Seamless Handoff between WLAN-Mobile Networks

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Abstract

The growth of wireless technology has brought about a revolution in the lives of people and has redefined as to how people communicate with each other. This has changed human life styles with the new generation hooked up to utilizing its enormous applications in their everyday lives. With the advancements taking place in micro-electronics and wireless communication, ubiquitous applications and services are being used by mobile users through their smart devices is gaining momentum. As a result, wireless communication is becoming integrated with other technologies to provide a unified networking and communication mechanism. This involves mobility into heterogeneous networks without the interruption of services. With the penetration of new data intensive value added services like live streaming big data, video conferencing and multi-media applications, the seamless mobility at high speeds crossing the boundaries of heterogeneous networks at enormous speeds has become a challenge for the researchers. This requires the provisioning of efficient mobility management with high quality of services. Smart handover mechanisms need to be developed to reduce call drop rates and take care of packet loss and latencies so as to provide the users with uninterrupted services.

This research work is directed towards coming up with the analysis and integration of the mobile networks with the wireless local area networks backed by optical fiber backhaul infrastructures to take care of the bandwidth issues and then evaluating the performance of the integrated networks with respect to various application running on them. At present the offered data rates on the cellular networks do not fulfill the bandwidth hungry applications. The research work contributed towards developing a model by creating a simulation environment that can provide the researchers with best results with different conceived network architectures including tightly or loose coupled networks. To be more specific, an integrated mechanism for the integration of these two heterogeneous networks with different variations of tight coupling, including, interconnecting wireless local area networks is implemented and analyzed. The simulated results are studied to ascertain mobility management and handover while looking at the integration performance for the applied applications, type of traffic and the measurement parameters. This has led to coming up with the best network architecture which can provide better response times, improved performance and networking flexibility. The simulation and analysis of the data has provided an efficient mobility solution between the cellular and WLAN network.

Keywords: Networking, Handover, Wireless, Seamless

1. 1. Background

With the evolution of next generation networks, revolutionary changes have been taking place in the telecom sector. The basic idea behind this integration relates to reaping benefits from both the technologies. There is a lack of research as far as coupling cellular & WLAN integrated networks is concerned [1].

Over the past decade, the mobile wireless traffic has experienced an unprecedented

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upsurge as a result of vast applications of mobile devices coupled with the recent application of social networks, e-commerce, traditional real-time voice communication and entertainment, resulting in exponentially growing in the number of electronic devices and data traffic. However, it is generally believed that the 4G mobile networks will not be able to meet the requirements of the trending scenario that will shape the mobile networks by 2020. Since the existing wireless networks are approaching the critical limits, the capacity of wireless communication systems can be further improved through innovation and by optimizing the network schemes and infrastructures to accommodate the next generation multimedia wireless traffic requirements. Seamless communication can be achieved by integrating short rang wireless networks (i.e. WLAN) and wide rang wireless networks (i.e. 5G, LTE, LTE-A, WiMAX). The seamless and systematic handover from one type of access technology to another, known as vertical handoff, is required, though this remains a challenging problem.

As we are aware that in case of integration of two networks, we come up with a term called the heterogeneous networks. When we integrate a Mobile or cellular network [2] with a Wireless Local Loop (WLAN) network, we come up with two homogeneous networks integrated together. The ideal working of these networks depends upon the way they are synchronized together to provide seamless connectivity. This leads to the concept of seamless roaming between the networks, which is the prime area of research and concern in the field of mobile communications. By seamless we mean smooth transition or migration from one network to the other. Cellular and WLAN networks need to complement each other for the provisioning of high speed and reliable service to the mobile users under all conditions.

For this uninterrupted reliable service, the main criteria to be looked into are the hand off mechanism. While the user is roaming from one network to the other, the user should not encounter any delay or interruption of service at any cost. If there is any change in the network condition, the user should not have to interact with system to achieve/enable the handoff. Because of the interdependence of the two wireless networks, there are basically two ways of integration which are described as tightly or loose coupled. But before discussing that, we need to look at the various types of networks which have to be integrated with each other. These includes;

1. Wireless Local Area Networks (WLAN)
2. Mobile Networks
3. Backhaul Backbone Networks

1. 2. Wireless Local Area Network (WLAN)

The network which we will be integrating with the cellular network will be Wireless Local Area Network commonly written as WLAN. Following are the data rates used for the WLAN networks;

- Data rate for (802.11 a) is 11 Mbps
- Data rate for (802.11 b) is 54 Mbps

Below table shows the comparison of IEEE 802.11 versions differences or commonalities.

Standard	Scope
IEEE 802.11a	Physical layer: 5-GHz OFDM at rates from 6 to 54 Mbps
IEEE 802.11b	Physical layer: 2.4-GHz DSSS at 5.5 and 11 Mbps
IEEE 802.11c	Bridge operation at 802.11 MAC layer
IEEE 802.11d	Physical layer: Extend operation of 802.11 WLANs to new regulatory domains (countries)
IEEE 802.11e	MAC: Enhance to improve quality of service and enhance security mechanisms
IEEE 802.11g	Physical layer: Extend 802.11b to data rates >20 Mbps
IEEE 802.11i	MAC: Enhance security and authentication mechanisms
IEEE 802.11n	Physical/MAC: Enhancements to enable higher throughput
IEEE 802.11T	Recommended practice for the evaluation of 802.11 wireless performance
IEEE 802.11ac	Physical/MAC: Enhancements to support 0.5-1 Gbps in 5-GHz band
IEEE 802.11ad	Physical/MAC: Enhancements to support ≥ 1 Gbps in the 60-GHz band

Table 1.1: IEEE Standard 802.11a, b & g

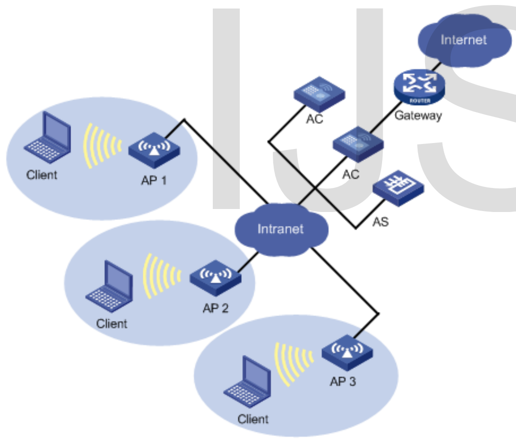
(Source: https://www.slideshare.net/chhattanshah/ieee-80211-architecture-and-services)

The evolution of the WLAN standard is shown below;

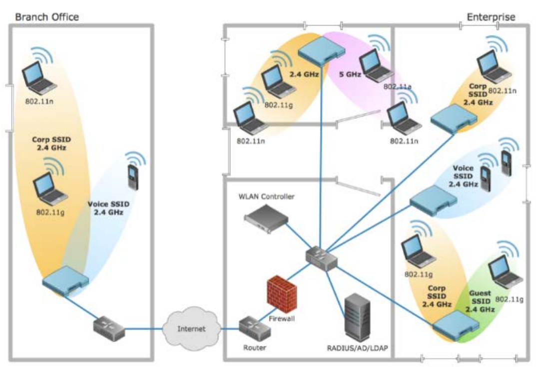
Standard	802.11a	802.11b	802.11g	802.11n
Year	1999	1999	2003	2005
Frequency	5 GHz	2.4 GHz	2.4 and 5 GHz	2.4 and/or 5 GHz?
Bandwidth	54 Mbps	11 Mbps	54 Mbps	100+ Mbps

Table 1.2: WLAN Evolution
(Source: https://www.slideshare.net/Garry54/presentation-4450161)

It should be noted that the deployment cost of the WLAN is minimum if you compare it with that of the cellular network. Various generic WLAN architectures are shown in figure below to understand how they are connected.



(a)



(b)

Figure 1.1: Generic WLAN Network Architectures
(Source: http://www2.ensc.sfu.ca/~ljilja/cnl/presentations/wan/wireless_TCP/sld007.htm)

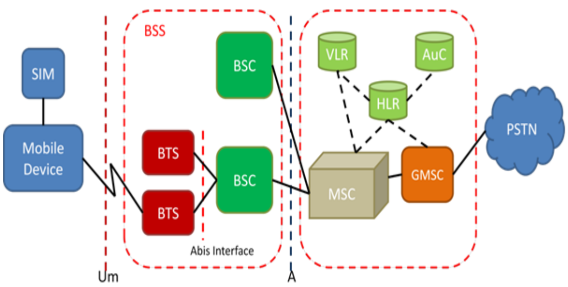
3.Mobile Networks

First generation (1G) wireless cellular started in early 1980s. It was primarily analog transmission, primarily for speech which included AMPS (Advanced Mobile Phone Systems) and others. Second generation (2G) wireless cellular started in late 1980s and was based on digital transmission and catered for primarily speech with low bit-rate data (9.6 Kbps). IT included GSM, IS-95 (CDMA), PACS, etc. 2G evolved to medium rate (< 100kbps) data (2.5G) followed by 3G broadband multimedia operating at speed s of 144 kbps - 384 kbps for high-mobility, high coverage 2 Mbps for low-mobility and low coverage. 3G, 4G and 5G technologies followed which further enhanced the data rates as shown below in the evolution of mobile services slide.

Technology	1G	2G/2.5G	3G	4G	5G
Bandwidth	2kbps	14-64kbps	2mbps	200mbps	>1gbps
Technology	Analog cellular	Digital cellular	Broadbandwidth/ CDMA/IP Technology	Unified IP and seamless combo of LAN/WAN/WLAN	4G+WWWW
Service	Mobile telephony	Digital voice, Short messaging	Integrated high quality audio, video and data	Dynamic information access, variable devices	Dynamic information access, variable devices with AI capabilities
Multiplexing	FDMA	TDMA/CDMA	CDMA	CDMA	CDMA
Switching	Circuit	Circuit/ circuit for access network and air interface	Packet except for air interface	All packet	All packet
Core Network	PSTN	PSTN	Packet network	Internet	Internet
Handoff	Horizontal	Horizontal	Horizontal	Horizontal & Vertical	Horizontal & Vertical

Table 1.3: Evolution of Mobile Networks
(Source: https://www.researchgate.net/figure/Suggested-5G-wireless-performance-We-now-give-a-comparison-of-1G-to-5G-technologies-in_tbl1_303819327)

A typical mobile network architecture is shown below to give an understanding of the networking design;



SIM: Subscriber Identity Module
BTS: Base Transceiver Station
BSC: Base Station Controller
BSS: Base Station Subsystem
MSC: Mobile Switching Centre
HLR: Home Location Register
VLR: Visitors Location Register
AuC: Authentication Centre
GMSC: Gateway MSC
PSTN: Public Switched Telephone Network

Figure 1.2: Typical Mobile Network Architecture
(Source: https://www.gta.ufrj.br/ensino/eel879/trabalhos_vf_2014_2/rafaelreis/background.html)

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1. 4. Backhaul Networks

In order to provide bandwidth from the Internet Cloud, the backhaul network architectures are put in place which provide broadband capabilities to both WLAN and mobile networks data communication infrastructures. It can be a wireless [6] network but ideally it is based on optical fiber backhaul systems. It provides a backhaul access to the cell sites in varied configurations as shown in the figure below.

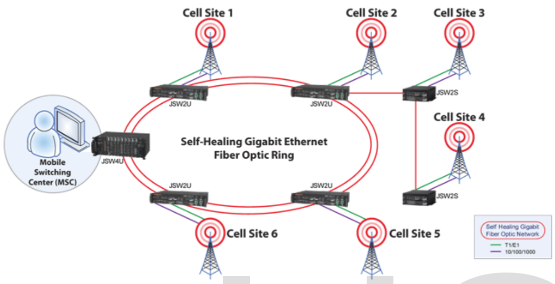

Figure 1.3: Optical Fibre Backhaul Network Architecture

(Source: https://www.tccomm.com/Literature/Default.aspx/Fiber-Optic-Network-Studies/network-System-Integrator-solutions)

5.Networks Integration

Now that we have explained different types of heterogeneous networks involved, we can now talk about the integration of these networks before going on to the analyzation of the traffic patterns and seamless communications. The figure below shows the integration of the WLAN-Mobile/cellular network.

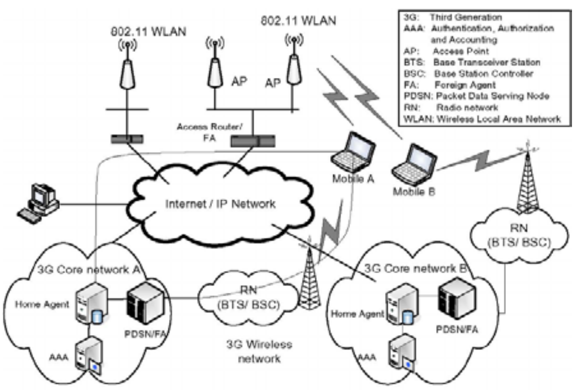

Figure 1.4: Mobile-WLAN integrated Network Architecture

(Source: https://www.researchgate.net/figure/Integrated-UMTS-WLAN-network-architecture_fig1_228943825)

Similarly, the integration of Mobile-WLAN with the backhaul network can be achieved as shown below.

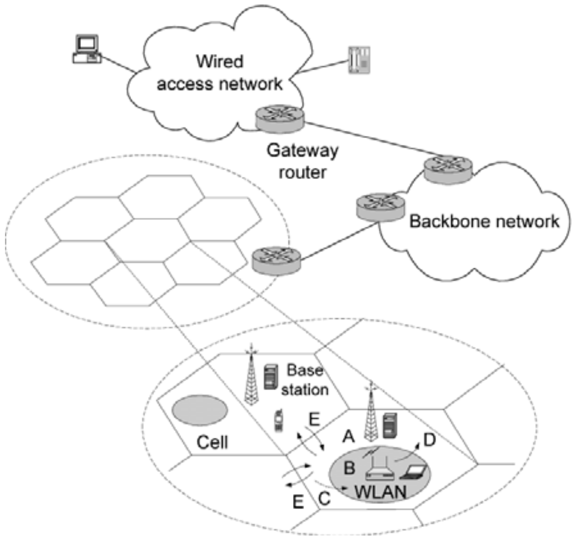

Figure 1.5: Mobile-WLAN-Backhaul Integrated Network Architecture

(Source: https://www.researchgate.net/figure/New-and-handoff-traffic-arrivals-in-a-cellular-WLAN-integrated-network_fig1_3433999)

There are basically two ways of integration which are described as tightly or loose coupled. They are shown in the figures below.

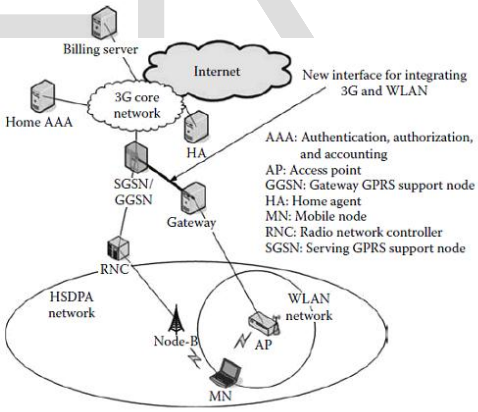

Figure 1.6: Tightly Coupled Mobile-WLAN integration

(Source: http://trends-in-telecoms.blogspot.com/2011/06/heterogeneous-wireless-networks.html)

In case of tightly coupled architecture, requires an interface between the Serving GPRS (General Packet Radio Services) Support Node / gateway GPRS Support Node and WLAN gateway, which requires changes to already deployed mobile networks. Hence it increases network [7] deployment and integration costs.

In case of loosely coupled integration, opposite to tightly coupled one, it integrates mobile/cellular and WLANs basing it on the Internet architecture. The architecture separates mobile and WLANs architectures because of its integration with the internet, hence not needing any modifications to the cellular/mobile network. However, in order to achieve this, mobile management protocol is needed for taking care of the handovers [4].

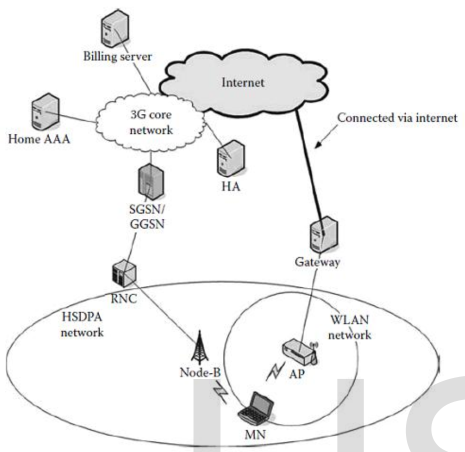

Figure 1.7: Loosely Coupled Mobile-WLAN integration

(Source: http://trends-in-telecoms.blogspot.com/2011/06/heterogeneous-wireless-networks.html)

Additionally, we also have very tightly coupled architectures in which WiFi access points (Aps) are covered by the cellular node and the data traffic can be offloaded to the WiFi network while the control functions i.e. security and mobility [3] etc. remain in the mobile network.

The basic idea of this research is to look at different integration architectures and then pass different nature of traffic through these networks and look at the delays and recommend the best architecture design by comparing the simulation results. The researchers strongly believe that the future of networking lies in having multiple heterogeneous networks integrated together. When we integrate these networks, we are faced with having multiple air interfaces and terminals thus requiring multiple homing facilities in order to ensure good quality of service [11], high bandwidth, less interference, minimum packet loss and lower costs.

These heterogeneous networks may comprise of (or varied architectures) the following;

- Mobile Networks
- Backhaul Landline Networks
- Wireless Wide Area Networks
- Wireless Local Area Networks
- Wireless Metropolitan Area Networks
- Wireless Personal Area Networks
- Satellite Networks

A comparison of the features of wireless technology are shown in the table below;

Network	Standard	Data Rate	Frequency band
Cellular Networks	UMTS 3G	Up to 2 Mbps	1990-2025 MHz
	4G	100 Mbips-1 Gbps	
WLAN	IEEE 802.11b	1-11 Mbps	2.4 GHz
	IEEE 802.11n	100-540 Mbps	2.4, 5GHz
Wireless Personal Area Networks (WPAN)	IEEE 802.15.3	11-55 Mbps	2.4 GHz
Zigbee	IEEE 802.15.4	20-250 Mbps	868, 915 MHz
Wireless Metropolitan Area Networks (WMAN)	IEEE 802.16a	75 Mbps	2-11 GHz
WiMAX	IEEE 802.16c	134 Mbps	10-66 GHz
Wireless Wide Area Networks (WWAN)	IEEE 802.20	2.25-18 Mbps	3.5 GHz

Table 1.4: Comparison of Wireless Technology Features

Users today need connectivity seamlessly when they move from one place to another without having to be bothered about which network they are using at the backend i.e. users do not recognize handover occurrences while using various applications. The continuity of the service is important to them at high speed and without any interruptions. With the penetration of new multi-media applications, the task has become difficult specially when we are dealing with wireless networks. The challenge here is to always get connected to the best possible network in this heterogeneous echo system. Hence, the mobility, management, handovers (vertical) and quality becomes a challenge.

The most crucial performance criteria for the handover design include;

- Latency [5]
- Packet Loss

Short handover latency (ideally below 50ms), low jitter and minimum packet loss are some of the main challenges to be achieved in the heterogeneous environment. This research work is focused on analyzing the integration between mobile/cellular and wireless local area network during the handover process and looking at its impact in terms of the following;

- Delay
- Throughput
- Packet loss

Two integration scenarios have been built;

- Tightly Coupled Integration
- Loosely Coupled Integration

The above two integrations are studies in the light of various kind of traffic data passed over them and then analyzing the results. The type of traffic considered will be;

- Video Conferencing data
- Hyper Text transport Protocol Applications
- File Transport Protocol Uploads

This will be followed by comparison and analysis of this traffic passing through different types of coupled networks. The handover [9] management between the heterogeneous networks will be discussed with the aim to propose scheme for the network selection and handover decisions in the light of evaluated performance parameters.

6.The Research Problem

While reaching an area where cellular network signals are weak/not available, but WLAN Network is available and wise versa. The user should not encounter any delay or interruption of service while roaming from one network to the other. If there is any change in the network condition, the user should not have to interact with system to achieve/enable the handoff.

1. 7. The Purpose of Study

This research aims to reduce the registration delay. The simulation and analysis of the data will provide an efficient mobility solution between the cellular and WLAN network. Integration architecture of the Cellular and WLAN networks, designing global mobility management framework, reducing the registration delay (handoff), designing efficient mobility model for handoff & Packet loss, throughput and average delay analysis will be the prime focus of our research.

1. 8. The Objectives of the Study

Following objectives will be achieved through this research work.

- To achieve efficient mobility for handoff.
- To design a framework that reduces the registration delay.
- To come up with a solution as to how we can reduce the Packet loss, throughput and average delay.
- To Integrate the Cellular and WLAN network's architecture.
- To design global mobility management framework.

1. 9. The Research Questions

Following are the research questions.

- How can we integrate Cellular and WLAN networks?
- How can a mobility management framework be developed?
- How will the framework contribute towards reducing the registration delay?

- How can packet loss, throughput and average delay be reduced?
- How efficient mobility for handoff be achieved?

1. 10. Simulator

Simulation is a cost effective method for developing, deploying and managing network centric systems. Users can evaluate the basic behavior of a network, and test combinations of network features that are likely to work. The network simulation tool will provide a comprehensive environment for creating and animating network scenarios, and analyzing their performance. For this research work, OPNET simulator is used which gives much better results.

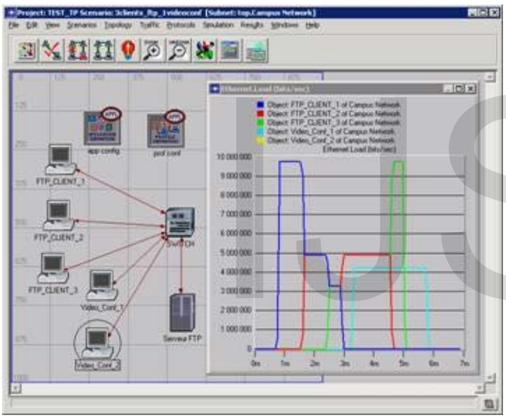

Table 1.5: OPNET Simulator (Snapshot)

11. Scenario

The building of a theoretical framework requires coming up with a scenario to be implemented. A user starts his day while starting his journey to his office on his mobile. When home, he is using the data services through his home installed WLAN network using 802.11 interface with the access point. He sits in his vehicle which is parked outside his home where WLAN access is still available. He switches on the rest of his devices present in the vehicle which includes his iPad and vehicle navigation system; which are dependent on internet connectivity all the time in addition to his mobile.

As the vehicle moves and the home WLAN signal is lost, all the devices in his car shift to the cellular [8] data network, which is detected by his mobile device, which in turn acts like a hotspot to provide connectivity to the iPad and vehicle navigation system. As his journey progresses, he passes through many Wi-Fi hotspots (Wi-Fi ad-hoc networks) and opportunistically selects to offload some data using the multi-hop wireless local area network (WLAN). By using WLAN, he benefits from a higher bandwidth, while using the cellular networks standard mobility mechanisms when the data requirement is less or in an area not covered by the hotspot. He reaches his office ultimately after navigating/moving through the heterogeneous networks.

During his journey, he uses many web applications like Video, HTTP and FTP. While driving his vehicle, he has switched on a video clip via YouTube while browser window on his ipad is used by his family in the car to surf the net. In parallel, his son is also uploading a file through the FTP protocol. In order to achieve seamless connectivity, different handover mechanisms are initiated on the 4G and multi-hop WLAN networks thus providing easy usage of various applications described without any break.

The scenario is very typical in nature as the handover from mobile data to the WLAN and from different WLAN's to again the mobile network data is happening too often during his journey from his home to his office which is located around 10 Km away. The vehicle driver is using all his devices features normally as if he is sitting at his home doing the work. This futuristic approach will allow him to be always on, anywhere and anytime and will provide connectivity at all the times. Any device which becomes the part of the next generation of vehicles system including the GPS, Navigation, Smart Cars, tracking etc. will use these always connected approach to locate and guide the driver in various innovative ways.

12. Scenario Network Architecture

Shown below is the Network Scenario Architecture in which the user is moving between heterogeneous networks of Cellular/Mobile and WLAN.

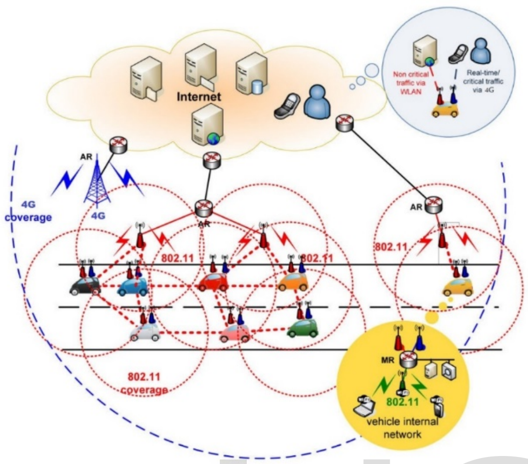

Figure 2.1: Network Scenario Architecture

Note that the backhaul to the internet setup is provided through the optical fiber backbone network for effective distribution of high bandwidth.

13. Proposed solution, and how to be resolved to achieve this scenario

The multiple technologies Integration architecture of the Cellular and WLAN networks is the new dimension of the technological innovation. The real issue pertains to the designing of global mobility management framework for WLAN to cellular and then back to the WLAN network. Things get complicated when we are dealing with vertical handover management for tight and loose coupling networks. More importantly, we need to analyze the results while using various applications like Video, HTTP and FTP on the mobile or the other attached devices. However, what we will be calculating will be the effect of usage of various applications like Video, HTTP and FTP involving seamless handovers between WLAN/Mobile Networks.

14. Requirements from User's Perspective

From the user's perspective, the network should be able to support seamless [10] handover while it moves from one network to the other. Similarly, all the devices working during this time should be using different applications like video, file transfers and browsing on the net without any break or reduction in the quality of service in terms of the bandwidth.

15. Requirements from Network Perspective

Requirement from the network perspective relates to the routing of traffic on the heterogeneous networks through the fast selection of Cellular or WLAN network by analyzing various parameters. This analysis has to be fast enough and ensure that there is no packet loss during this exchange. It should also take care of the tight or loose-coupled network architectures in comparison to apply the respective algorithm for the decision-making. It should take care of the Mobility and Handover management, handover algorithm and the system initiation of the handover process and the final selection of the network (Cellular or WLAN).

16. Requirements from Services Perspective

The service level requirement relates to the continuation of the running of the services on the mobile devices. The services can be broadly categorized as;

- Data Services
- Heavy File Transfers
- Browsing of the Internet

To be more specific, it relates to the applications of video, FTP and HTTP.

17. Technical Setup

Many proposals and approaches considering the handoff schemes are proposed in the literature. These include:

- Received Signal Strength
- Artificial intelligence techniques
- Policy based approaches

The designed model consists of the following segments;

1. Handover Execution
2. Handover Decision Making
3. Handover Initiation
4. Network and Mobile

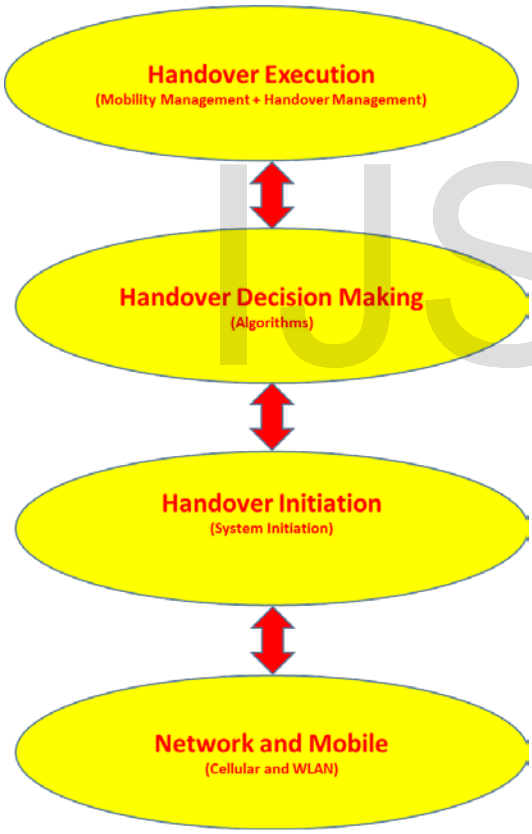

Figure 2.2: System Model

The handover execution comprises of Mobility Management and Handover [12] Management. The handover algorithms reside in the handover decision making block. System initiation takes place when the mobile device moves from one network to the other through a handover initiation mechanism. And finally network selection lets the devices move into the cellular or WLAN network thus ensuring inter-working.

18. Handover Mechanism

Here we are considering a scenario in which a user is moving out of the coverage area of WLAN and exploits the cellular network via vertical handover process. The cellular and WLAN networks can be integrated in two different ways i.e.

- Tight Coupled architecture
- Loosely coupled architecture

The above two architectures were discussed in detail in the previous chapter. The comparison of the two is summarized in the below table for more clarity.

Features	Architecture	
	Tight Coupling	Loose Coupling
Deployment Complexity	Medium	High
Handover Latency	Low	High
Network Management	Cellular and WLAN to be owned by same operator	Independent Deployment of both Networks
Authentication	Cellular Key for WLAN Encryption	Mobile Gateway used for Authentication
Billing	Cellular Billing Platform	Billing Mediator
Teal Time Applications Support	Yes	Not Suitable
Mobility Scheme	Mobility Management Features	Integration Mobile-IP functionality in WLAN Gateway

Table 2.1: Features Comparison (Tight vs Loose Coupling)

For the handover mechanisms, many approaches exist in the literature which are based on;

- Received Signal Strength
- Artificial Intelligence
- Policy Based
- Best Technology System Matrix Based
- Decision Process Based System
- Vertical Handover Based

These are just some of the options available for an efficient handoff. In this research, the vertical handover mechanism is selected. The figure below shows the proposed vertical handover process of Cellular/WLAN integrated networks in a flow chart form.

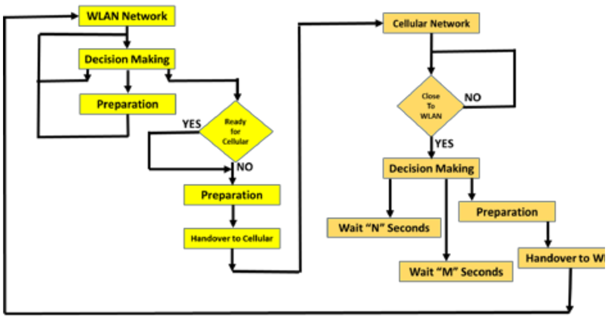

Figure 2.3: Handover between Cellular and WLAN Network

At this stage it is important to select a cellular network from a generation of cellular networks. Universal Mobile Telecommunications Service is selected for its interoperability with the WLAN network.

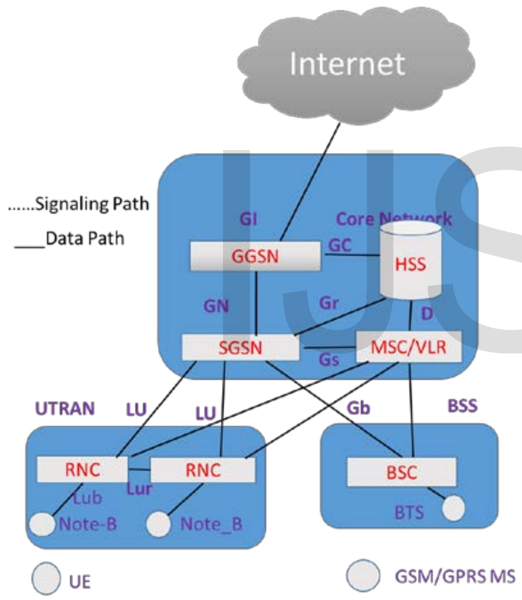

Figure 2.4: Universal Mobile Telecommunications Service Cellular Network

Where,

CN	=	Core Network
AN	=	Access Network
PS	=	Packet Switched Domain
CS	=	Circuit Switched Domain
IMS	=	IP Multi Media Subsystem
SGSN	=	Serving GPRS Support Node
GGSN	=	Gateway Mobile Switching Centre
MSC	=	Mobile Switching Centre
GMSC	=	Gateway Mobile Switching Centre
HSS	=	Home Subscriber Server
BSS	=	Base Station System
MS	=	Mobile Station
RNS	=	Radio Network System
UE	=	User Equipment
UMTS	=	Universal Mobile Telecommunications Service
BTS	=	Base Transceiver Stations
BSC	=	Base Station Controller
RNC	=	Radio Network Controller
UTRAN	=	UMTS Terrestrial Radio Access Network

Once we have defined both the cellular and WLAN networks, it's time for their integration and implementing the scenario. Here the user is at a certain position under the WLAN network. As the coverage area of WLAN is limited, hence it has to use the cellular network as backup. In short, now the user is moving out of the coverage area of the WLAN network and by using the vertical handover process, has to register with the cellular network. Now as we have studied that there are two ways by which the cellular and WLAN network architectures can be integrated, namely in a tightly or loosely coupled manner.

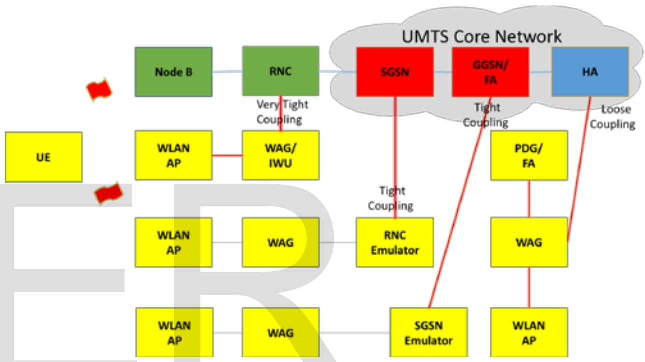

Figure 2.5: Cellular-WLAN integration (Tight & Loose Coupled)

These architectures can provide the roaming facilities between the two networks. All the traffic passes from the WLAN network to the core cellular network. The vertical handover decision is made by following the below mechanism/process.

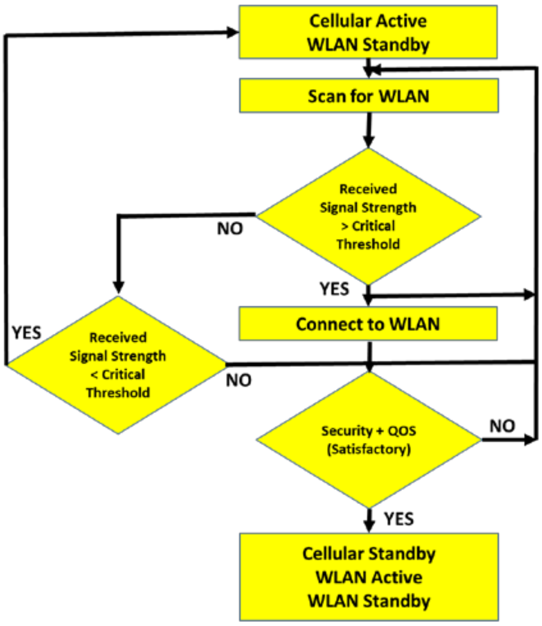

Figure 2.6: Network Selection and Handover Decision

When the mobile node is moving from WLAN network to the cellular network, as is the case with our scenario, the mobile triggers a network selection algorithm for the selection of cellular access node. If the access node is detected, the network selection will be triggered. Hence if the WLAN signal level drops below a certain point, vertical handover will be performed. The traffic will follow the tightly or loose coupled architecture route and the traffic patterns analyzed in the next section will show which architectural route is more effective than the other.

Simulation Analysis & Research Findings

In our research analysis we are looking at the following two network architectures mainly;

- Tightly Coupled Architecture for Cellular/WLAN integrated networks
- Loosely Coupled Architecture for Cellular/WLAN integrated networks

The above two networks were simulated using OPNET simulator and the analysis was carried out for the following internet traffic data.

- Video Applications
- File Transfer protocol (FTP) Applications
- Hyper Text Transfer Protocol (HTTP) Applications

The performance of the above was evaluated for the coupling schemes. We shall discuss the respective applications and the architectures on which they were analyzed.

- Video Applications

Jitter and end to end delay were evaluated which are responsible for the overall quality of service. The jitter response for the tight and loose coupled architectures is shown below.

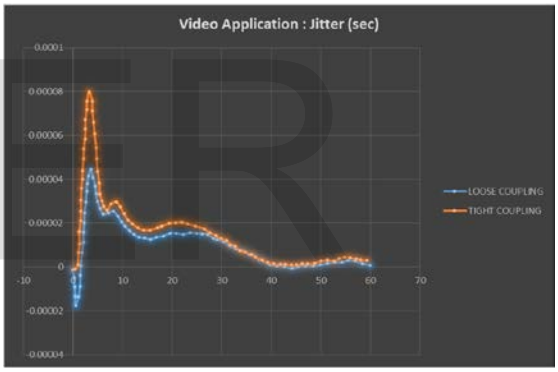

Figure 3.1: Jitter Analysis for Video Application

Jitter is basically defined as the variations of packets inter arrival delay which becomes significant at the time of the process of handoff. In order to calculate the jitter, two consecutive packets leaving the source nodal point were identified where;

T1 = Packet 1 leaving the source node at a time.

T2 = Packet 2 leaving the source node at a time

They arrive at the receiving node at the following times;

T3 = Packet 1 arriving at the destination node at a time

T4 = Packet 2 arriving at the destination node at a time

The jitter is calculated as;

Jitter (J) = {T4 – T3} / {T2 – T1}

As observed in the above graph, the negative values of the jitter indicate that the difference of time between the arrival of the packets at the destination node was less than that at the source node. As can be seen from the simulation results, the loose coupling architecture is providing with a better quality of service having less jitter as compared to that of the tight coupling network path.

Now let's have a look at the end-to-end delay in case of the video application.

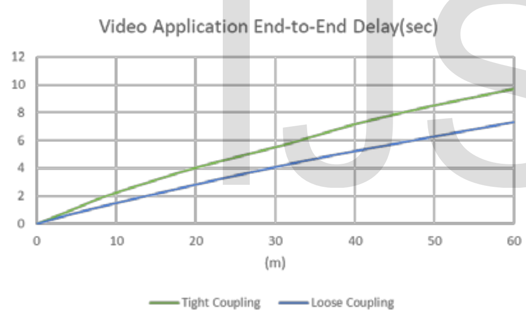

Figure 3.2: End-To-end Delay Analysis for Video Application

As the simulation time increases on the horizontal axis, there is increase of traffic with time and resultantly the end-to-end delay shows increase on the vertical axis. At the start as the traffic is less, hence the delay is less but as the traffic increases over time, the delay becomes much more prominent. Here we also observe that in case of the loosely coupled network the end-t-end delay is observed to be less.

- **File Transfer Protocol (FTP) Applications**

File Transfer Protocol deals mostly with uploading and downloading of the big data files hence the uplink and downlink response times are important. Upload response time is the elapsed time between sending the file and then getting its response. By download response time we mean the elapsed time between sending a request and then waiting its response. The File Transfer Protocol download and upload response times are shown in the figures below.

Figure 3.3: Download Response for File Transfer Protocol Application

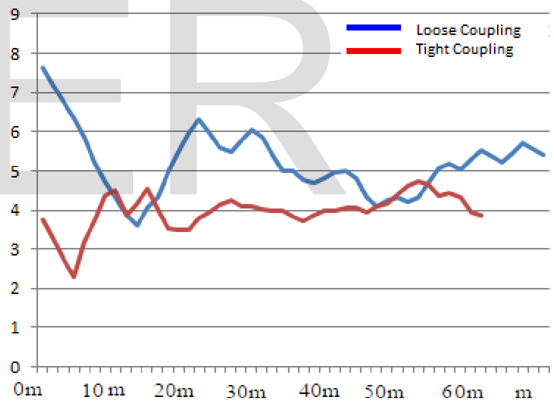

Figure 3.4: Upload Response for File Transfer Protocol Application

In order to understand the above graphs, kindly note that the spikes on the simulated results depict the time when the user is sending a request to the file transfer protocol server for the downloading of the file. I t is observed that when the traffic is less, the response timings for uploading and the downloading times are low. As the simulation time increases, the traffic builds up and the response times start increasing. As can be seen, the loose coupling architecture traffic pattern depict lower download response times. However, in case of the tightly coupled network, it takes more time during the upload when a request to send the file is placed.

- **Hyper Text Transfer Protocol (HTTP) Applications**

The figure below shows the response for loose and tight coupling architectures when hypertext transfer protocol is used to transfer the data.

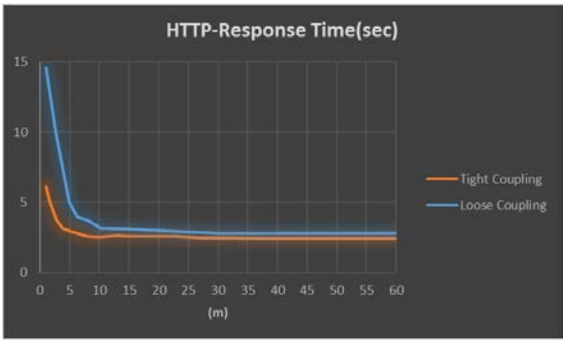

Figure 3.5: Response Time for Hyper Text Transfer Protocol

The figure below shows the response for loose and tight coupling architectures when hypertext transfer protocol is used to transfer the data. HTTP applications traffic was passed through the two network architectures. Increasing simulation times are shown on the horizontal axis. The web pages' response times are shown on the vertical axis. It is observed that the response time of the pages is fast when the traffic of the network is less. However, the response becomes less as the traffic grows. The tightly coupled architecture is showing better results as compared to the loosely coupled network in terms of the response times.

Conclusions

Following are concluded from our simulation results.

- There is a need for the mobile users to move from one network to another network (homogeneous networks) without having to worry about the speed and with the ease of swift uninterrupted handovers.
- To have the best connected mode to achieve ubiquitous communication in a heterogeneous environment is a must.
- Inter System mobility architectures have to be well made.
- Cellular-WLAN integration performance was analyzed in this research work.
- A model architecture was developed in the simulation environment.
- Tight and Loosely coupled architectures were designed and implemented through simulation.
- Both the architectures have advantages/disadvantages which depends on the type of traffic being sent on the network.
- The coupling techniques affect the traffic flows.
- Handoff is also affected by the network architecture.
- Authenticity and mobility, both, are dependent on the type of architecture used.
- For the implementation of the tightly coupled architectures, the prevail ant protocols used in the wireless local area networks need improvements.
- It was found that the loosely coupled network architecture can be easily implemented and can provide us with more efficiency for cellular and WLAN networks integrations.

Contribution to Knowledge (Academic Contribution)

The researcher looked at the integration architecture of the Cellular and WLAN networks and designed a global mobility management framework. This results in reducing the registration delay in the case of handoff. The researcher has come up with a solution as to how we can reduce the packet loss, jitter and average delay and achieve efficient mobility for handoff.

Statement of Significance (Practical Contribution)

Keeping in view the concept of seamless roaming, the packet loss and the throughput mechanisms need to be improved. This will involve deployment of the hot spots at the right places in the network and to study the packet loss, jitter and throughput while the user is roaming between the two networks thus requiring excellent handoff mechanisms. Integration architecture of the Cellular and WLAN networks, designing global mobility management framework, reducing the registration delay (Handoff), designing efficient mobility model for handoff & packet loss, throughput and average delay analysis are helpful in the practical implementations.

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