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Performance Analysis of Hybrid Coupling Interworking Architecture

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Abstract: Heterogeneous network designing involves some interworking issues such as seamless handoff or roaming, mobility management, security and charging problems etc. The integration of WLAN and UMTS network is probable to create more opportunities for service providers to provide enhanced services to customers. There are mainly three issues measured to obtain seamless continuity: interworking architecture, fast inter-system handovers and real time services similar (QoS) in both networks. This paper focuses on exploring enhancement in the service domain through the hybrid architecture (hybrid of loose coupling and tight coupling) compare to individual architecture based interworking between UMTS and WLAN. The loose coupling internetworking architecture, though it is simplest and easy to deploy, offer increased handover latency reducing QoS by way of delayed services. Under tight coupling internetworking system, users of WLAN are able to get the services of UMTS with guaranteed QoS along with seamless mobility. On other hand the capacity of UMTS core network nodes may not handle/manage bulky data traffic from WLAN because of the fact that UMTS core network nodes are primarily designed to handle/manage circuit voice calls or short packets. Based on the traffic type, a hybrid coupling scheme differentiates the data paths. The data path for real time traffic is taken up tightly coupled network architecture while non-real time traffic/bulky traffic is taken up loosely coupled network architecture to enhance over all service level.

Keywords: hybrid coupling, tight coupling, loose coupling, WLAN, UMTS, Heterogeneous Networks.

I. INTRODUCTION

The last decade has attracted the considerable attention for enhancement of service levels by way of higher levels of mobility and data transfer rate integrating existing cellular systems (UMTS) with wireless access (WLAN) technologies. WLAN is 802.11 based networks and offer low cost, low mobility with high data rates (bandwidth up to several hundreds of Mbps) in the unlicensed frequency bands of 2.4 GHz and 5 GHz. The cellular networks (UMTS) offer high mobility with less data transfer rate (2 Mbit/s for stationary users and 384 Kbit/s for moving users). The UMTS network requires larger bandwidth as number of users increase in hotspots like railway stations, stadiums etc. As the number of user's increases in UMTS, mobile users and stationary users get lower bandwidths, lower level of QoS and pay higher costs.

To overcome this problem, UMTS and WLAN integrate these two technologies together in such a way that, short coverage and high data transfer rate WLAN and long coverage with low data rate cellular network enables to provide better services for users.

The integration of UMTS and WLAN technologies can provide ubiquitous connectivity and high data rate at low cost as well as achieve benefits to users such as load balancing, extension of coverage area, better Quality of Service (QoS), improved security features, etc.

The seamless continuity among various internetworking technologies, improved mobility and handover management are factors of to be monitored and improved.

The Roaming (i.e. movement of a wireless node between two adjacent cells) mechanism occurs not only in infrastructure networks built around multiple cells, but also between different networks such as UMTS and WLAN.

The study analysis of UMTS and WLAN network architectures as loosely coupled, tightly coupled and integrated hybrid coupled is targeted to compare handover latency.

The literature survey of research paper [1] describes the issues -data rate, coverage area, cost of services etc. - associated to diversity in existing and emerging wireless technologies. The referred paper data is quoted in Table 1.

Table 1. Diversity in Existing and Emerging Wireless Technologies

Network	Coverage	Data Rates	Cost
Satellite	World	Max. 144 kb/s	High
GSM/GPRS	Approx. 35 Km	9.6 kb/s up to 144 kb/s	High
IEEE 802.16a	Approx. 30 Km	Max. 70 Mb/s	Medium
IEEE 802.20	Approx.20 Km	1.9 Mb/s	High
UMTS	20 Km	Up to 2 Mb/s	High
HIPERLAN2	70 up to 300 m	25 Mb/s	Low
IEEE 802.11a	50 up to 300 m	54 Mb/s	Low
IEEE 802.11b	50 up to 300 m	11 Mb/s	Low
Bluetooth	10 m	Max. 700 Kb/s	Low

This paper is organized as follows: Section 2 introduces the basic network architecture and components of UMTS. Then a brief introduction of the architecture of WLAN is presented in section 3. Section 4 introduces coupling scenario. Section 5 introduces performance evaluation with results; section 6 introduces handover mechanism between UMTS and WLAN. Finally we conclude this paper.

II. NETWORK ARCHITECTURE OF UMTS

The Universal Mobile Telecommunications Systems (UMTS) is one of the standardized systems for 3G mobile systems. This solution is considered the natural evolution path for GSM/GPRS-based networks. The network architecture of UMTS is shown in below Figure 1:

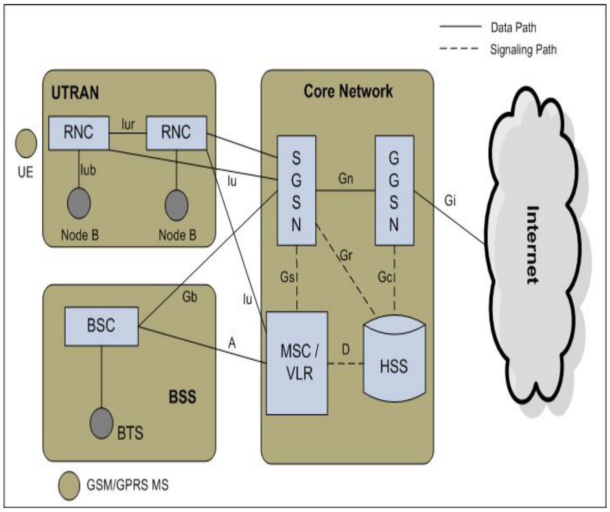

Figure1. The UMTS architecture with the interfaces between the respective network components

The literature survey of research paper [2] provides UMTS architecture with the interfaces between the respective network components. In above Diagram (1), the solid line depicts data and signaling links whereas dashed lines depicts signaling links.

UMTS developed from General Packet Radio Service (GPRS). Mobile devices connect to the **Base station** (Node B in UMTS terms) through a radio interface based on **Wideband Code Division Multiple (WCDM)** Access technologies.

The UMTS system architecture functionality divided into three groups are: **User Equipment (UE), UMTS Terrestrial Radio Access Network (UTRAN)/Access Network (AN) and Core Network (CN).**

UTRAN consists of Node B and Radio Network Controller (RNC) connected by an ATM network. RNC performs mobility management, encryption and radio resource management. Mobile users also access wireless network provided by node-B [11].

The UMTS CN is further logically divided into i) the packet-switched domain (PS-domain), where packets are routed independently, ii) the circuit-switched domain (CS-domain), where dedicated resources are granted for voice calls, and iii) the IP Multimedia Subsystem (IMS) that provides IP multimedia services over the PS-domain. The Core Network contains two basic nodes: **Serving GPRS Support Node (SGSN)** and **Gateway GPRS Support Node (GGSN).**

In the CN, the routing of data between the UMTS network and the external network is performed at the Serving GPRS Support Node (SGSN) via the Gateway GPRS Support Node (GGSN) for the PS-domain.

MSC (Mobile Switching Center) is a special telephone switch which performs the similar functionalities to support mobile applications. The MSC connects the calls from the user equipments to the Public Switched Telephone Network (PSTN). And the **Gateway Mobile Switching Centre (GMSC)** is used for the CS-domain.

The **Home Subscriber Server (HSS),** which maintains the users' profiles and is common in both domains. The **Home Location Register (HLR)** and the **Visitor Location Register (VLR**) are the ones which provide mobility management.

The CN can connect to different types of ANs concurrently. An AN can be either a Base Station System (BSS), offering GSM/GPRS services to Mobile Stations (MSs), or a Radio Network System (RNS), accustomed for UMTS services to User Equipments (UEs). A BSS consists of Base Tranceiver Stations (BTSs) and one Base Station Controller (BSC) that are responsible for radio communications and radio resource control respectively. Similar functionalities are provided by the respective RNS entities, Node-Bs and the Radio Network Controller (RNC). The part of the network that consists of RNCs and Node-Bs is the UMTS Terrestrial Radio Access Network (UTRAN).

The **Gateway GPRS Support Node (GGSN)** provides connections and access to the Internet. It maintains routing information for the **User Equipment (UE)** to tunnel Protocol Data Units to the SGSN. The GGSN communicates with the HLR for session management. Usually, the GGSN communicates with the HLR indirectly through the SGSN. With the use of Gi interface, GGSN provides internetworking with external packet switched networks such as IP networks.

The **Serving GPRS Support Node (SGSN)** delivers the packets to the UEs within its service area. It performs security, mobility management and session management functions by communicating with the HLR. The RNC is also connected to the SGSN. The Iu interface connected to RNC and SGSN. With the use of UMTS radio interface Uu, UE is connected to UTRAN.

Since the core network consists of two service domains: **the circuit-switched (CS) service domain (i.e. PSTN/ISDN) and the packet-switched (PS) service domain (the Internet),** for the users, there are three operation modes defined by UMTS, which are

a. ***PS/CS mode:*** User equipment can attach to PS and CS domain simultaneously.

b. ***PS mode:*** User equipment can only attach to PS domain.

c. ***CS mode:*** User equipment can only attach to CS domain.

III. NETWORK ARCHITECTURE OF WLAN

The WLAN architecture is much simpler as compare to UMTS. An IEEE 802.11 LAN is based upon a cellular architecture. It is a type of local area network that uses electromagnetic waves (radio and infrared) instead of wired connections to send and receive information between the two devices. These entities or mobile hosts communicate with the wired backbone network via one or more access points as shown in the following figure. The mobile hosts contain WLAN adapters which allow them to access the WLAN.

In Figure 2, each Access Point (AP) is controlling a cell which is a Basic Service Set (BSS); these cells constitute a cellular architecture. The whole of this diagram is seen by the upper layers in the OSI model as a single network, which is also called Extended Service Set (ESS) [3].

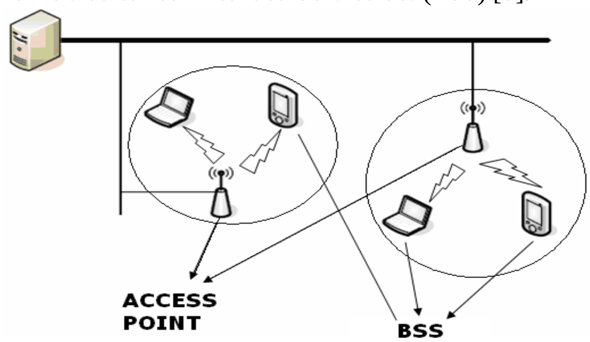

Figure 2. WLAN architecture

The WLAN architecture divides into two parts: (a) Peer-to-peer or ad-hoc mode and (b) infrastructure mode. In **ad-hoc mode**, the mobile hosts communicate with each other directly without involving access points. When two or more hosts are within range of each other they can interconnect and share information. [12] There isn't any requirement of the administration.

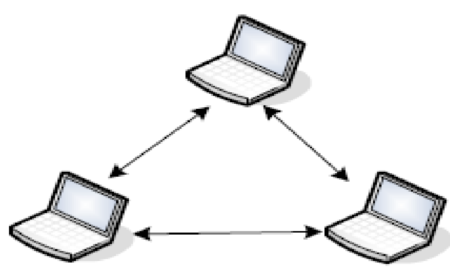

Figure 3. Ad-hoc WLAN mode configuration

The **infrastructure mode** consists of multiple access points connected to the wired backbone network. This allows the WLAN users to share network resources efficiently. The access points act as central communicating stations and balance the network traffic.

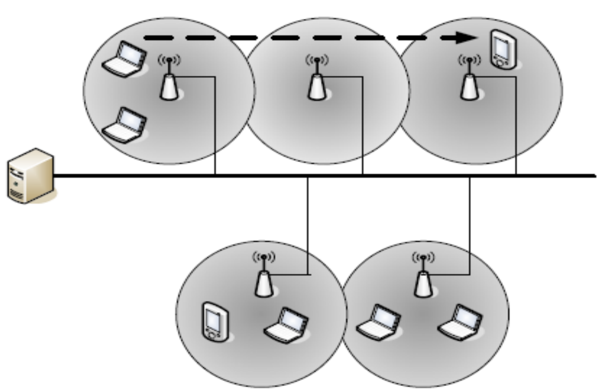

Figure 4. Infrastructure WLAN mode configuration

IV. COUPLING SCENARIO

The ETSI standard developing body has defined standard for the interoperation/interworking of the two systems (WLAND and UMTS). The literature survey of research paper [4] defines loosely coupled and tightly coupled interworking. These two solutions provide different integration level between two networks. The main difference between tight coupling and loose coupling is whether the user's traffic is delivered through the core network of UMTS or not. That is, in case that UMTS and WLAN are tightly coupled, traffic from WLAN flows into the core network of the UMTS and flows out to the external PDN via SGSN and GGSN. On the other hand, in the loosely coupled, WLAN doesn't share any core network nodes of UMTS except AAA functionality. Through tight coupling scheme, the users from WLAN can access the UMTS services with guaranteed QoS and seamless mobility. The designed capacity of UMTS core network nodes are to handle circuit voice calls or short packets so it does not hold the bulky data traffic from WLAN.

The **Mobile IP** [8] internetworking architecture considers 3G and WLANs as independent networks. It allows easy deployment but suffers from long handoff latency and might not be able to support real-time services and applications. The **gateway approach** [9] permits independent operation of the two networks and provides seamless roaming facility between them. It connects the two networks using a new logical node called the virtual GPRS support node. The gateway approach does not require the use of Mobile IP and has a comparatively lower packet loss during handoff. The **emulator approach [8]** is well suited for real time applications because of low handoff latency and requires combined ownership of the two networks. Finally, the **peer-networks** [10] approach allows easy deployment but also suffers from high handoff delays, thereby making it unsuitable for real-time applications. The choice of the integration architecture is important since multiple integration points exist with different cost-performance benefits for different scenarios.

The integration of UMTS and WLAN – loose coupling, tight coupling and hybrid coupling describes in [13] is discussed in detail as below:

A. Loosely Coupled Interworking:

When WLAN and UMTS are loosely coupled, both networks interconnect independently and utilizing one common subscription. In this interworking mechanism, WLAN gateway does not have any direct link to 3G network elements and directly connected to the Internet. They provide independent services. The WLAN data traffic does not pass through the 3G core network but goes directly to the IP network (Internet). For mobility between WLAN and UMTS it uses IP network and MIP mechanism. They connected to each other at the Gi reference point, where GGSN (Gateway GPRS Node) is connected to external packet data network. The architecture of loose coupled network is shown in below Figure 5.

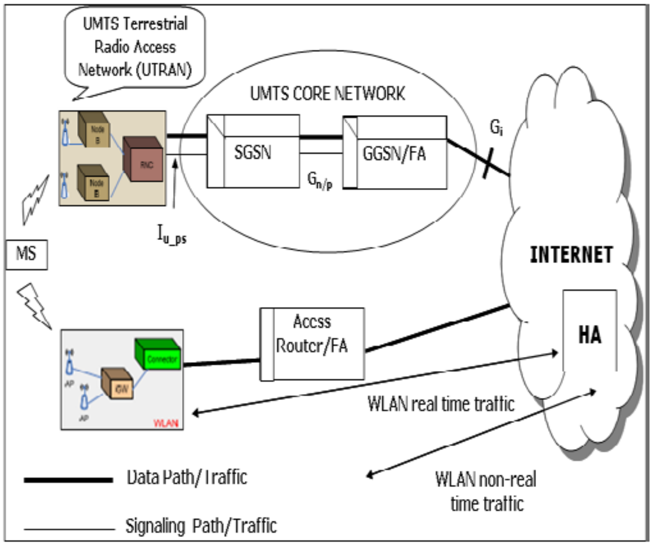

Figure 5. Loose coupled Architecture

In the loosely coupled interworking approach, different mechanisms and protocols can handle authentication, billing and mobility management in the WLAN and UMTS portions of the network. In case of third party network mobility and roaming is enabled via dedicated connections between the operator and wireless LAN. The WLAN gateway must support MIP functionalities for handling mobility access the different networks.

The advantage of using loose coupling is that low investment and it allows independent deployment & traffic engineering of heterogeneous network. It also enables 3G operators without major investment to take advantage of WLAN.

Since each network operates independently, under loose coupling scheme, networks don't need to change their network architectures or protocol stacks. Widespread coverage is possible through roaming agreements with many partners, though loose-coupled network cannot support service continuity to other access network during handover, thus loose-coupled scheme has long handover latency (high handoff delays) and packet loss as well service disruption periods.

B. Tightly Coupled Interworking:

A below given Figure 6 shows the network architecture when WLAN and UMTS are tightly coupled. WLAN is connected to UMTS through Iw-interface which is similar to Iu_ps interface connecting RNC to SGSN. To support Iw interface and connecting WLAN to SGSN, a new node named APGW (Access Point Gateway) should be added. In the core network of GPRS, the WLAN is seemed as a kind of radio access network.

In this approach, the UMTS core network and WLAN network is directly connected to each other. Therefore, UMTS core network accept all the traffic from WLAN. To handle higher bit rates supported in the WLAN network, Support GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN) need to be modified.

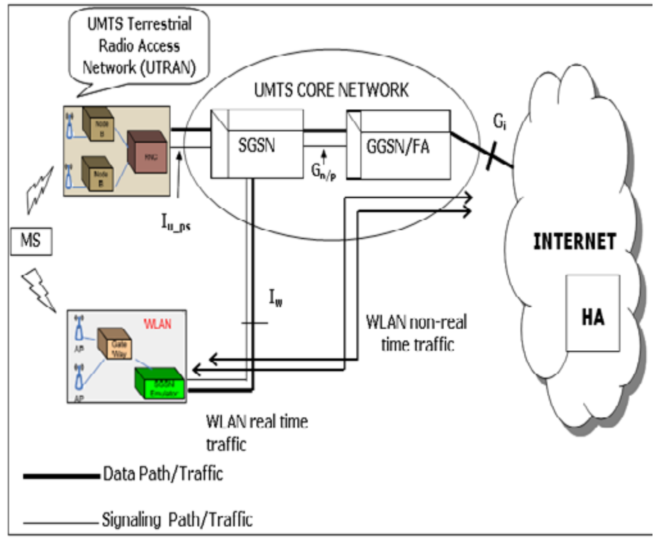

Figure 6. Tight Coupled Architecture

C. Hybrid Coupled Interworking:

The combination of loose coupling and tight coupling architecture is known as hybrid coupling scheme which differentiates traffic paths according to the type of the traffic. For the real-time traffic, tightly coupled network architecture is chosen, and for the non-real time and bulky traffic, loosely coupled network architecture is chosen. For example, the traffic generated from SIP would be delivered along the path of APGW-SGSN-GGSN to application server in external PDN, but the traffic like FTP would be forwarded to Access Routers. The network architecture for the proposed coupling scheme is shown in below Figure 7.

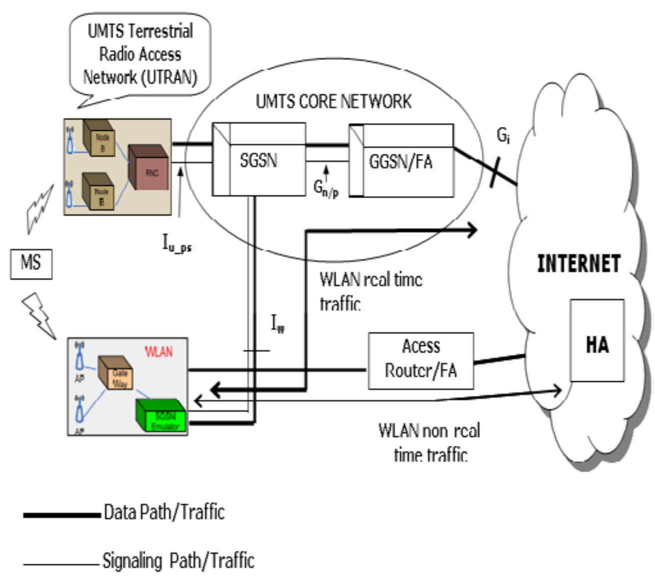

Figure 7. Hybrid Coupled Architecture

The hybrid coupling scheme enables to hold traffic from WLAN efficiently with guaranteed QoS. In addition, it also guarantees mobility and provides seamless service like the tightly coupled scheme while users are moving or need to change their access technologies. Similar to tight-coupled network, APGW should be added to connect WLAN to UMTS network. The functions of APGW are as following:

a. Forward packets to/from AP from/to SGSN or AR.
b. Support Iu_ps-like interface (which is similar to RANAP signaling protocol and Iu data bearer transport)
c. Manage radio resources in WLAN and map them onto radio resources in cellular network.
d. Set data path to SGSN or AR according to the type of traffic.
e. Differentiate service types: UE sets its service type in the TOS (Type of Service) or DSCP (DiffServ Code Point) in the IP header, and APGW checks that and uses to decide path.

Function (1) to (3) are also needed for tight coupling scheme, but the functions related to differentiating service types and paths are needed additionally for implementing hybrid coupling scheme.

In loose-coupled network, real-time traffic could not have appropriate delay and jitter when forwarded through WLAN and internet but due to long handover latency and traffic experiences large packet loss or whole packet calls are even blocked. But when connecting WLAN to UMTS based on proposed hybrid coupling scheme, it is possible to support quality of service of real-time traffic and service continuity during vertical handover for WLAN users.

When tight-coupling scheme is applied, handover latency and packet loss may decrease, but if bulky data traffic like FTP flows into the cellular core network from WLAN, packet loss rate in core network would abruptly increase. But proposed coupling scheme can prevent core network nodes from traffic overflow by means of detouring non-real time traffic of WLAN and not sharing the capacity of core network nodes.

When WLAN and UMTS are coupled by hybrid scheme, it is possible to support seamless handover like tight coupling scheme, using inter-RNC handover-like procedure. In this case, Iu-bearer can be reused and handover procedure doesn't need the procedure to set up new bearers, so latency, dropping probability and packet loss probability during handover would decrease. And hybrid coupling scheme also supports UMTS services like Location based service and Broadcast/Multicast service to users in WLAN.

To support user's IP mobility for all of two paths of real time and non-real time traffic, it is assumed that the mobile IP and its simultaneous binding option are used. That is, when a UE accesses through WLAN, it belongs to two FAs. Then for real-time traffic of WLAN user, FA in UMTS acts as a FA, and in the other case, FA in WLAN acts as a FA. To use simultaneous binding option, HA should have ability to support this option and a user sets the s-bit in Mobile IP header to 1. Packet transmission procedure is the same as the case without simultaneous binding option. To receive packets, two kinds of operations are possible. First, the user receives the same packets twice from two FAs. This is the default operation of simultaneous binding, but has a problem to waste network resources. Second operation needs to use TOS or DSCP in IP header. Users set the TOS or DSCP field according to their traffic type, then HA selects one of two FAs based on value of the field and forwards packets to the FA.

V. HANDOVER MANAGEMENT PROCEDURE

Handover management is a fundamental operation for any mobile network. Though its implementation and functionality differs along with the various technologies but some basic characteristics are common.

Handover management facilitates the network to keep active connections during the Mobile Terminal (MT) movement or even balance the network load consistently surrounded by different areas.

The handover process can be divided into three stages: ***initiation***, ***decision*** **and** ***execution*** [5]. **Handover initiation** is responsible for triggering the handover according to specific conditions such as radio bearer deterioration or network congestion. In **handover decision**, the decision for the most appropriate new Access Point (AP - any point of attachment between the mobile terminal and the network.) is taken. At this phase several parameters (e.g., signal strength of neighboring APs, available radio resources, etc) are considered before a final decision is reached. In **handover execution**, the required signaling exchange for communication re-establishment and data re-routing through the new path is made.

There are mainly three alternatives for handover decision which depending on the way the network and the MT contribute to it: ***network-controlled*** **handover,** ***mobile-assisted*** **handover and** ***mobile controlled*** **handover** [6, 7].

In a **network-controlled handover**, the network decides based on the measurements of the received radio signal from the MTs at a number of APs. This is a completely centralized solution that provides the network with the ability to apply its policy. The main drawbacks of this approach are: i) the requirement for considerable computational power at a central point of the system, and ii) the lack of knowledge about the current conditions at each MT.

In a **mobile-assisted handover**, the MT performs several measurements but the network takes the final decision. In this way, real-time conditions at the MT can be taken into account, although the network still faces major signaling and computational load.

In a **mobile-controlled handover**, the MT has the authority and intelligence to select the target AP based on its own measurements. Obviously, this is a distributed solution where the MTs share the handover decision-making load. This, however, may have impacts on aspects such as network stability, fairness and security, since a global policy cannot be applied.

The main aim of handover management is to care for the communication quality during the handover of a MT. This is strongly related to the way the old links are released and the new ones are established.

In handover, mainly two basic types are exists: the ***soft handover*** and the ***hard*** **handover**.

During the entire handover period, if at least one active link exists between the MT and any AP (old or new) then this procedure is known as **soft handover**. This type of handover is mostly used in CDMA systems where a MT can communicate using two different codes in the same frequency and at the same time.

During the entire handover period, if the MT has an active link with only one AP at a time, then this procedure is known as hard handover [6]. This type of handover is usually found in TDMA and FDMA systems where a period of time is needed for the MT to get synchronized in the new time slot or frequency.

The main challenge is to always perform soft handovers if these are supported by a system and if this is possible. It may possible for the execution of a hard handover because of abrupt signal loss due to physical obstacles.

The intersystem handover avoid change of IP. Therefore, Mobile IP is used as a solution of the network layer issue.

Another issue arise during handover is maximum packet loss and which version of IP used.

To **minimize packet loss** – soft handover is preferred. But to achieve soft handover in different network environment, the mobile device must have multiple interfaces to communicate with the different networks at the same time as needed for soft handover. The mobile device has two transceivers: one for WLAN interface and one for UMTS interface. The mobile device is designed such that it has the intelligence to monitor the signal strength and can make the decisions of handover. Hence, the handover is mobile initiated.

The WLAN can support both IPv4 and IPv6 but the UMTS SGSN does not support the IPv6.

VI. PERFORMANCE AND NUMERICAL RESULTS

According to different approaches based on simulation, here we present some performance and evaluation for the UMTS-WLAN interworking.

In UMTS-WLAN interworking architecture, the resultant data is shown below Diagram (8) as well as tabular data in Table 3. In our test bed simulation data, the architecture of UMTS and WLAN, in which WLAN has 25 access points and provides 100Kbps data service where as the UMTS network has 100Mbps backbone with 5 radio network subsystems and offers 32Kbps data services. WLAN users are 50% and UMTS users are also 50% that assume. Another most important thing is that, all the traffic from both the networks, total 50% of users are dual mode and moves between any two networks. And the other 50% are single mode users using either WLAN or UMTS. Dual mode users have a 0.5 probability to enter the WLAN and a 0.5 probability to enter the UMTS [14].

The vertical handover latency of different strategies of UMTS/WLAN interworking can be found in below chart and Table 2 where experiment results have been illustrated clearly. We implement this on OPNET MODELER 9.1 simulator.

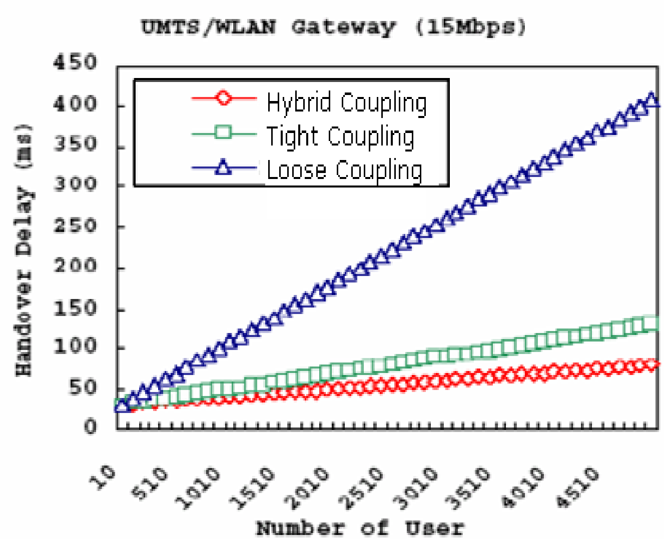

Figure 8. Handover latency of different UMTS/WLAN interworking strategies

The properties of table describes as below for the three interworking scenario:

Table 2. Vertical handoff latency according to UMTS-WLAN interworking

No of Users	Methods		
	Loose Coupling	Tight Coupling	Hybrid Coupling
10	20 ms	20 ms	18 ms
510	75 ms	35 ms	30 ms
1010	125 ms	45 ms	35 ms
1510	150 ms	50 ms	45 ms
2010	200ms	55 ms	50 ms
2510	223 ms	60 ms	60 ms
3010	249 ms	70 ms	65 ms
3510	270 ms	75 ms	70 ms
4010	300 ms	80 ms	75 ms
4510	350 ms	85 ms	80 ms

VII. CONCLUSION

An integrated of WLAN and UMTS networks enhance the benefit to users for high-speed connectivity as well as widespread coverage. Development of architectures that allow interoperability and internetworking between these technologies along with seamless roaming facility is a challenge today.

Handover has been a critical process in both WLANs and cellular systems. This functionality is more difficult to be performed in an efficient manner when user's connections are handed over from one technology to another. In this surveyed paper, Handover management architectures in WLAN/Cellular networks providing a comprehensive summary of interworking solutions about

WLANs and GPRS/UMTS cellular networks. The different frameworks have been described and classified based on the functional point of integration at the UMTS architecture.

Three different categories of coupling handover described. When UMTS and WLAN are connected by hybrid coupling scheme, it is expected that the packet loss probability is lower compared to tight-coupling and from the table statistics shown that the handover latency decreases as compared to the loose coupled network. That is, hybrid coupling scheme enables that the interworking network accommodates the real-time traffic from WLAN efficiently without needs of capacity upgrade of core network nodes nor changes in network and protocol architecture of cellular network.

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