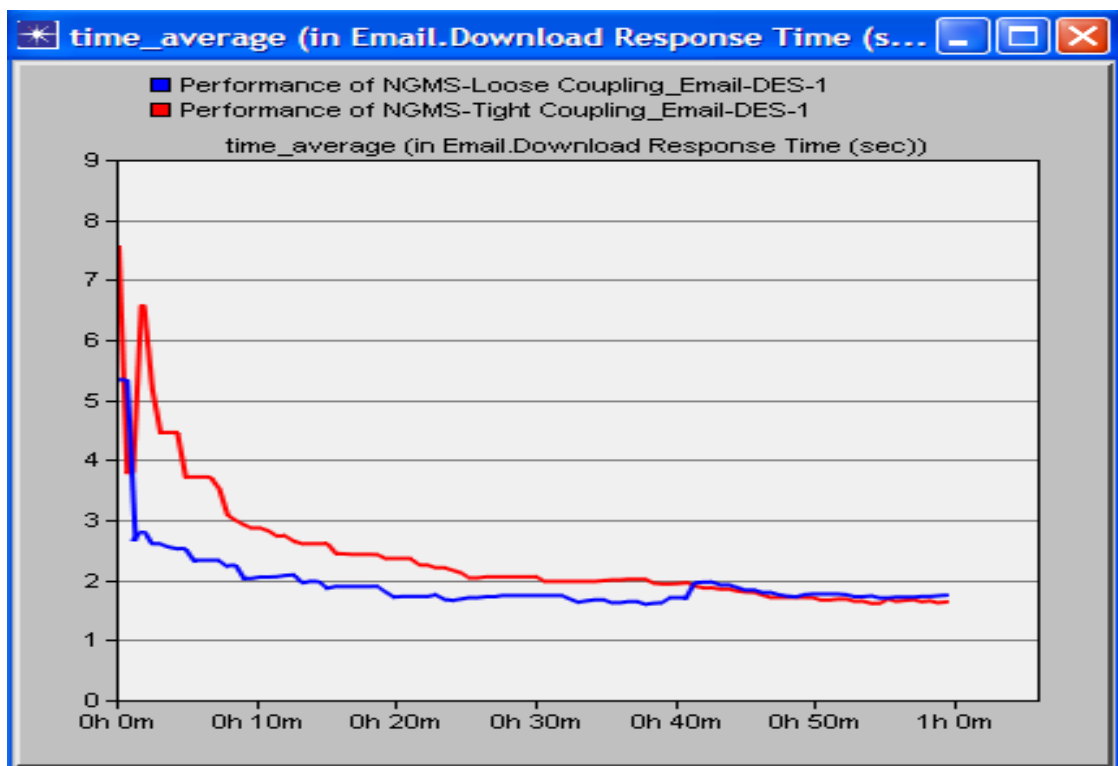


Figure 5-7 Email response time to download

In Figure 5-6 the graphs show the email response time including the spike where the user actually sends the request to upload email. It is clear from the graph that initially when there is less traffic the email download response time is high but as the simulation time passes more and more traffic is sent including more email requests and consequently the response time is lower. If a comparison was made between the response times for tight and loose coupling architectures then tight coupling architecture is seen to be better at the beginning of the simulation, however during the peak time loose coupling provides better performance due to a lower response time.

Figure 5-7 shows the response time to download an email from an email server and as the user load increases with time the response time for both coupling schemes decreases. During the peak traffic period, the loose coupling scheme takes more time to get a response for an email download request compared to tight coupling. However, initially when there was less traffic, loose coupling provides a lower response time to download email rather than tight coupling.

5.2.4 HTTP Applications

Two different parameters were used to evaluate the http application performance including:

- http object response time and
- http page response time

The http object response time specifies the response time for an inline object from a Hypertext Markup Language (HTML) page.

The http page response time specifies the time required to retrieve the entire HTML page with all of the inline objects.

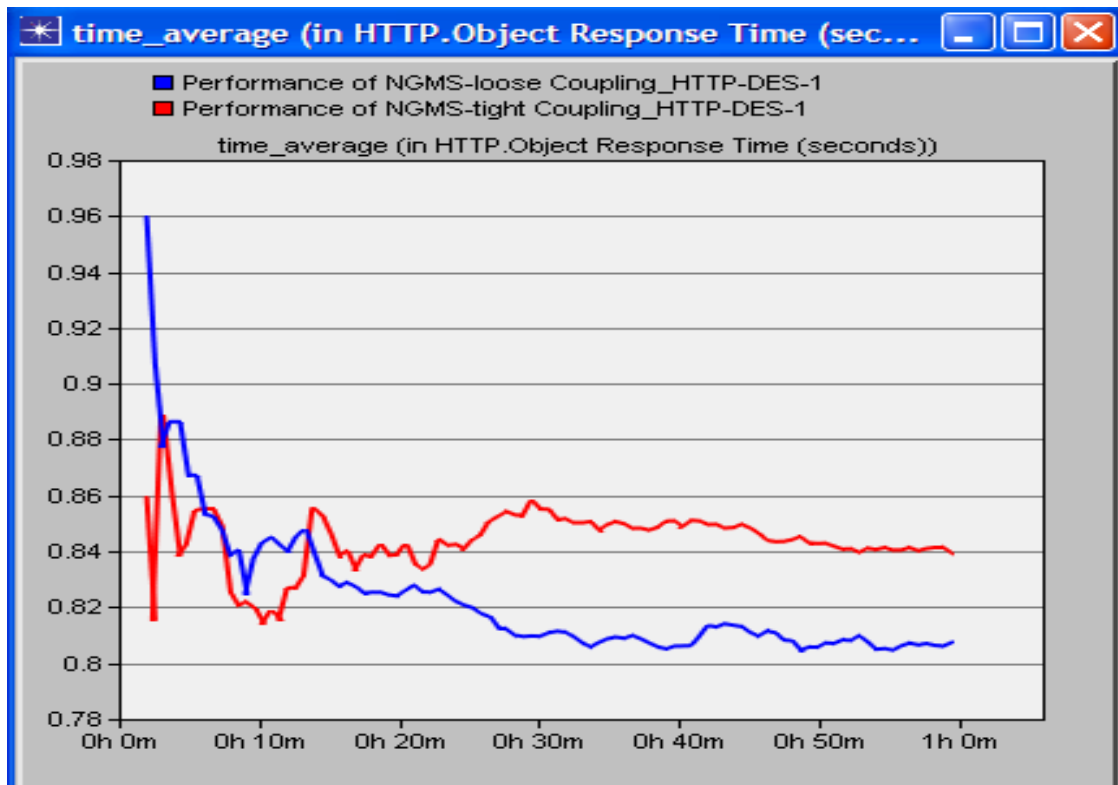


Figure 5-8 http object response time

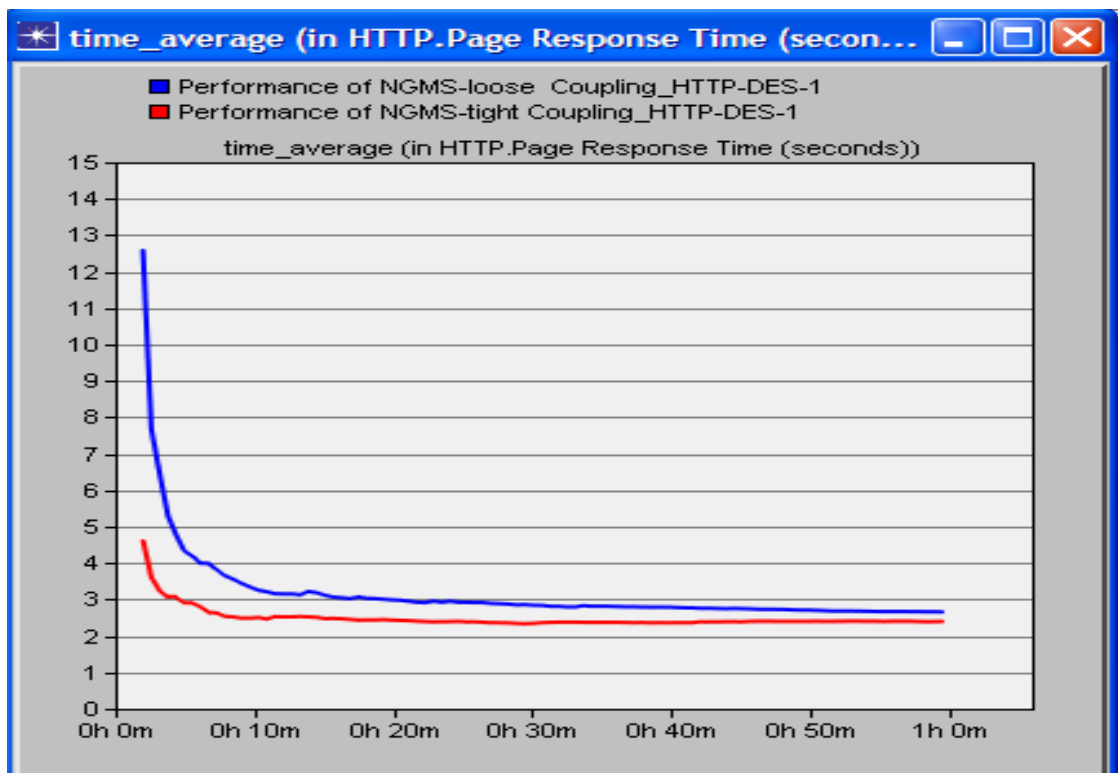


Figure 5-9 http page response time

Figure 5-8 shows the object response time for http traffic. The horizontal axis shows the increasing simulation time from left to right and the vertical axis shows the time for the object response. It is clear from the figure when there is less traffic at the start of the simulation the object response time is higher and as we move left to right the traffic increases and this causes a reduction in the http object response time. The simulation results show that the loose coupling architecture achieves a lower http object response time than tight coupling. Although, during periods of lower traffic, loose coupling takes a greater time to get a http object response from a HTML page.

In Figure 5-9, the horizontal axis shows the increasing simulation time from left to right and the vertical axis shows the time for a http page response. Where there is less traffic at the start of the simulation the object response time is higher and as we move left to right the traffic increases and this causes the http page response time to decrease. The results highlight that the tight coupling architecture is better than loose coupling due to a lower response time.

5.3 Comparison

As discussed in Chapter 2, Munasinghe and Jamalipour [JAMALIPUR 2008] have proposed an IMS based integration to integrate UMTS and WLAN where it can manage the real time sessions with the use of the IMS as a unified session controller. However, the study has not considered the authentication protocol and implementing an authentication protocol in an integrated network can make a significant difference to results. Munasinghe and Jamalipour propose an IMS-SIP (Session Initiation Protocol) based handover management for mobility [KUMUDI 2007]. However, the study still lacks the implementation of an authentication protocol thereby reducing the effectiveness of the research results.

From the research presented in the literature the G.723.1 and G.729 codecs appear to have the worst end-to-end delays. Furthermore, the research presented in the literature also found the G.723.1 and G.729 codecs to have the lowest jitter values. On the other hand, the research results presented in this section highlight that the G.729A codec has the lowest jitter and end-to-end delay compared to other selected codecs where authentication and mobility management were incorporated into the simulation scenarios. The ITU G.729A 8 kbit per second speech codec is a reduced-complexity

version of the ITU G.729 CS-ACELP speech vocoder and the performance is equivalent to G.729 in most operating conditions [RAZVAN 2005]. From this comparison, it is seen that the G.729A codec can be selected as a most suitable codec for integrating UMTS and WLAN. The study presented by Abu-Amara et al. evaluates the performance of UMTS/WLAN where the study included two coupling schemes: open and loose coupling [MARWAN 2008]. The authors used two different authentication schemes for both coupling schemes that do not meet the requirements of the 3GPP Scenario 2 [TS 23.234 2006]. In contrast, the research results presented here focus on performance with a common authentication and appropriate mobility management protocols. Abu-Amara et al. found that loose coupling provides better performance than open coupling considering a lower response time for ftp and http [MARWAN 2008]. Again in contrast, the research results presented here highlight that both coupling schemes are comparable to each other except for voice application loose coupling with the G.729A codec which provides better overall performance. The summarized results obtained from Opnet Modeller based simulations are tabulated in Table 5.2.

	Tight coupling	Loose coupling
Jitter	GSM	G729A
End-to-End delay	G729A	G729A
Traffic received	G729A	G729A
FTP download response time	Higher	Lower
FTP upload response time	Lower	Higher
Email download response time	Negotiable	Negotiable
Email upload response time	Negotiable	Negotiable
HTTP object response time	Higher	Lower
HTTP page response time	Lower	Higher

Table 5-2 Summary of simulation results

5.4 Summary

This chapter highlights that tight and loose coupling have advantages depending on the application. The results in this chapter highlighted the interworking architecture and the need to include authentication, access control and mobility management to ensure that the simulation results more closely reflect a real-world implementation of a hybrid network. For VoIP loose coupling with the G729A codec provides lower jitter and end to end delay. Loose coupling was also found to provide a lower response time for a http page although when fetching http objects, tight coupling provides a lower response time. Tight coupling provides a lower response time for ftp file uploads however to download ftp files loose coupling provides a lower response time. Tight and loose coupling were found to be comparable when downloading and uploading emails. To implement tight coupling, changes to the protocols used in WLAN are necessary. Loose coupling may be implemented more readily and provides simplicity and efficiency for 3G/WLAN integration.

6 Conclusion

The scope and objectives of this research were to investigate integration architectures for the NGMS. A performance analysis of various internet applications was carried out using integration architectures identified in this research. The internet applications used provide a reasonable range of traffic types and characteristics that were found to highlight positive and negative aspects of the integration architectures being studied. An important outcome of the literature review was the apparent lack of a complete analysis of an interworking architecture that more closely reflects the operation of a real-world system. To ensure the simulation results achieved were more accurate than results presented in the literature the interworking architecture included authentication, access control and mobility management. The scope and objectives of this research have been successfully achieved.

The research was presented at the ICCIT 2009 conference (IEEE sponsored), which was held in Dhaka, Bangladesh during December 2009. The conference paper [SAYED 2009] is provided in Appendix B. Another refereed paper was accepted at the ATNAC 2010 conference (IEEE sponsored), which will be held in Auckland, New Zealand between October 31- November 03, 2010 [ATNAC 2010]. A journal paper [Appendix C] has submitted to the IEEE TRANSACTIONS ON MOBILE COMPUTING [IEEE TMC 2010] in early June 2010.

The research focused on an analysis of Scenario 1 to Scenario 4 proposed by the 3GPP [TS 23.234 2006]. The research included the development of an architecture that would satisfy the 3GPP Scenario 1 to Scenario 4 requirements, and analyzed the performance of the proposed architecture using a range of internet applications that are different traffic types and have different traffic characteristics. The results provided in this thesis include:

- Background investigation of mobile wireless technologies and WLAN 802.11x.
- Anticipated requirements for next generation wireless mobile technologies.

-
- Proposed integration architecture and investigation of the integration architecture utilising:
 - Mobility Management
 - Authentication
 - Coupling based architecture for next generation wireless mobile network modelled using Opnet Modeller v15. A common authentication protocol and mobility management protocol was used.
 - Comprehensive comparison of two coupling techniques using a range of internet applications.
 - In tight coupling the GSM codec was found to be more appropriate for voice applications based upon certain QoS measures.
 - In loose coupling the G729A codec was found to be more appropriate for voice applications based upon certain QoS measures.
 - The research identified the need to carry out further research on how to reduce http object and ftp file download response times when using tight coupling.

The concept of integrating two or more access networks to provide faster services to mobile users is not new. The compatible system which is interoperable with IPv6 and with various access technologies such as IEEE 802.11x is required for the next generation mobile system. The current growth of WLANs worldwide has yielded a demand to integrate with existing 3G mobile technologies [TS 23.234 2006]. Throughout recent years there has been development of the technologies needed to achieve high speed data transmission in cellular wireless mobile networks. As a result, HSDPA and HSUPA provide increased performance by using improved modulation schemes and by refining the protocols by which handsets and base stations communicate. These improvements lead to a better utilization of the existing radio bandwidth provided by 3G. HSPA is a collection of two mobile telephony protocols HSDPA and HSUPA that extend and improve the performance of existing 3G protocols. It improves the end-user

experience by increasing peak data rates up to 14 Mbps in the downlink and 5.8 Mbps in the uplink [K. FREUDENTHALER and JOACHIM2006].

However, these techniques are incapable of meeting the demand of the ubiquitous data services and very high data rates as 100 Mbps or more for the next generation wireless mobile system. This is the motivation to integrate UMTS and WLAN to meet the requirement for high speed data in the NGMS.

The first stage of the research was to design and develop the initial architecture for interworking the UMTS and the WLAN system. In the literature review four possible couplings were found that may be used to integrate UMTS and WLAN: (1) Open coupling, (2) Loose coupling, (3) Tight coupling and (4) Very tight coupling.

The second stage of the research further extended the existing frameworks to be capable of meeting the 3GPP proposal [TS 23.234 2006]. Then the research was focused on the six scenarios proposed by 3GPP for interworking a UMTS and the WLAN system. The first scenario is similar to open coupling, where a different authentication management technique was used. The second scenario, where common authentication was proposed and loose coupling with EAP-AKA was found to be appropriate. The third scenario extended 3G Packet switched access services to subscribers in the WLAN environment and loose, tight and very tight coupling could be selected for this scenario. Very tight coupling was found to be a complicated solution which is why it was not selected as an appropriate solution for this scenario. The fourth scenario is where a user can start a WAP session from WLAN and may utilize this session after moving to a UMTS network and vice versa. Again, loose and tight coupling were found appropriate for this scenario where Mobile IP was used for handover management. Scenarios five and six are beyond the scope of this study as they do not meet the scope of the current goals.

The research highlighted that loose and tight coupling are possible techniques for the NGMS. The third stage of the research was to evaluate the performance of both loose and tight coupling using Internet applications with different traffic types and different traffic characteristics.

The final and last stage of this study was to propose an integration framework depending on the performance of both loose and tight coupling where EAP-AKA was used for common authentication and Mobile IP was used for mobility management.

Results were presented and discussed in Chapter 5. Loose coupling with the G729A VoIP codec was found to provide better performance overall with less jitter and end to end delay. Also, this approach received higher traffic when compared to the other approaches studied. Tight coupling with GSM included negative jitter, however, greater End-to-End Delay and less received traffic were key outcomes that led to the research outcome that a loose coupling framework with the G729A codec for voice application is suitable for use in the NGMS.

Considering the results found for Internet applications, both loose and tight coupling frameworks were found to be generally similar. When downloading files using the ftp application it was found that loose coupling had a lower response time. However, at the beginning of the simulation when traffic was reduced loose coupling was slower to get a response when compared to tight coupling. As traffic increased the results showed that tight coupling was not as responsive as loose coupling. On the other hand, for uploading files the simulation results showed that tight coupling had a lower response time than loose coupling. For an email application, both coupling schemes provided roughly equal response times though at the beginning of the simulation when traffic was lower the loose coupling scheme provided a lower response time when compared to tight coupling. However, during peak traffic period as the simulation progressed the response time for both coupling schemes decreased. For a http application, the page response time using tight coupling had a lower response time than loose coupling, though for a http object the loose coupling response time provided better performance due to a lower response time.

People are always looking for faster, cheaper access solutions to the Internet. The role of 3G-WLAN in future networks will be compatible with the role of 4G LTE, WiMAX and other 4G implementations when integrated with WiFi and other wireless variants and provide users with access to the Internet while they are on the move or away from their desk or office promises and thereby deliver many benefits for corporate entities and consumers. The results of this research are directly applicable to the development of new hybrid networks utilising 4G technologies in conjunction with higher speed hotspot wireless technologies such as WiFi (802.11x).

In summary this research highlights that tight and loose coupling both have advantages depending on the application studied. The reason for the variability in results is found in the way the coupling technique affects traffic flow, handoff, authentication and mobility. To implement tight coupling changes to the current protocols used in WLAN are necessary. Loose coupling may be implemented more readily and thus providing simplicity and efficiency for 3G/WLAN integration.

7 Future Work

A number of future research topics were identified during this research. Future research may include further investigation of the two architectures, tight coupling and loose coupling. The following is a suggested list of possible research directions.

- Tight coupling was found to be generally unsuitable for voice applications. Since tight coupling has advantages with regards to other applications, a new VoIP codec may be designed to improve voice application performance using tight coupling. The new codec may reduce End-to-End Delay and reduce packet loss by increasing traffic received.
- Prospective research work may include how to reduce the http object and ftp file download response times for loose coupling.
- Loose coupling with G729A was found to be an appropriate framework for voice applications in a next generation mobile system. Jitter was found to be higher for loose coupling than tight coupling when used with the GSM codec. To reduce the jitter in loose coupling the G729A codec may be modified as possible future research work.
- Potential research work may include how to reduce the http page and ftp file upload response time for loose coupling.
- An integrated UMTS/WLAN network provides an opportunity for competing overlapping network providers to manage their customer pricing model based upon factors such as total traffic, traffic flowing to the overlapping network and QoS. An optimal pricing scheme can be proposed for bandwidth sharing in an integrated UMTS/Wi-Fi network using Game theory [DUSIT 2007].
- Future research may include development of a cost effective dual mode terminal for NGMS. Two proposals were found in the literature review for dual mode terminals, one is [ASHRAF 2008], where the authors proposed two new nodes in the protocol stack of the mobile terminal. One node is in the IP layer and another one is in the data link layer. The second proposal included an IP switching layer

between the IP layer and data link layer in the protocol stack [SIDDDQUE 2005]. A new proposal may be developed by modification of IP layer of the mobile terminal without adding further protocol layers or nodes.

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Appendix A

EAP-AKA and Mobile IP in Opnet

This section presents the configuration of EAP-AKA and mobile IP in Opnet modeller. At first task definition has dragged from object palette to the scenario. After that a name has made by using set name. The next step was to specify the task. From edit attributes the tasks has assigned by using task specification (figure A1). Then task has configured.

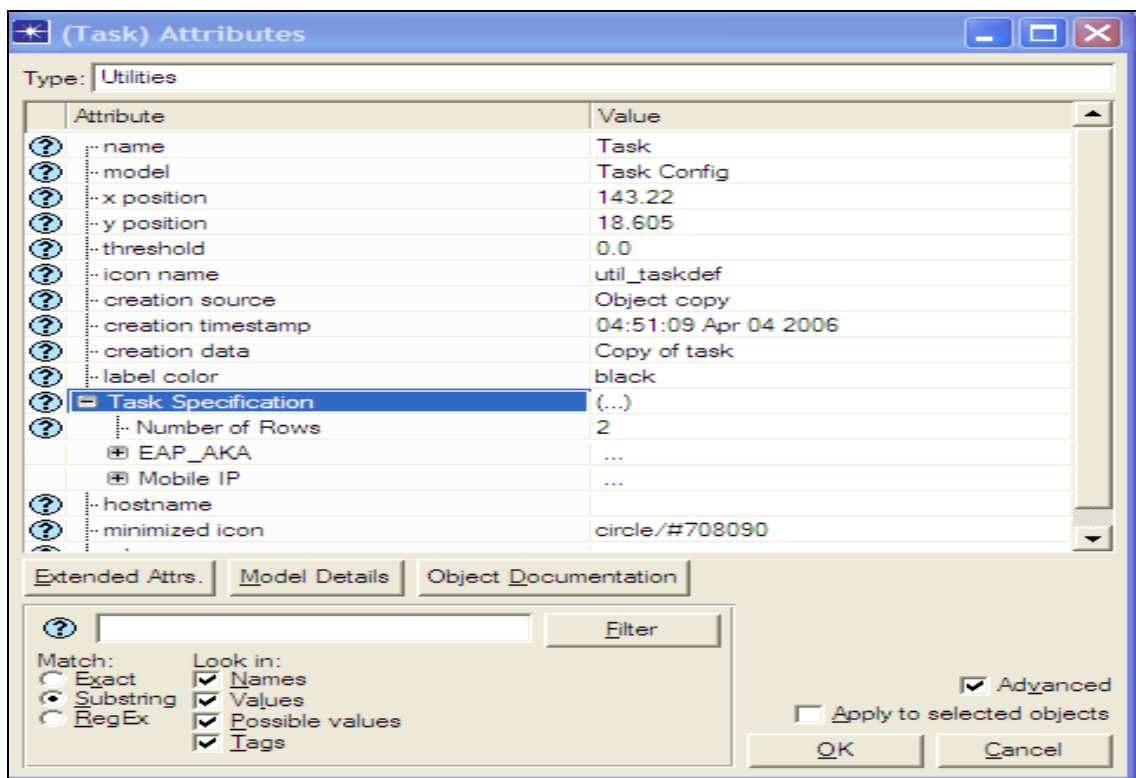


Figure A-0-1 Task Specification

- Configuring EAP-AKA task by using manual configuration from task attributes.

(Task) Attributes

Type: Utilities

Attribute	Value
y position	18.605
threshold	0.0
icon name	util_taskdef
creation source	Object copy
creation timestamp	04:51:09 Apr 04 2006
creation data	Copy of task
label color	black
Task Specification	(...)
Number of Rows	2
EAP_AKA	
Task Name	EAP_AKA
Manual Configuration	(...)
Connection Policy	Refresh After Task
ACE Filename	Not Applicable
ACE Parameters	Not Applicable

(Manual Configuration) Table

	Phase Name	Start Phase After	Source	Destination
App Starts	App Starts	Application Starts	Originating Source	AAA
EAP req	EAP req	Previous Phase E...	AAA	Originating Source
EAP response	EAP response	Previous Phase E...	Originating Source	AAA
EAP response	EAP response	Previous Phase E...	AAA	3GAAA
Req Security	Req Security	Previous Phase E...	3GAAA	HLR
Retrieve Security	Retrieve Security	Previous Phase E...	HLR	3GAAA
EAP req	EAP req	Previous Phase E...	3GAAA	AAA
EAP req	EAP req	Previous Phase E...	AAA	Originating Source
EAP response	EAP response	Previous Phase E...	Originating Source	AAA
EAP response	EAP response	Previous Phase E...	AAA	3GAAA
EAP success	EAP success	Previous Phase E...	3GAAA	AAA
EAP success	EAP success	Application Starts	AAA	Originating Source

12 Rows

☒ Show row labels

Figure A-0-2 EAP-AKA Task configuration

- Configuring Mobile IP task by using manual configuration from task attributes.

Next, the application has defined in the application attribute and configured the Custom task definition considering the following step. Figure 8-4 and 8-5 describes the step to define the manual tasks in application definition.

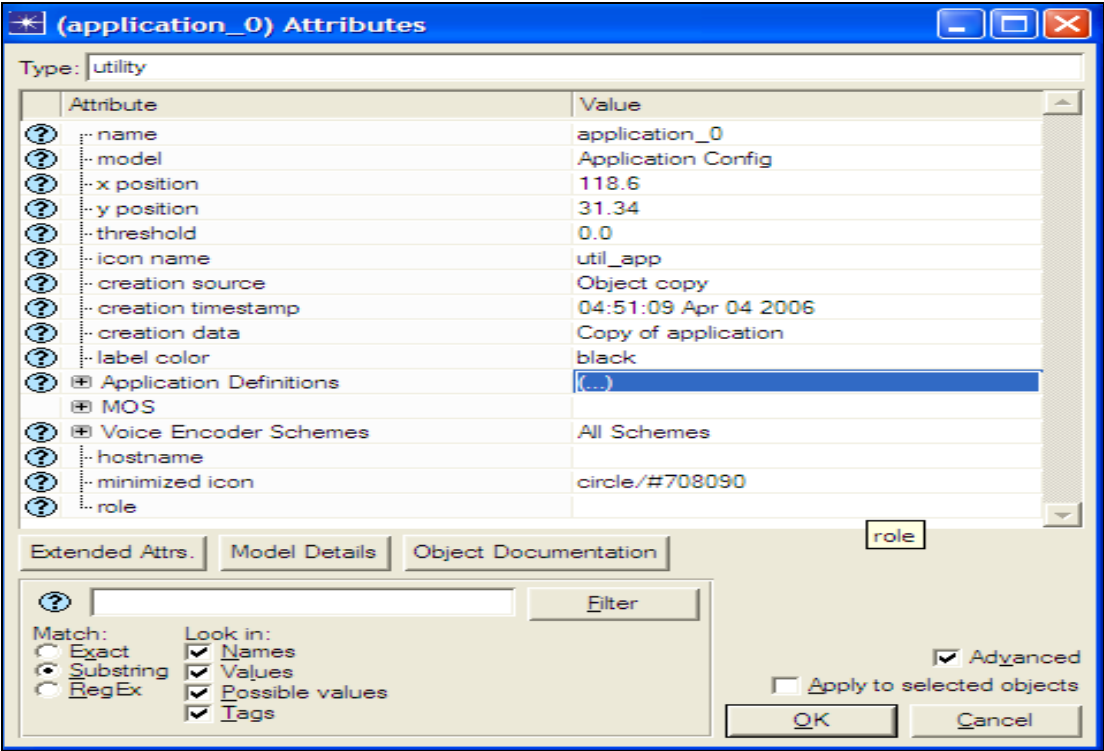


Figure A-0-4 Application Definition

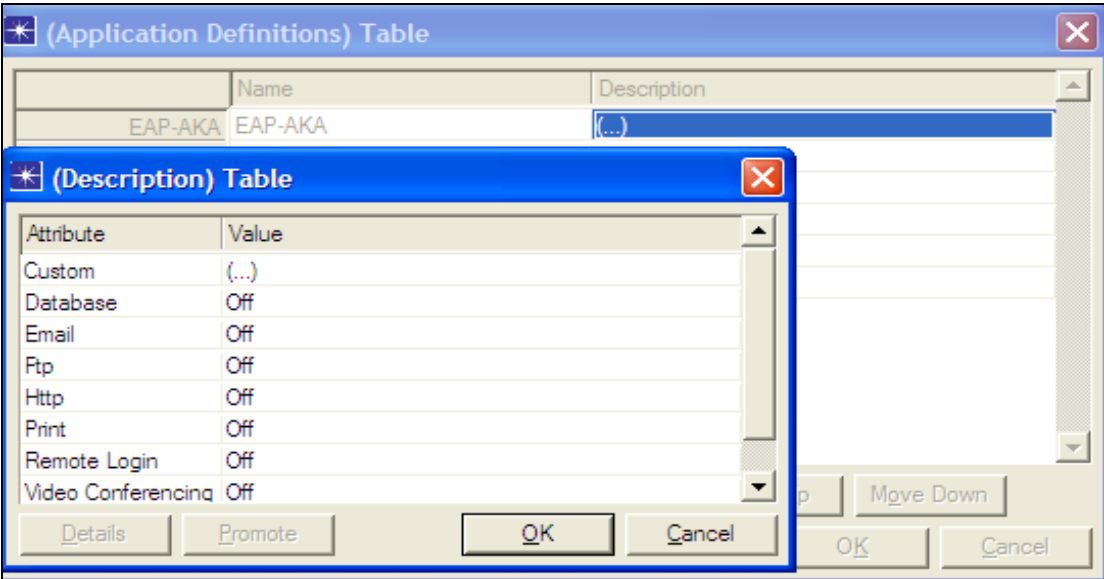


Figure A-0-5 Custom task definition

Figure 8-5 and 8-6 describes the step to custom table for manually configured tasks.

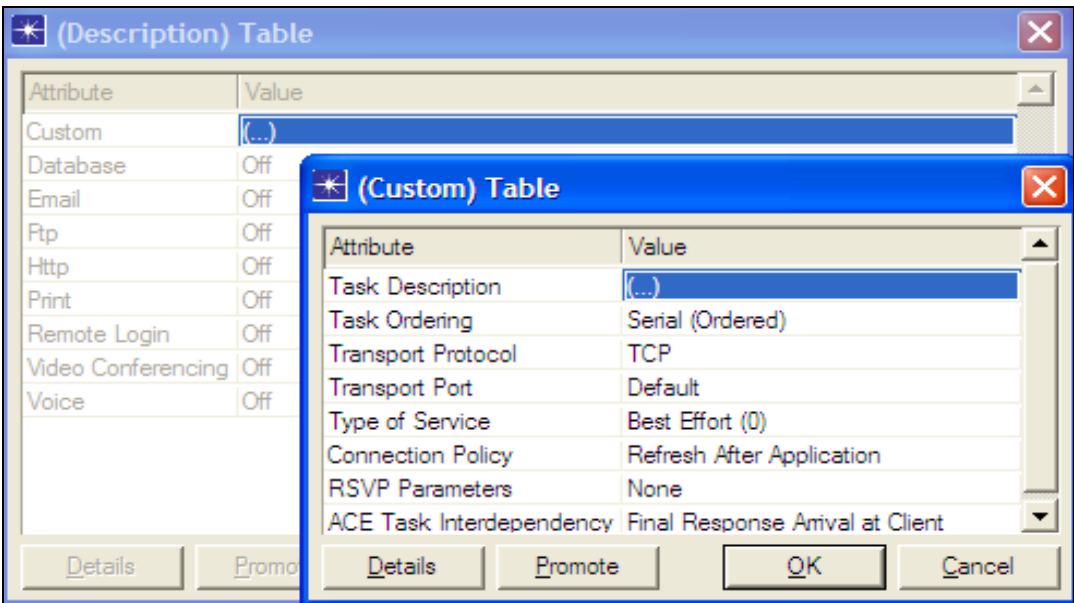


Figure A-0-6 Custom table

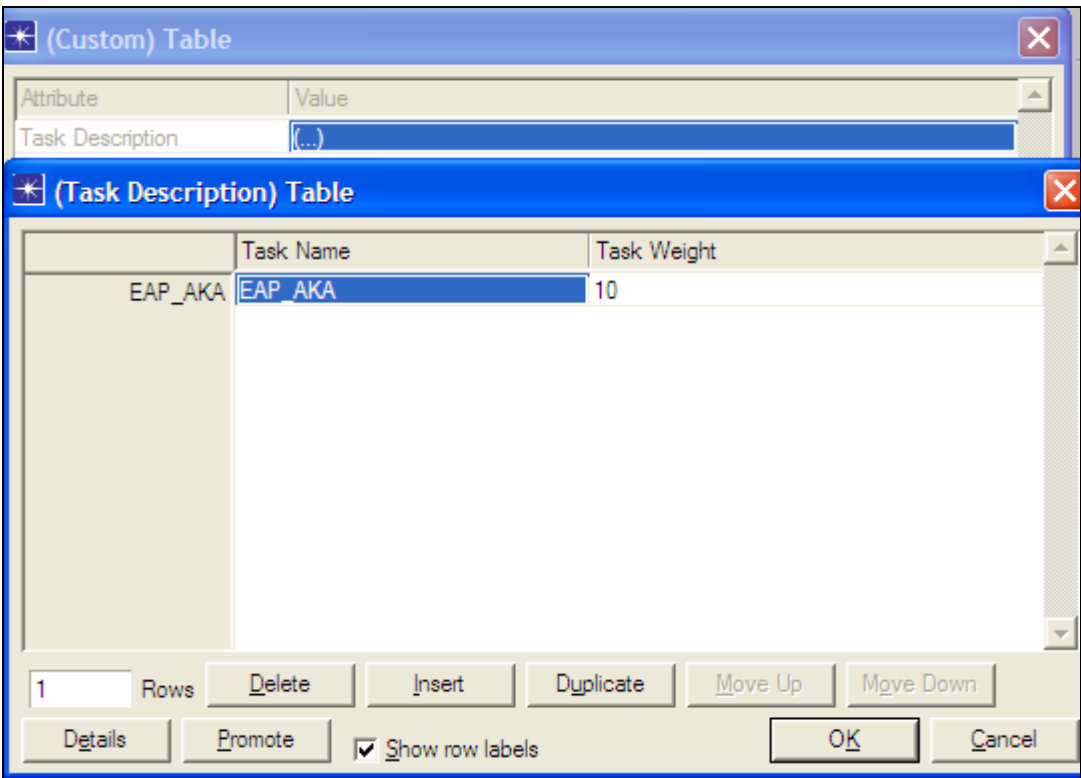


Figure A-0-7 Task description table

Task Weight

When multiple tasks are contained in an application and they are configured to run in a random order, task weight is used to decide the probability with which a task is chosen. Task weight can be any integer number. Internally all the task weights will be normalized.

Next, a profile definition has set up for all the applications used in this research. The profile configuration is same to application configuration. Figure A-8 shows the profile definition has made for this research.

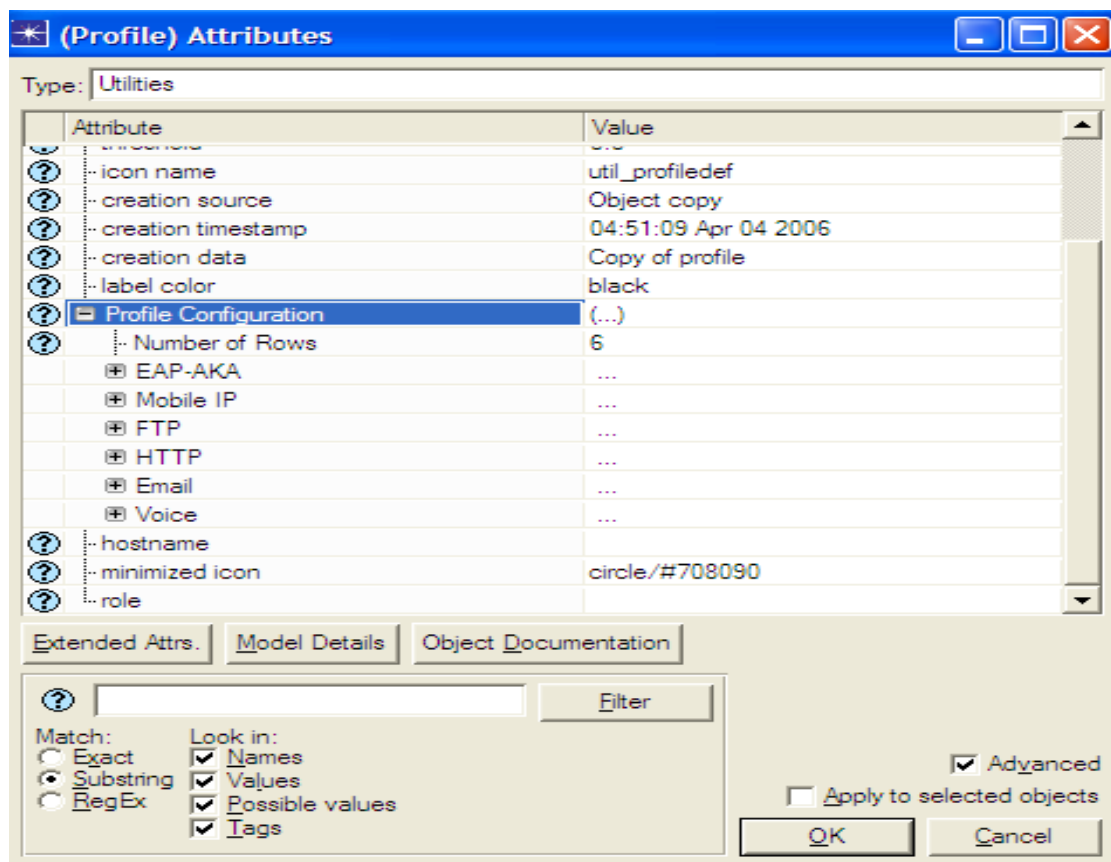


Figure A-0-8 Profile Definition

After that the tasks has assigned for user by using destination preference.

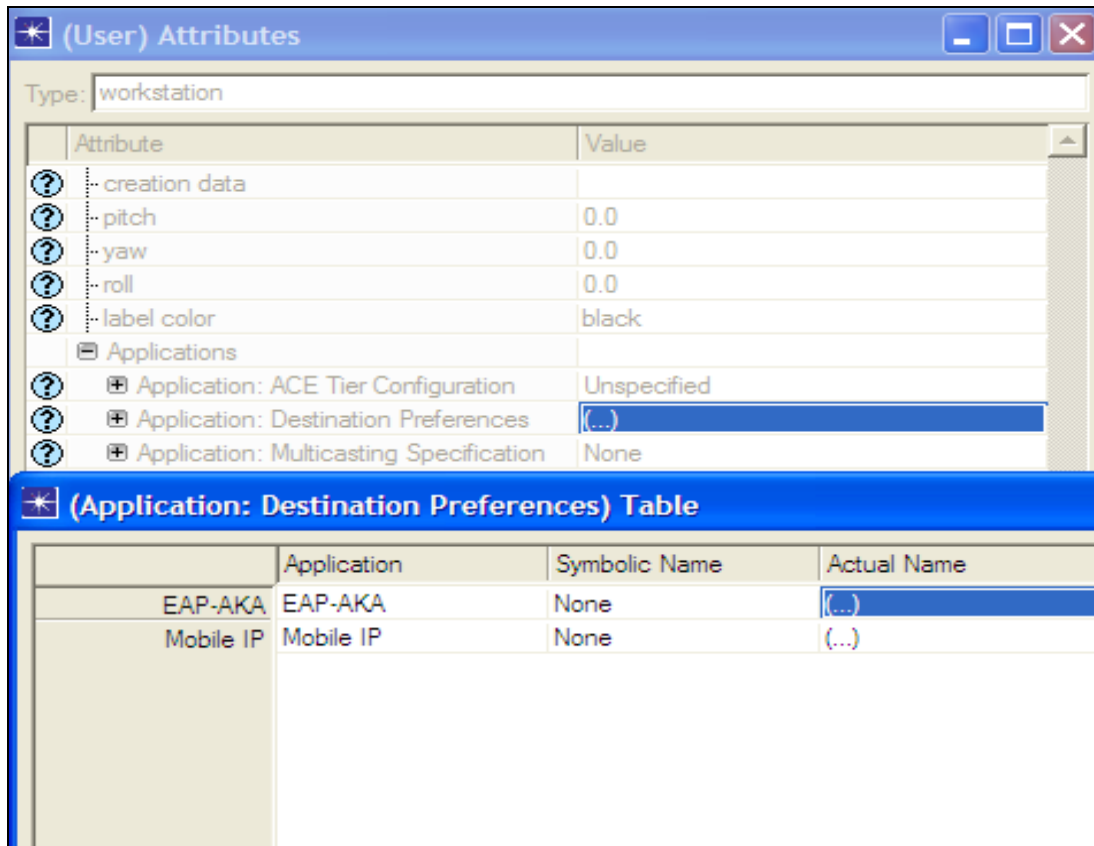


Figure A-0-9 Destination table

Appendix B

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PERFORMANCE EVALUATION OF HETEROGENEOUS NETWORK FOR NEXT GENERATION MOBILE

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Abstract

It is a universally stated design requirement that next generation mobile systems will be compatible and interoperable with IPv6 and with various access technologies such as 802.11x. The current growth of WLANs worldwide has yielded a demand to integrate with existing 3G mobile technologies. Interworking incorporates all of the best features of an individual network into a single integrated system thus providing ubiquitous data services with high data rates in WLAN hotspots. The attempt to build hybrid networks has been linked with many technical challenges such as seamless vertical handovers across WLAN/3G radio technologies, security, common authentication, unified accounting & billing, etc. This paper evaluates the performance of two 3G/WLAN integration schemes: Tight and Loose Coupling. Mobile IP is used as a mobility management scheme and EAP-AKA for common authentication.

Keywords: WLAN, 3G, Mobile IP, EAP-AKA, VOIP Codec.

I. INTRODUCTION

One of the goals for next generation mobile systems is to provide better access and integration with existing Internet Protocol (IP) based networks. Successful integration of the third-generation cellular network (3G) and wireless local area networks (WLAN 802.11x) would be a

step along the path towards a next generation network. The 3G network aims to provide customers with a highly developed global service providing circuit switched or packet switched traffic; new mobile multimedia services (e.g. streaming/mobile TV, location base services, downloads, multi-user games) giving more flexibility for the operator to introduce new services to its portfolio and from the user point of view, more services and a variety of higher, on-demand data rates compared with the previous 2.5-2.75G mobile system. However existing 3G implementations have a moderate data rate and high-priced wide area deployment. WLAN on the other hand have been deployed in small areas or hotspots and are cost-effective, easy to deploy and provide high data rates in an unlicensed frequency band. WLAN was not designed for wide area deployment. In order to provide large varieties of services at high data rate in the hotspots and campus-wide areas, 3G service providers regard WLAN as a technology to compliment their 3G system. Thus, efficient authentication and a mobility management scheme are crucial to support a heterogeneous domain and a seamless

handover scheme is needed to ensure the success of 3G/WLAN interworking. The concept of integrating two or more access networks to provide ubiquitous service to mobile users is not new. Considerable research has been completed focusing on interworking issues between WLAN and the Universal Mobile Telecommunication System (UMTS) networks including 3G mobile networks [1-5]. In heterogeneous network literature, a terminal with a double communication capability allows the user to switch connection from one radio access network to another without packet loss [6, 7]. Studies may be found on the performance of these hybrid WLAN/UMTS networks for various internet applications. For example, Song and Jamalipour [8] focus on the performance of a network selection algorithm rather than individual traffic sessions. The performance of a loose coupling architecture with regard to the continuity of real-time video traffic for UMTS connections was modelled by Salkintzis, et al. [9]. Kumudu and Abbas [10] have proposed an IP Multimedia Subsystem (IMS) based integration where the system presented can manage real time sessions with the use of the IMS as a unified session controller. In [4], Salkintzis proposed architectures that enable 3G subscribers to benefit from high throughput IP connectivity in strategic hotspot locations. Salkintzis also discussed authentication, authorisation, accounting (AAA) signaling for interworking 3G/WLAN rather than analysing performance. Finally, Abu-Amara, et al. [11] present the performance of loose coupling and open coupling with two mobility schemes. The results presented by Abu-Amara, et al. provided the motivation to analyse the performance of loose coupling and tight coupling with various internet applications. The paper is organized as follows: Section ii provides an overview of

3G/WLAN interworking; Section iii presents the mobile IP based interworking; Section iv presents the authenticate key agreement scheme for the integration of 3G/WLAN; Section v briefly describes the system being tested; Section vi describes the simulation strategy for the network design and Section vii provides a discussion of the simulation results. Finally, in Section viii conclusions are presented.

II. Overview of 3g-WLAN INTERWORKING

UMTS/WLAN is currently being studied within the 3GPP [12]. Until now, WLAN is mainly operated as an extension of the 3GPP access network. A literature review highlighted four interworking architecture approaches: tight coupling, loose coupling, open coupling and very tight coupling.

A. Open Coupling

In an open coupling scheme WLAN and UMTS use their own separate access and transport networks and billing and user management occurs through different authentication mechanisms.

B. Loose Coupling

In a loose coupling scheme the use of a common authentication mechanism provides a link between the authentication, authorisation and accounting (AAA) server in the WLAN network and the Home Location Register (HLR) in the UMTS network. In other words, loose coupling provides the subscribers with access to the 3G based packet services without making any changes to the WLAN and UMTS protocols. The key element to support mobility management in this architecture is mobile IP [13]. However,

there are other variants to this coupling, which may involve the user data traffic being routed to the UMTS Core Network (CN) [3, 4]. The data traffic is routed directly via an IP network which is an advantage of this method.

C. Tight Coupling

The tight coupling scheme integrates two networks at the CN level where a WLAN Access Point (AP) is connected as a Radio Network Controller (RNC) to the UMTS Service GPRS Support Node (SGSN) to support the handover between WLAN and UMTS networks. In other words, tight coupling makes two different radio access technologies work together with a single core network. The key functional element in the system is the handover between a WLAN and a UMTS network and this may be likened to the handover occurring between two individual wireless network cells. The tight coupling integration scheme includes the reuse of UMTS AAA mechanisms, usage of common subscriber databases and billing systems, and increased security features (since the UMTS security mechanisms are reused). Tight coupling provides for the possibility of continuous sessions as users move across the two networks, since the handoff in this case is very similar to an intra-UMTS handoff as the WLAN AP appears as another RNC to the SGSN node. An obvious benefit of this approach is that the UMTS mobility management techniques can be directly applied.

D. Very Tight Coupling

The very tight coupling approach is the same as that in the tight coupling scheme with the addition that the WLAN AP is connected to the RNC.

III. Mobile IP Based Interworking

Mobile IP is one of the most popular network layer solutions for IP network mobility and it fulfils the requirement to maintain internet connectivity throughout user sessions. When integrating 3G and WLAN, mobile IP is employed to restructure the connections while a Mobile Station (MS) moves from one network to another, eg. from UMTS to WLAN. Outside of the UMTS network, the MS is identified by a Care of Address (COA) associated with its point of attachment to the UMTS network. Encapsulation and packet delivery is managed by a collocated foreign agent. In a loose coupling scheme network integration mobile IP is used to support mobility management.

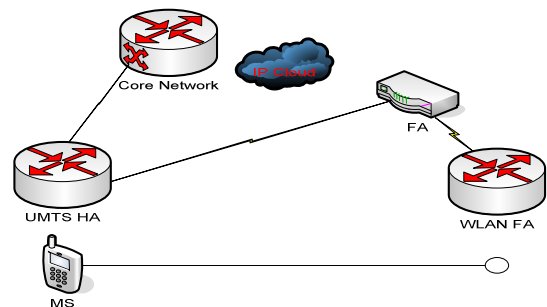


Fig. 1. Mobile IP showing session continuity with handover

IV. Authenticate Key Agreement

EAP-AKA was proposed by the 3GPP to provide access security for 3G/WLAN interworking [14]. It is based on the UMTS-AKA mechanism. In the EAP-AKA scheme the 3G home domain does not delegate the responsibility for authentication to the WLAN network. EAP-AKA was used for authentication of 3G/WLAN during the simulations presented in this paper. A successful EAP-AKA procedure is illustrated in Figure 2.

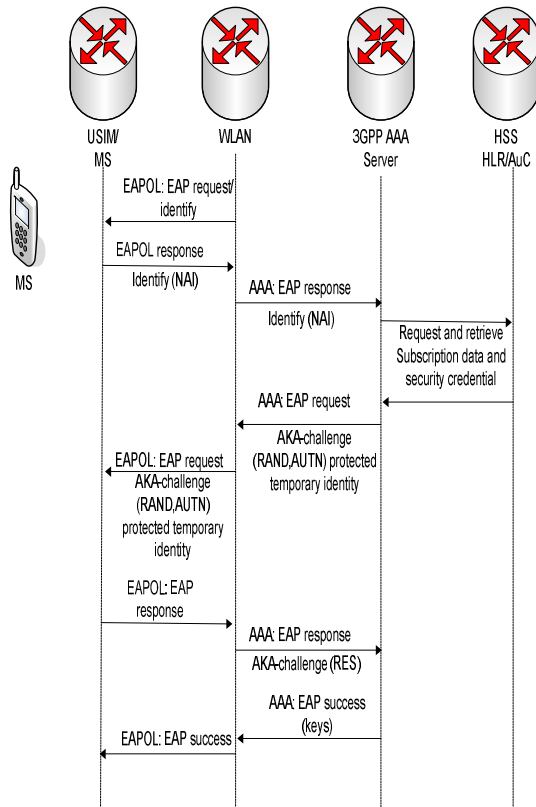


Fig. 2. EAP-AKA Procedure

V. VOIP Codec

A codec (Coder/Decoder) converts analogue signals to a digital bit stream, and another identical codec is placed at the far end of the communication system to convert the digital bit stream back into an analogue signal. In a Voice over IP (VoIP) system, codecs are used to convert voice signals into digital data to be transmitted over the Internet or any IP based digital network supporting VoIP calls. Some codecs also support silence suppression, where silence is not encoded and transmitted. In Table 1 the codecs that were used in the simulation are identified.

Table I Simulation VoIP Codecs

Codec	Algorithm	Bit rate (Kbps)
ITU G.711	PCM (Pulse Code Modulation)	64
ITU G.729A	CS-ACELP (Conjugate Structure Algebraic-Code Excited Linear Prediction)	8
GSM FR	RPE-LTP (Regular Pulse Excitation Long-Term Prediction)	13

VI. Simulated Network Design Architecture

This section describes the simulation model and the applications used to evaluate the performance of tight and loose coupling. In this research Opnet Modeler 15.0 [15] was used to simulate the hybrid UMTS and WLAN network. OPNET is a very flexible tool which provides drag and drop facilities for the communication devices like (routers, user equipments, and servers), interconnecting models (ATM link, fiber optics, both wired and wireless LAN and PPP links) and multiple protocols. However, Opnet doesn't provide some of the major components needed in the network such as AAA, HLR, 3GAAA, Mobile IP under UMTS model and the EAP-AKA protocol. All of the additional components have been developed during this research. Two network scenarios were developed and the first included a tight coupling scheme and the second included a loose coupling scheme.

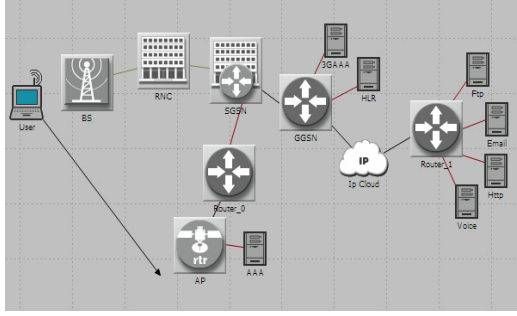


Fig. 3. Tight Coupling

A 3G model was combined with a 802.11g model to evaluate the network performance. In the tight coupling scheme a WLAN AP was connected through a router to a UMTS CN at the SGSN node while in the case of the loose coupling scheme the AP was connected through the router to an IP cloud. The service applications used in the simulation were added to the network design and the applications included ftp, http, email and VoIP. The network design for the two scenarios is shown in Figure 3 and Figure 4.

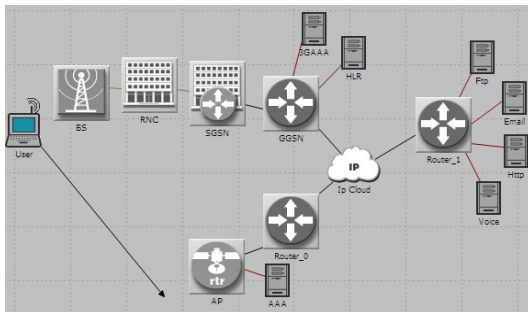


Fig. 4. Loose Coupling

VII. Result Analysis

In this section the simulation results will be presented and discussed. Figure 5 shows the jitter for the three different VoIP codecs used for both coupling schemes. Jitter, the variation of packet or cell inter-arrival delay, is another factor which affects delay, especially during a handoff.

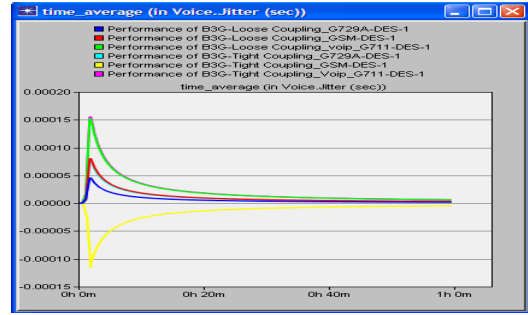


Fig. 5. Jitter for 3G/WLAN

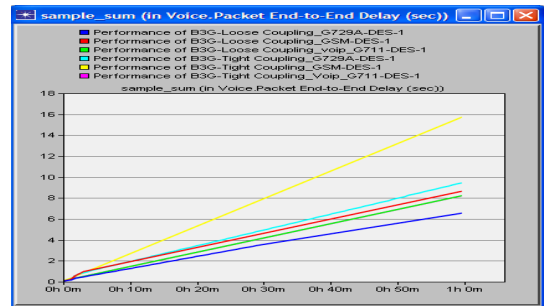


Fig. 6. End to End Delay for a VoIP application

Figure 6 shows the end to end delay for voice packets. From the result of Figure 5 and Figure 6, loose coupling with G729A give a better performance overall with less jitter and end to end delay. The simulation results for tight coupling with GSM included negative jitter. Negative jitter indicates that the time difference between the packets at the destination node was less than that at the source node. However, considering the end-to-end delay tight coupling with GSM was found to have greater delay when compared to loose coupling with G729A.

Figure 7, represents the ftp download and upload response time for both coupling schemes. To download files loose coupling had a lower response time though at the beginning of the simulation when traffic was reduced loose coupling was slower to get response when compared to tight coupling. However, as traffic increases the results showed that tight coupling

was not as responsive as loose coupling. On the other hand, for uploading files the simulation results showed that tight coupling had a lower response time.

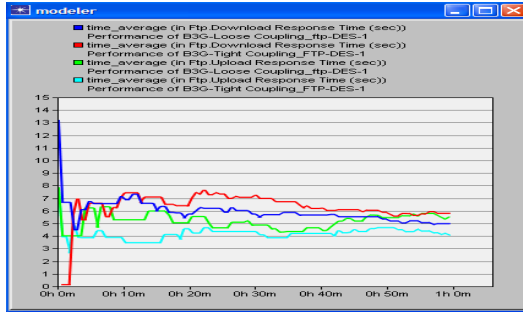


Fig. 7. FTP response time

In Figure 8, both coupling schemes provided roughly equal response times though at the beginning of the simulation when traffic was lower the loose coupling scheme provided a lower response time when compared to tight coupling. However, during the peak traffic as the simulation progressed the response time for both coupling schemes decreased. Regarding the http page response time as shown in Figure 9 tight coupling had a lower response time, though for an object the response time of loose coupling provided better performance.

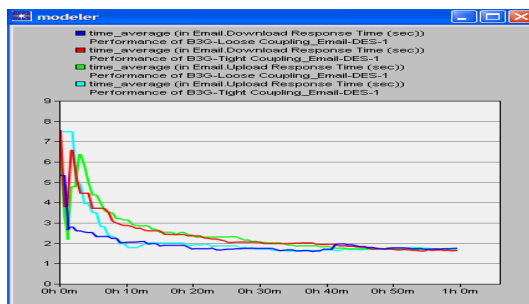


Fig. 8. Email response time

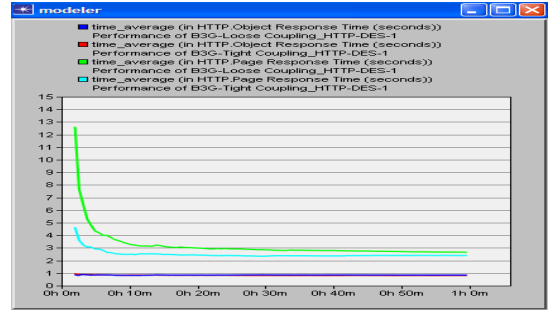


Fig. 9. HTTP response time

VIII. Conclusion and Future Work

This research highlights that tight and loose coupling have advantages depending on the application. For VoIP loose coupling with the G729A codec provides lower jitter and end to end delay. Loose coupling was also found to provide a lower response time for a http page although when fetching http objects tight coupling provides a lower response time. Tight coupling provides a lower response time for ftp file uploads however to download ftp files loose coupling provides a lower response time. Tight and loose coupling were found to be comparable when downloading and uploading emails. To implement tight coupling changes to the protocols used in WLAN are necessary. Loose coupling may be implemented more readily and provides simplicity and efficiency for 3G/WLAN integration. Prospective research work may include how to reduce the http page and ftp file upload response time for loose coupling.

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Analysis of a Hybrid Next Generation Mobile System

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Abstract— The ongoing growth of new and improved services and applications has contributed to demand for next generation access networks and customer devices. To address the present and future demand the next generation mobile systems are being designed to provide compatibility and interoperability with network protocols and access technologies that will enhance the overall system capabilities. Currently various technologies such as the recently developed High Speed Packet Access (HSPA) or the developing Long Term Evolution (LTE) technology are being evaluated and incorporated into next generation mobile systems. However, the HSPA and the LTE technologies are not sufficient to provide ubiquitous data services. To provide ubiquitous data services with coverage areas that provide higher data rates a hybrid interworking of access technologies is being considered. The hybrid network interworking aims to include the key features of an individual network into a single integrated system thus providing ubiquitous data services with higher data rates in designated coverage areas. This paper evaluates the performance of two integration schemes: Tight and Loose Coupling. The hybrid network was based upon third generation mobile wireless and 802.11x. Mobile IP is used as a mobility management scheme and EAP-AKA is used to provide a common authentication scheme.

Index Terms—WLAN, 3G, Broadband, Wireless, Mobile IP, EAP-AKA, VOIP.



1 INTRODUCTION

IN recent years, there has been a consistent growth in the mobile communications market. Growth in demand for mobile telephony and data services has provided the impetus for research and development aimed at providing further convergence between the mobile telephony and data service technologies. Improvements in the Voice over Internet Protocol (VoIP) technology has reached a point where it is now possible to merge the telephony and data services provided on a mobile wireless system into an Internet Protocol (IP) based network. New systems are constantly under development to support mobile telephony and data services. Wireless networking technologies have been categorized according to the network coverage area: Wireless Wide Area Networks (WWAN), Wireless Metropolitan Area Networks (WMAN), Wireless Personal Area Networks (WPAN) and Wireless Local Area Networks (WLAN). Wireless networks may be used to complement or replace wired networks in some situations. Mobile communications are differentiated from each other by the word 'generation', and can be categorized as 'first-generation' (1G), second-generation (2G) and third-generation (3G), which has been quite appropriate due to the generation gap between the technologies. One of the goals for next generation mobile systems is to provide better access and integration with existing IP based networks. Successful integration of the 3G cellular network and WLAN (802.11x) would be a step along the path towards a next generation network. The 3G network aims to provide customers with a highly developed global service providing circuit switched

or packet switched traffic; new mobile multimedia services (e.g. streaming/mobile TV, location base services, downloads, multi-user games) giving more flexibility for the operator to introduce new services to its portfolio and from the user point of view, more services and a variety of higher, on-demand data rates compared with the previous 2.5-2.75G mobile system. However existing 3G implementations have a moderate data rate when compared with WLAN or wireless networks. WLAN on the other hand has been deployed in libraries, airports, train stations and other areas known as hotspots and are cost-effective, easy to deploy and provide high data rates using unlicensed frequency bands. WLAN was not designed for wide area deployment, whereas 3G is a wide area mobile wireless network. In order to provide services and applications at high data rates mobile service providers regard WLAN as a technology that may be used to complement the 3G network. To facilitate the possible use of WLAN with 3G networks, there is a need for an efficient coupling architecture that also includes authentication and mobility management. The concept of integrating two or more access networks to provide ubiquitous service to mobile users is not new. Considerable research has been completed focusing on interworking issues between WLAN and the Universal Mobile Telecommunication System (UMTS) networks including 3G mobile networks [1-5]. In heterogeneous network literature, a dual access terminal allows the user to switch connection from one radio access network to another without packet loss [6, 7]. Studies may be found on the performance of hybrid WLAN/UMTS networks for various services and internet applications. For example, Song and Jamalipour [8] focus on the performance of a network selection algorithm rather than individual traffic sessions. The performance of a loose coupling architecture with regard to the continuity of real-time video traffic for UMTS connections was modeled by Salkintzis, et al. [9]. Kumudu and Abbas [10 - 12] have proposed an IP Multimedia Subsystem (IMS) based integration where the

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system presented can manage real-time sessions with the use of the IMS as a unified session controller. The study by Welling et al. showed that WLANs are economically profitable as a complementary, rather than competing solution for 3G mobile wireless data network operators [13]. Salkintzis proposed architectures that enable 3G subscribers to benefit from high throughput IP connectivity in strategic hotspot locations [4]. Salkintzis also discussed authentication, authorization, accounting (AAA) signaling for interworking 3G/WLAN rather than analyzing performance. Finally, Abu-Amara et al. present the performance of loose coupling and open coupling with two mobility schemes [14]. The results presented by Abu-Amara et al. provided the motivation to analyze the performance of loose coupling and tight coupling with various services and Internet applications. The paper is organized as follows: An overview of 3G/WLAN interworking is provided in Section II; Mobile IP based interworking is discussed in Section III; The authenticate key agreement scheme for the integration of 3G/WLAN is provided in Section IV; The system to be used in this study is presented in Section V; The simulation strategy for the hybrid network design is shown in Section VI and Section VII provides a discussion of the simulation results. Finally, in Section VIII conclusions are presented.

2 OVERVIEW OF UMTS-WLAN INTERWORKING

A number of mobile and fixed wireless network systems have been proposed and deployed during the past few years. It is possible that multiple network standards will coexist for future mobile and fixed wireless communication systems. Seamless roaming between heterogeneous wireless networks is an important requirement for future mobile wireless communication systems so that a greater range of services and applications may be provided to customers. Radio access networks have different properties that reflect the technologies used to achieve the network characteristics. A high-tier system such as UMTS provides high mobility but with lower data transmission bandwidth [1]. On the other hand, a low-tier system such as WLAN provides high data bandwidth but with less mobility due to a small coverage area for each access point (AP) deployed. To provide hotspot coverage in locations such as a building, a train station or an airport, WLAN AP are deployed to provide adequate coverage and it is possible that other service providers may also provide coverage in the hotspot. From a service integration perspective, the integration of WLANs and 3G mobile wireless data networks leads to six possible service integration scenarios provided by the 3rd Generation Partnership Project (3GPP) group [15]. The list of the six service integration scenarios are provided in Table 1.

TABLE 1 INTERWORKING SCENARIOS AND FEATURES

Scenario	Features
1	Common billing and customer care
2	Scenario 1 + common authentication
3	Scenario 2 + access to 3G packet-switch based services
4	Scenario 3 + service continuity
5	Scenario 4 + seamless service continuity
6	Scenario 5 + access 3G circuit-switch based services with seamless mobility

UMTS/WLAN is currently being studied by the 3GPP participants. A literature review highlighted four UMTS/WLAN interworking architecture approaches: tight coupling, loose coupling, open coupling and very tight coupling.

2.1 Open Coupling

In an open coupling scheme WLAN and UMTS use separate access and transport networks. Billing and user management occurs through different authentication mechanisms. This is the simplest coupling of 3G-WLAN interworking. The connection between the WLAN and the 3G system is that there is a single customer relationship. The customer receives one bill from the mobile operator for the customer's use of both 3G and WLAN services. Integrated customer care allows for a simplified service offering from both the operator and the customer's perspective. The security implementation for the two systems is independent. A large handover delay may arise due to authentication traffic

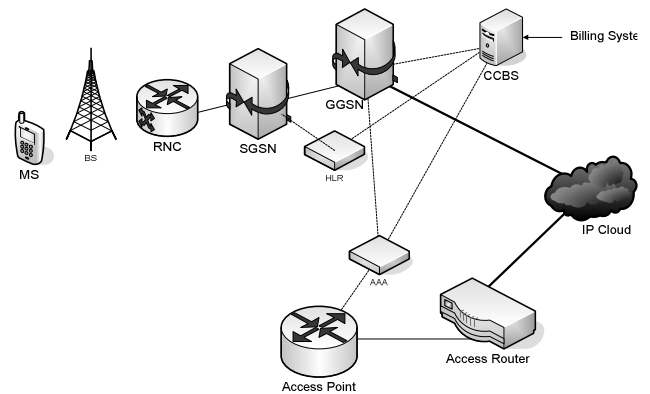


Fig 1. Open Coupling

between the AAA server and the Home Location Register (HLR) [14]. Due to handover delay open coupling may not be suitable for operational 3G and WLAN hybrid networks although open coupling does meet the 3GPP Scenario 1 requirements. Open coupling was not selected for this study.

2.2 Loose Coupling

In a loose coupling scheme the use of a common authentication mechanism provides a link between the authentication, authorization and accounting (AAA) server in the WLAN network and the HLR in the UMTS network. In other words, loose coupling provides the subscribers with access to the 3G based packet services without making any changes to the WLAN and UMTS protocols. The key element to support mobility management in this architecture is

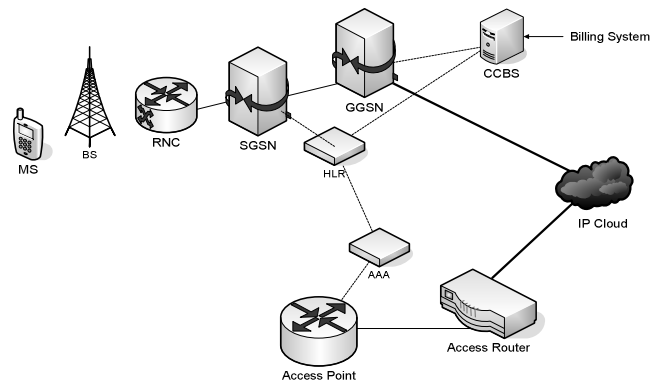


Fig 2. Loose Coupling

Mobile IP [16]. However, there are other variants to this coupling, which may involve the user data traffic being routed to the UMTS Core Network (CN) [3, 4]. The data traffic is routed directly via an IP network which is an advantage of this method.

2.3 Tight Coupling

The tight coupling scheme integrates two networks at the CN level where a WLAN AP is connected as a Radio Network Controller (RNC) to the UMTS Service GPRS (General Packet Radio Service) Support Node (SGSN) to support the handover between WLAN and UMTS networks. In other words, tight coupling makes two different radio access technologies work together with a single core network. The key functional element in the system is the handover

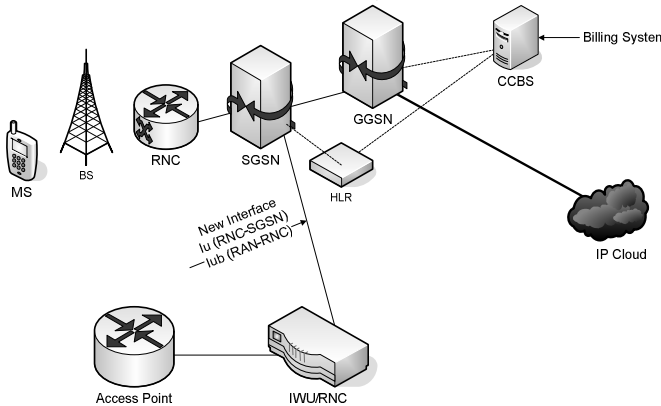


Fig 3. Tight Coupling

between a WLAN and a UMTS network and this may be likened to the handover occurring between two individual wireless network cells. The tight coupling integration scheme includes the reuse of UMTS AAA mechanisms, usage of common subscriber databases and billing systems, and increased security features (since the UMTS security mechanisms are reused). Tight coupling provides for the possibility of continuous sessions as users move across the two networks, since the handoff in this case is very similar to an intra-UMTS handoff as the WLAN AP appears as another RNC to the SGSN node.

An obvious benefit of this approach is that the UMTS mobility management techniques can be directly applied.

2.4 Very Tight Coupling

The very tight coupling approach is the same as that in the tight coupling scheme with the addition that the WLAN AP is connected to the RNC. The access point connects to the RNC through the Iub interface, presenting itself as a node B (Base Station) [17]. Iub is the interface providing an interconnection point between Radio Network Subsystem and the CN [18]. Using very tight coupling enables the collection of information relating to air interface conditions and network capacity. However, it is considered quite

complicated and only a few solutions have been proposed in this area [4,5,17]. The reason it is regarded as a complex interworking solution are given below:

It needs to implement a new interface for RNC-WLAN, where WLAN is seen as cell management at the RNC.

The WLAN AP also needs to implement the 3G protocol stack.

Other required modifications mainly affect RNC and more specifically Radio Resource Control (RRC).

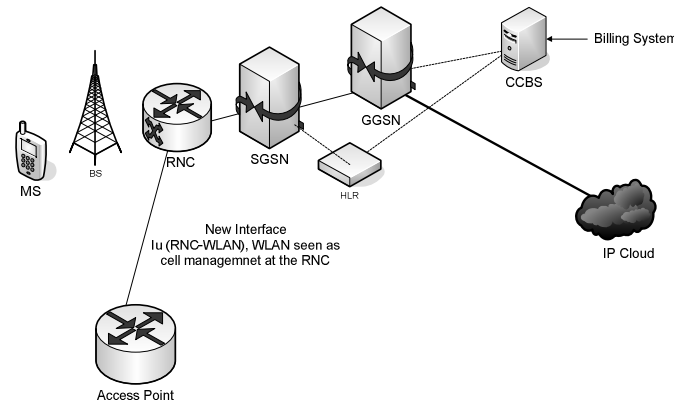


Fig. 4. Very Tight Coupling

The decision for selecting the proper radio interface, the WLAN management, the handover control, and the RRC state model are some points that should be changed in RRC functionality.

3 MOBILE IP BASED INTERWORKING

Mobile IP is one of the most popular network layer solutions for IP network mobility and it fulfils the requirement to maintain Internet connectivity throughout user sessions when integrating 3G and WLAN. Mobile IP is employed to restructure the connections while a Mobile Station (MS) moves from one network to another, eg. from UMTS to WLAN. Outside of the UMTS network, the MS is identified by a Care of Address (COA) associated with its point of attachment to the UMTS network. Handoff management is the process by which a mobile station terminal (MT) keeps its connection active when it moves from one AP to another. It is necessary for a mobile terminal to employ various points of attachment to maintain connectivity to the network at all times. There is a clear difference between the two types of handover which are known as horizontal and vertical handover. Horizontal handover refers to handover between node B and AP that are using the same kind of network interface. Vertical handover refers to handover between a node B and an AP (or vice versa) that are employing different wireless technologies. In the case of a vertical handover, two distinctions are made:

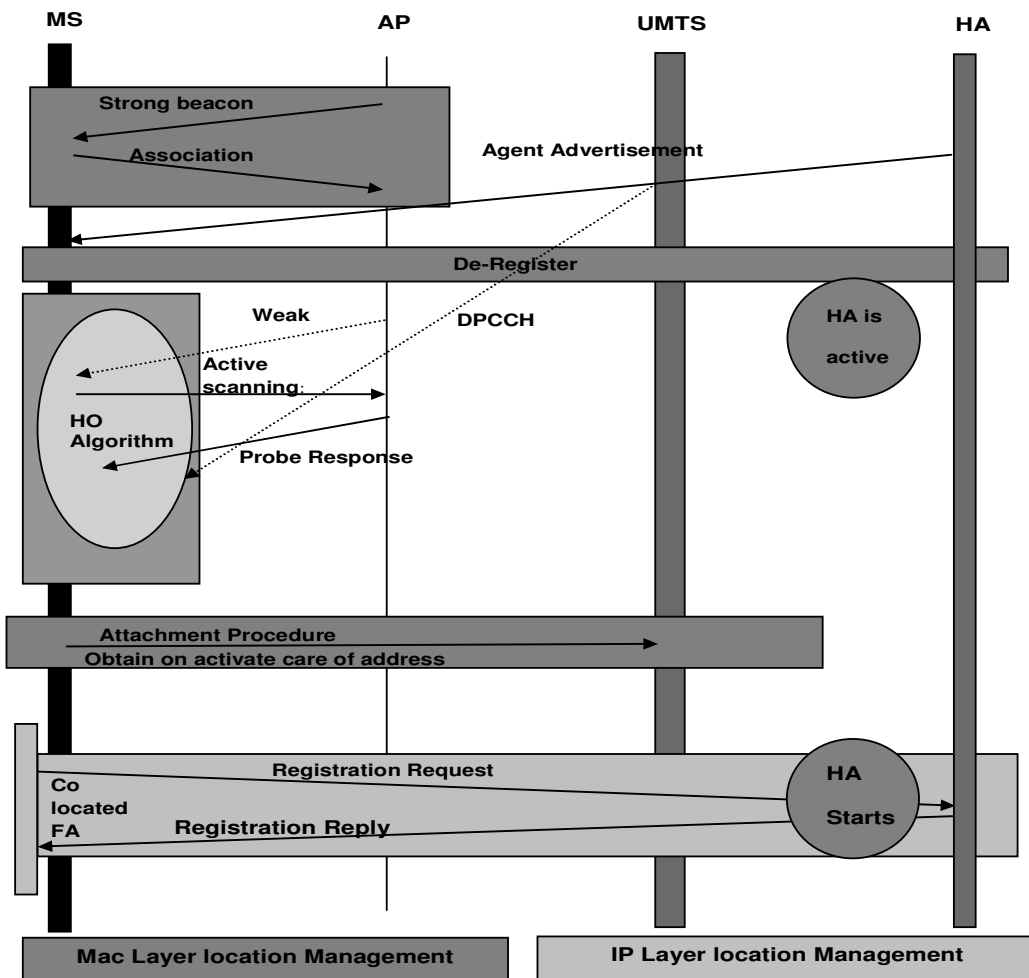


Fig. 5. Handover Process [19]

1. Upward vertical handover, which occurs from IEEE 802.11 WLAN AP with small coverage to an UMTS node B with wider coverage.
2. A downward vertical handover, which occurs in the reverse direction.

A downward vertical handover takes place when a user MS connected to a UMTS service moves into a WLAN service coverage area. The user MS connected to the UMTS network listens to the underlying WLAN AP. If several WLAN AP beacons are received successfully, the user MS will switch to the WLAN service using the Mobile IP registration process.

An upward vertical handover takes place when a user MS connected to a WLAN service starts to leave the WLAN service coverage area. As the user MS moves away from the WLAN AP the beacon strength decreases and at some point the user MS decides that the current WLAN AP is not reachable and commences an upward vertical handover to the overlying UMTS service using the Mobile IP registration process.

The vertical handover decisions are made on the basis of the presence or absence of the WLAN AP beacon packets. Encapsulation and packet delivery is managed by a collocated foreign agent. An illustration of the WLAN to UMTS handover management process is shown in Fig. 1. The UMTS to WLAN handover management process is provided by Falowo and Chan [20]. Initially the WLAN AP beacon signal is not received by the MS. As the MS moves into the WLAN service coverage area the MS detects a WLAN AP beacon signal, which indicates that the underlying WLAN

network has become available. The MS commences the vertical handover from the UMTS to the WLAN service. The Foreign Agent (FA) in the UMTS network is deactivated, the Mobile IP registration process is carried out and the home IP address is used until a new local IP address is allocated. The HA in the WLAN network is instructed by the MS to no longer do a proxy ARP on its behalf through the Mobile IP protocol.

4 AUTHENTICATE KEY AGREEMENT

EAP-AKA [21] was proposed by the 3GPP to provide access security for 3G/WLAN interworking. EAP-AKA was used as the authentication protocol in the model presented in this paper. EAP-AKA is based on a UMTS AKA mechanism. In the EAP-AKA protocol the 3G home domain does not delegate responsibility for security and billing authentication to the underlying WLAN network. A successful EAP-AKA procedure is shown in Fig. 2. EAP-AKA uses two message roundtrips to support mutual authentication and to generate session keys. An identity request/response message pair is exchanged first. For complete authentication the MS identity is included in the user International Mobile Subscriber Identity (IMSI) or a temporary identity (TMSI) is used.

After obtaining the MS identity, the 3G home domain AAA server requests and retrieves subscription data and authentication vectors from the HLR and uses this information as part of the MS authentication process. It is important to notice that, several vectors may be obtained at a

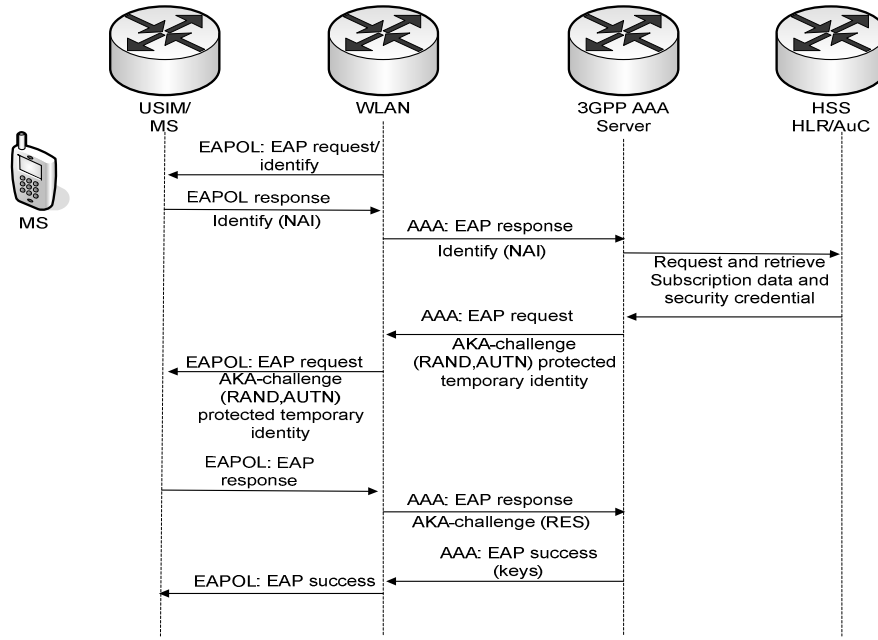


Fig. 6. EAP-AKA Procedure [22]

time and stored in AAA server for use at a later time; however they may not be reused. After that, the AAA server starts the actual AKA protocol by sending an EAP-Request/AKA-Challenge message. The EAP-Request/AKA-Challenge message contains a random number and a network authentication token. Furthermore, the message optionally contains encrypted data, which is used for identity privacy and fast re-authentication. Next, the MS runs the AKA algorithm typically using a Universal Subscriber Identity Mobile (USIM) identifier and verifies the MS authentication. If this is successful, then the MS is communicating to a valid AAA server and proceeds to send the EAP-Response/AKA Challenge. This message contains a result parameter (RES) that allows the AAA server in turn to authenticate the MS. Finally, the AAA server should also include a session key in the message sent to the WLAN system. Since EAP authentication may be performed frequently in some environments the EAP-AKA full authentication procedure makes use of the UMTS AKA algorithms that require fresh authentication vectors from the HLR. Therefore a variation of EAP-AKA optionally supports fast re-authentication and this extension is beyond the scope of the research carried out.

5 HANDOVER PROCEDURE

5.1 Tight Coupling Handover

In a tight-coupled network, it is possible to support a user's IP mobility using tunneling protocols without using Mobile IP. On the other hand, Mobile IP can also be applied in a tightly coupled network [23], but even in that case, handover between the different access networks (i.e. the UMTS and the WLAN) does not need to change the FA since those access networks belong to the same FA (GGSN). So, the vertical handover between UMTS and WLAN is an intra-FA handover, as are other inter-RNC handover or inter-AP (SGSN emulator) handovers, which does not need to change the user's IP address and to register to an FA or the HA. The RNC decides whether or not to start handover based on the measurement results from the UE, and if required, it sends a relocation required message to the SGSN. Then, the SGSN sends handover messages to the appropriate SGSN Emulator. The UE (User) is associated with an AP, and the SGSN requests the SGSN emulator to begin the radio access bearer setup procedure. After completing the bearer setup procedure, the SGSN requests the GGSN to update the PDP context to the UE. The complete handover process is shown in Fig. 7 [24].

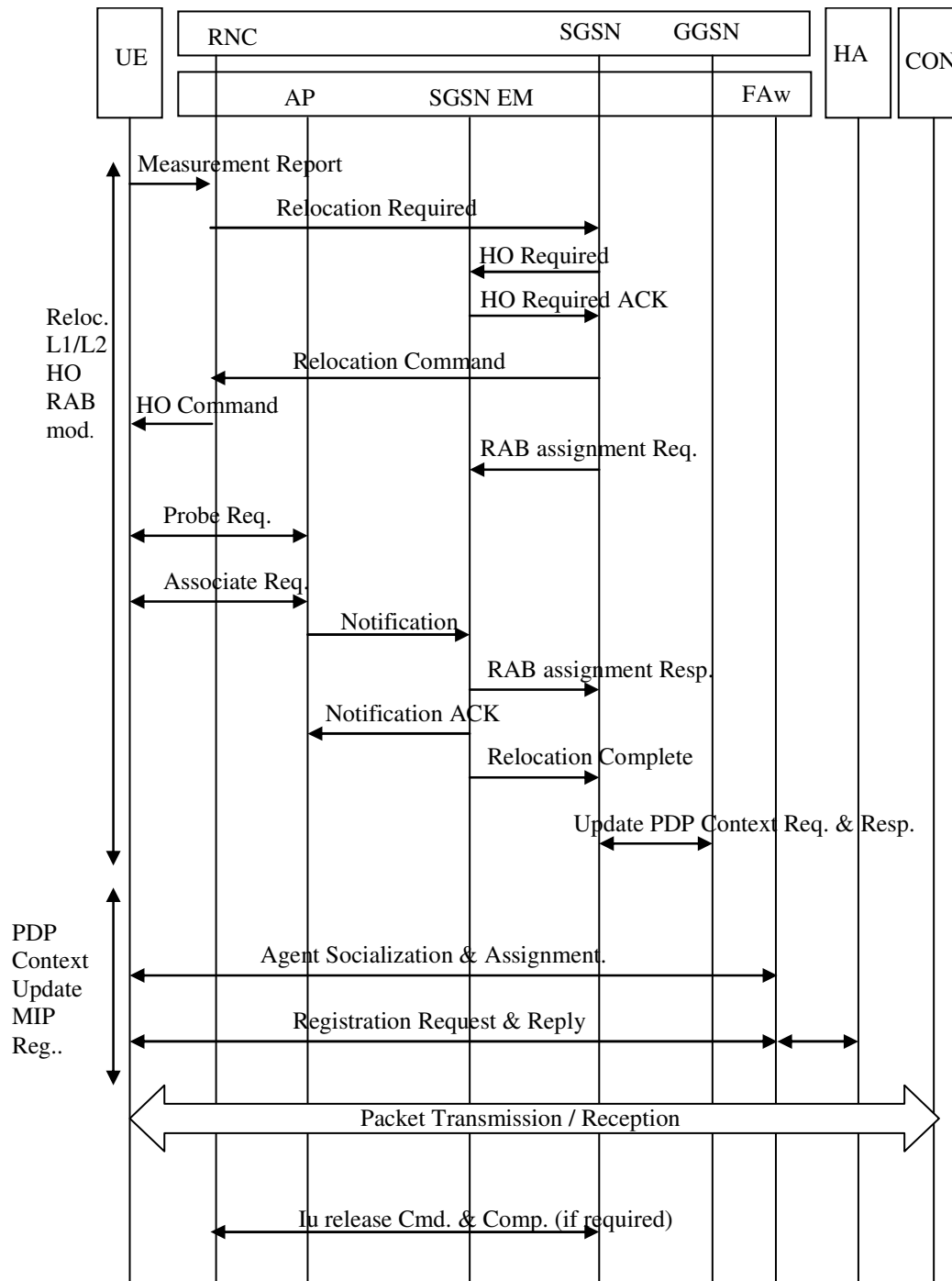


Fig. 7. Handover to WLAN for a tight coupling scenario

5.2 Loose Coupling Handover

To support IP-level mobility in a loose-coupled network, it is assumed that the Mobile IP (MIP) is applied and that the WLAN and the UMTS networks have their own FAs. (A GGSN acts as an FA in UMTS, and the HA and the Correspondent Nodes (CON) are located in the external IP networks.) The handover procedures to/from WLAN from/to UMTS are shown in Figure 8 [24]. User (UE) turns its power on, and is associated with an AP. Then, the UE and the AP start the 802.1x authentication procedure. After completing authentication successfully, an IP address is assigned to the UE by AAA for MIP registration. Using this IP address, the UE registers to the FA in the WLAN and restarts transmitting and receiving packets.

6 VoIP CODEC

A codec (Coder/Decoder) converts analogue signals to a digital bit stream, and another identical codec is placed at the communication system receiver to convert the digital bit stream back into an analogue signal. The Voice over IP (VoIP) quality can be significantly improved by using a codec that is designed for the channel and available bandwidth. In a VoIP system, codecs are used to convert voice signals into digital data to be transmitted over the Internet or any IP based digital network supporting VoIP calls. Codecs may also support silence suppression, where silence is not encoded and transmitted. In Table 2 [25] the codecs that were used in the simulation are identified.

TABLE 2 SIMULATION VOIP CODECS

Codec	Algorithm	Bit rate (Kbps)
ITU G.711	PCM (Pulse Code Modulation)	64
ITU G.729A	CS-ACELP (Conjugate Structure Algebraic-Code Excited Linear Prediction)	8

GSM FR	RPE-LTP (Regular Pulse Excitation Long-Term Prediction)	13
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7 SIMULATED NETWORK DESIGN ARCHITECTURE

This section describes the simulation model and the scenarios used to evaluate the performance of tight and loose coupling. Opnet Modeler 15.0 [26] was used to simulate the hybrid UMTS and WLAN network. Opnet Modeler is a very flexible

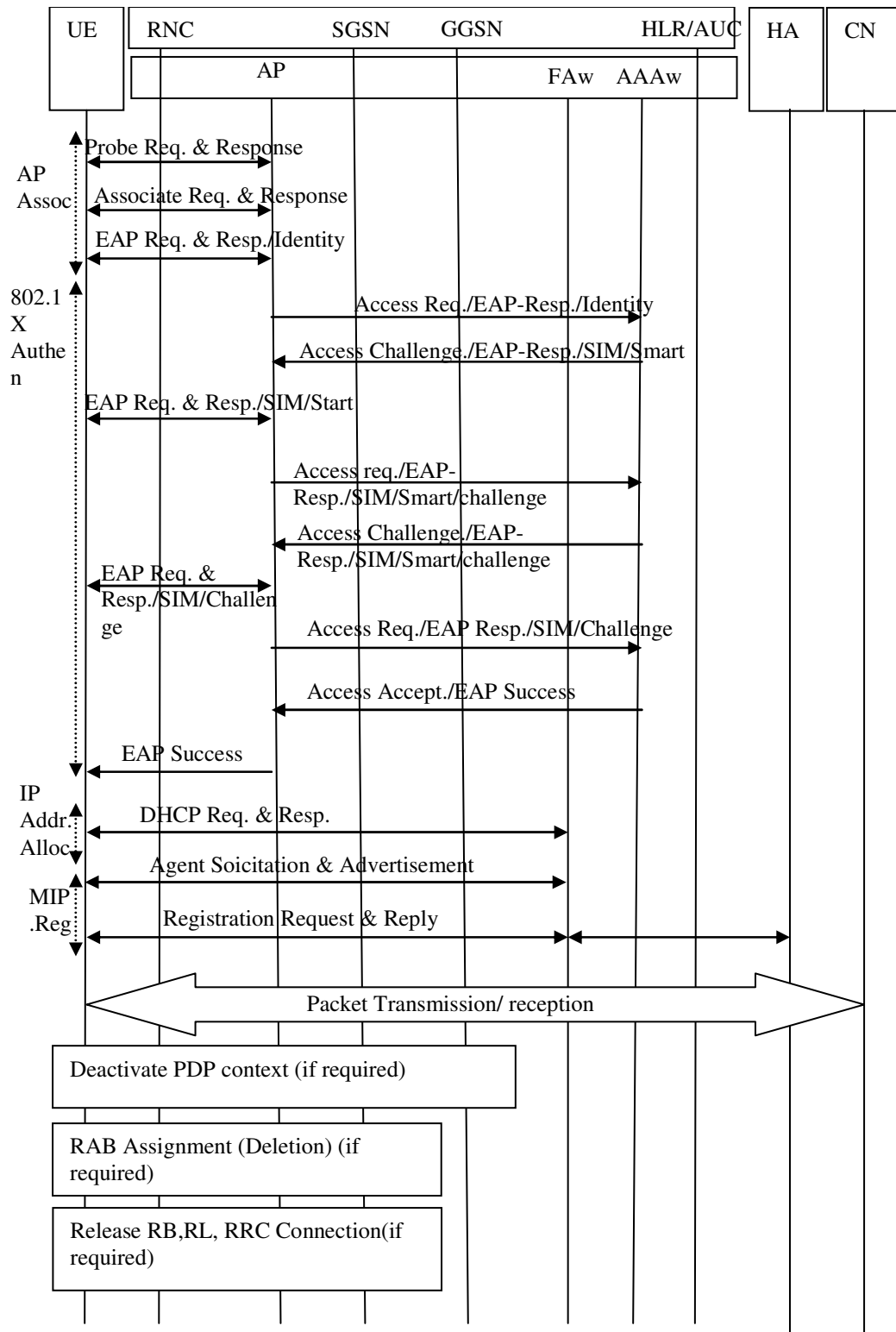


Fig. 8. Handover to WLAN for a loose coupling scenario

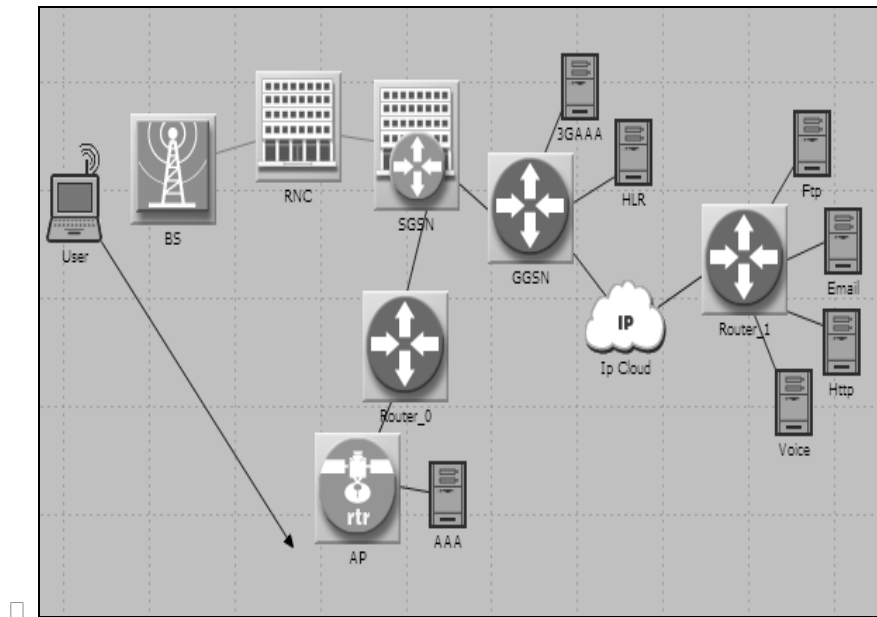


Fig. 9. Tight Coupling

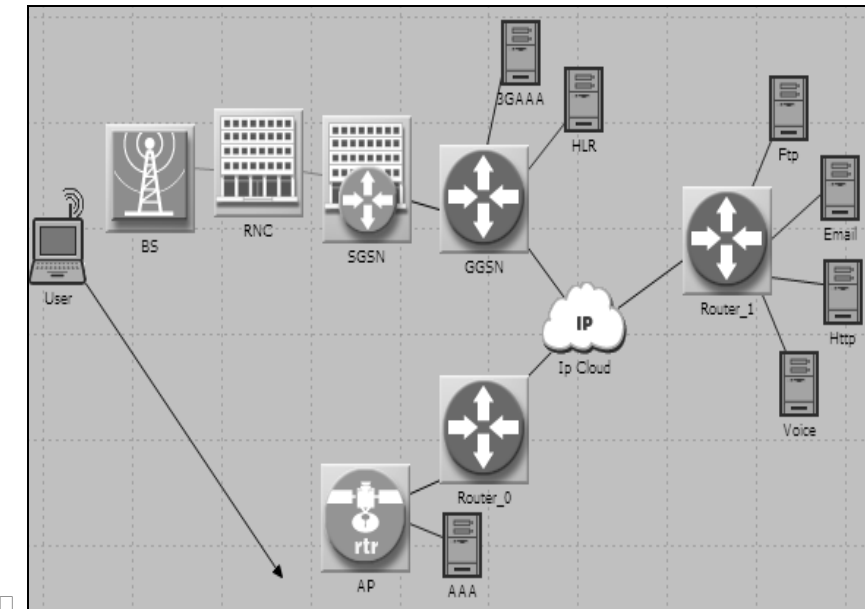


Fig. 10. Loose Coupling

tool which provides a range of generic protocols and device models. It is possible to construct quite sophisticated models and simulation scenarios using the protocols and device models provided and where a protocol or device model is not available Opnet Modeler provides a facility for the user to add protocols and device models. The protocols required for this research including AAA, HLR, 3GAAA, Mobile IP within the UMTS model and the EAP-AKA protocol were developed and added to the hybrid UMTS and WLAN network. Two network scenarios were developed and the first included tight coupling scheme and the second included a loose coupling scheme. A 3G model was combined with an 802.11g model to evaluate the network performance. In the tight coupling scheme a WLAN AP was connected through a router to a UMTS CN at the SGSN node and for the loose coupling scheme the WLAN AP was connected through the router to an IP cloud. The applications used in the simulation were added to the network design and the applications included ftp, http, email and VoIP. The network design for

the two scenarios is shown in Fig. 9 and Fig. 10.

8 RESULT ANALYSIS

In this section the simulation results will be presented and discussed. Three different codecs were used and are described in Table 2. For each codec, 4ms frame sizes were used and for each frame size the Frames per Packet value was set to two. In all, six simulations were carried out where two different network architectures and three codecs were used. For each simulation data was collected and analyzed.

Fig. 11 shows [27] the jitter for the three different VoIP codecs used for both coupling schemes. Jitter, the variation of packet or cell inter-arrival delay, is another factor which affects delay, especially during a handoff. In this study the jitter was calculated, if two consecutive packets leave the source node with time stamps t_1 & t_2 and are played back at the destination node at time t_3 & t_4 , then:

$$\text{jitter} = (t_4 - t_3) - (t_2 - t_1) \quad (1)$$

Negative jitter indicates that the time difference between the packets at the destination node was less than that at the source node.

The simulation results showed that the voice capacity over a hybrid network is a function of the system parameters, voice packet payload length (depending on the codec used), and sampling period. In Fig. 11, the horizontal axis shows the simulation time and the vertical axis shows the jitter value. The G729A codec with loose coupling was found to provide less jitter and better overall performance. However, the GSM codec with tight coupling provides negative jitter when compared to the other scenarios. At the beginning of the simulation, the jitter values varied widely and as the

simulation progressed, indicating an increase in traffic within the network, the scenario jitter values settled into a narrow range as shown in Fig. 11.

Fig. 12 shows [27] the End-to-End delay for voice applications and the End-to-End delay formula used is provided in (2).

End-to-End delay = network-delay + encoding-delay + decoding-delay + compression-delay + decompression-delay (2)

- Network delay is the time at which the sending node transmits the RTP packet to the time the receiving node receives the RTP packet.
- Encoding delay (on the sender node) is the time for the digital voice stream to be encoded prior to transmission.
- Decoding delay (on the receiver node) is assumed to be equal to the encoding delay.
- Compression and Decompression delay is the time for the voice signal to be compressed or decompressed using the current system codec.

The traffic received for voice applications for the simulation scenarios is shown in Fig. 13 with the horizontal axis showing the simulation time and the vertical axis showing the amount of traffic received by the mobile user.

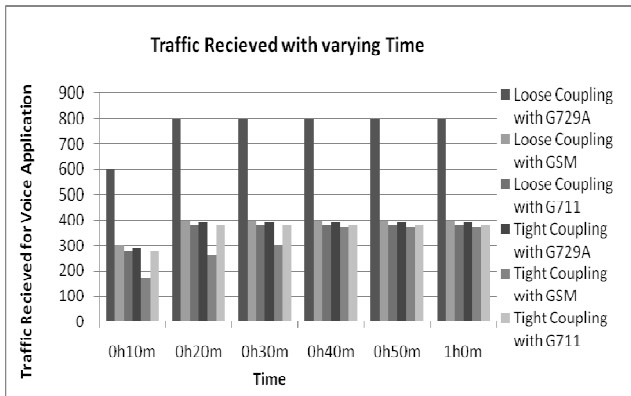


Fig. 13. Traffic received for voice applications

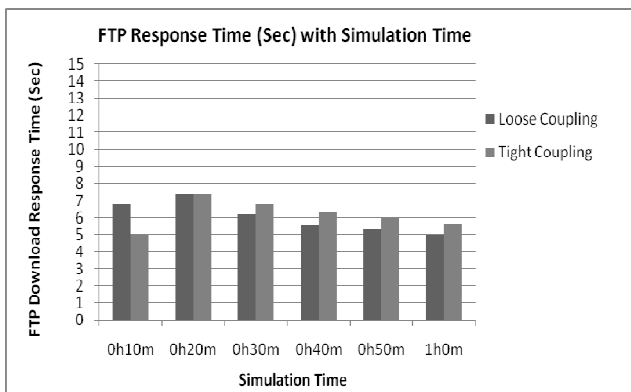


Fig. 14. FTP download response time

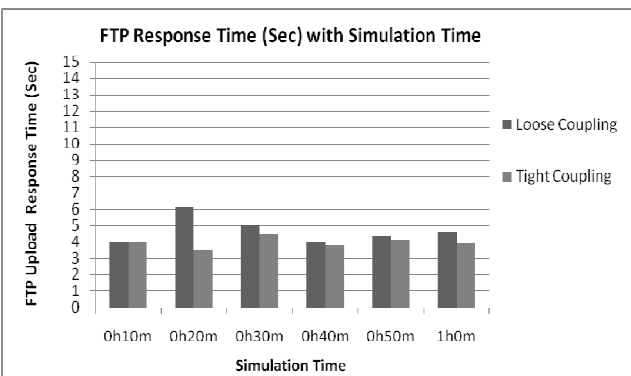


Fig. 15. FTP upload response time

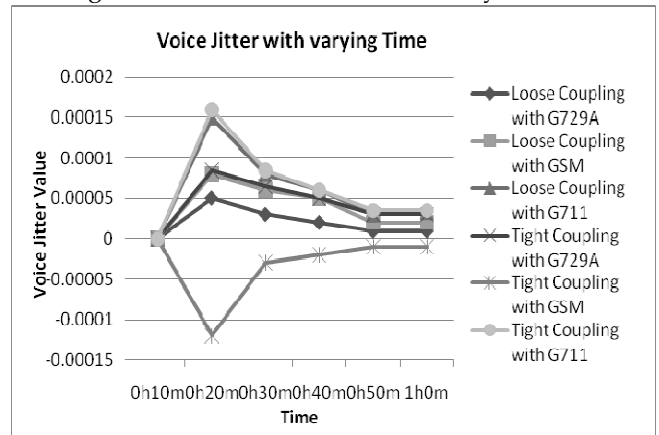


Fig. 1. 11 3G/WLAN jitter

The G729A codec with loose coupling was found to provide better overall performance by receiving more traffic compared to the other scenarios. The simulation outcome also showed that the G729A codec scenario packet loss was less than that for the other scenarios as the same traffic volume was used in each scenario.

The simulation results for the GSM codec with tight coupling included negative jitter. However, considering the end-to-end delay and traffic received the GSM codec with tight coupling was found to have greater delay and less traffic received when compared to the G729A codec with loose coupling. From the simulation results shown in Fig. 11, Fig. 12 and Fig. 13, the G729A codec with loose coupling is seen to be the more appropriate scheme for the next generation heterogeneous network framework.

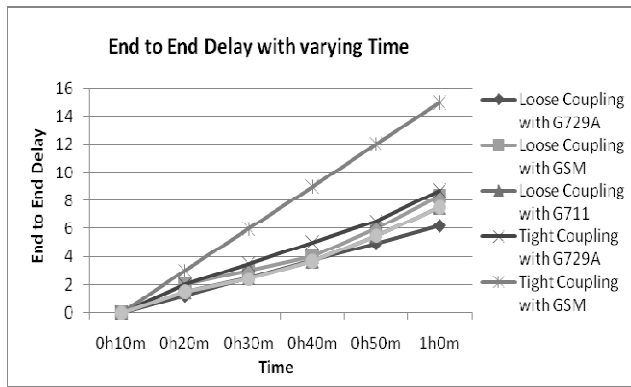


Fig. 12. End to End Delay for a VoIP application

The FTP download time simulation results shown in Fig. 14 highlight [27] that loose coupling provides a lower download time overall. Initially when the simulation traffic was low the first two result readings showed that tight coupling produced a lower FTP download time. As the simulation traffic increased over time loose coupling was found to achieve a lower FTP download time.

The FTP upload time simulation results shown in Fig. 15 highlight [27] that tight coupling provides a lower upload time overall. The loose coupling architecture AAA server and the UMTS packet switched services are a part of an IP cloud which explains why the response time for downloading is less and than that for uploading. For the tight coupling architecture the AAA server is part of the RNC and this facilitates faster authentication when establishing a FTP connection to upload a file.

The email application download response times are shown in Fig. 16 [27]. The simulation outcome shows that initially the tight coupling architecture provides lower email download response times; however, this trend reverses when the network traffic grows as the simulation progresses. Overall loose coupling provides a lower email download response time for a network with expected traffic.

The email application upload response times are shown in Fig 17 [27]. The simulation outcomes show a similar trend to that for the email application download response time, except for the final simulation reading. The reason for this variation is that the tight coupling downward handoff message exchange has more process steps than the tight coupling upward handoff message exchange [28].

The HTTP object download response times are shown in Fig. 18 [27]. The simulation outcomes show that as the simulation progressed and the traffic increased the HTTP object download response times were lower using the loose coupling architecture. The HTTP page download response times are shown in Fig. 19 [27]. The simulation outcomes show that the time differential between tight and loose coupling decreased as the simulation progressed and that overall the HTTP page download response times were slightly lower using the tight coupling architecture.

9 CONCLUSION

This research highlights that tight and loose coupling have advantages depending on the application. Loose coupling with the G729A VoIP codec was found to provide better performance overall with less jitter and end to end delay. Also, this approach received higher traffic when compared to

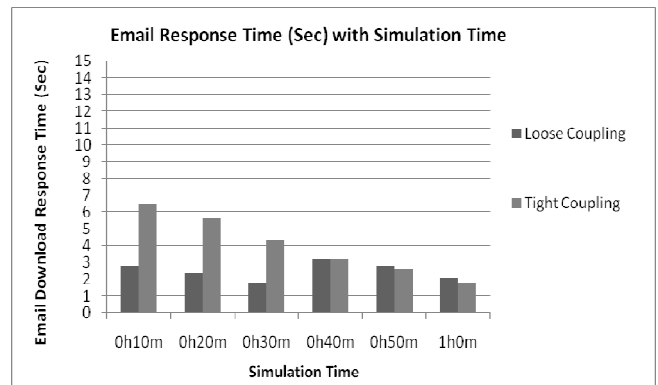


Fig. 17. Email download response time

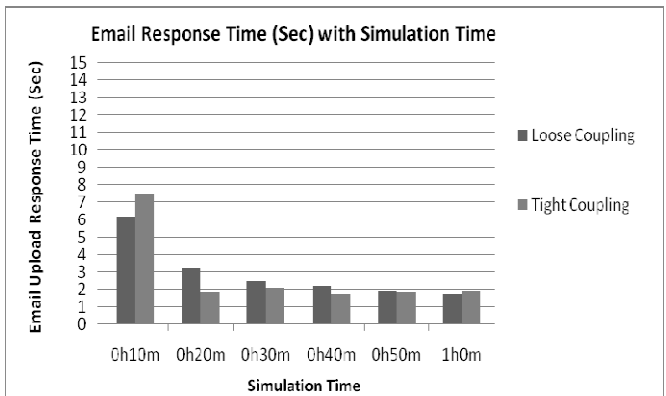


Fig. 17. Email upload response time

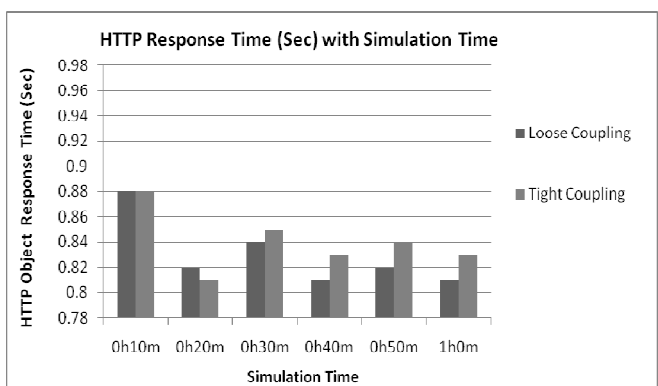


Fig. 18. HTTP object download response time

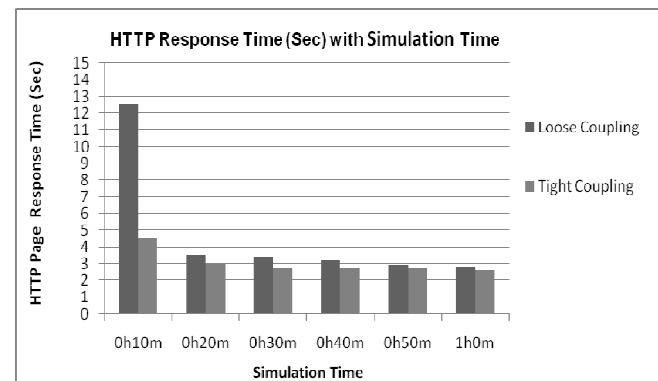


Fig. 19 HTTP page download response time

the other approaches studied. Tight coupling with GSM included negative jitter; however, greater End-to-End Delay and less received traffic were key outcomes that led to the research outcome that a loose coupling framework with the

G729A codec for voice application is suitable for use in a next generation wireless mobile system.

TABLE 3 SUMMARY OF SIMULATION RESULTS

	Tight coupling	Loose coupling
Jitter	GSM	G729A
End-to-End delay	G729A	G729A
Traffic received	G729A	G729A
FTP download response time	Higher	Lower
FTP upload response time	Lower	Higher
Email download response time	Negotiable	Negotiable
Email upload response time	Negotiable	Negotiable
HTTP object response time	Higher	Lower
HTTP page response time	Lower	Higher

Considering the results provided in Table 2, both loose and tight coupling frameworks were found to be generally similar. When downloading files using the ftp application it was found that loose coupling had a lower response time. Though, at the beginning of the simulation when traffic was reduced, loose coupling was slower to get a response compared to tight coupling. However, as traffic increased the results showed that tight coupling was not as responsive as loose coupling. On the other hand, for uploading files the simulation results showed that tight coupling had a lower response time than loose coupling. For an email application, both coupling schemes provided roughly equal response times though at the beginning of the simulation when traffic was lower the loose coupling scheme provided a lower response time when compared to tight coupling. However, during peak traffic period as the simulation progressed the response time for both coupling schemes decreased. For a http application, the page response time using tight coupling had a lower response time than loose coupling, though for a http object the loose coupling response time provided better performance due to a lower response time. To implement tight coupling changes to the protocols used in WLAN are necessary. Loose coupling may be implemented more readily and provides simplicity and efficiency for 3G/WLAN integration. Prospective research work may include how to reduce the http page and ftp file upload response time for loose coupling.

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