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EVALUATION OF VERTICAL HANDOVER PROCEDURE IN HETEROGENEOUS WIRELESS NETWORKS ENVIRONMENT

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ABSTRACT:

Modern day communication system supports both real and non -real time services as such they are required to provide seamless end-to-end connectivity between heterogeneous networks. While handover management which bothers on mobility scenarios, metrics, decision algorithms and procedures remains a challenge in this domain, handover latency remains a pressing challenge in wireless mobility. Overall, handover latency causes loss of packets which is intolerable for services such as Voice over Internet Protocol (VoIP) and Multimedia. In this work, we propose an integration mechanism for UMTS-WLAN integration. This is in a bid to realize easy network deployment, and seamless vertical handover (VHO) of mobile user. We also seeks to minimize packet loss and latency incurred as mobile user transverses between the coverage areas of loose-coupled integrated Universal Mobile Telecommunications System (UMTS) and Wireless Local Area Network (WLAN). Simulation of the proposed integration architecture was carried out using OPNET and results from the simulation show that the proposed scheme offers latency of about 2.5% and packet loss of 0.75% during vertical handover and better data services when compared with tight-coupled integration mechanism.

KEYWORDS: *NGN, QoS, UMTS, VOIP, WLAN*

1. INTRODUCTION

The ubiquitous demand for broadband connectivity has evolved the field of Wireless communication. Current mobile communication networks come in two flavors: mobile cellular networks (such as GSM, UMTS) and wireless data networks (such as IEEE 802.11 WLANs, Wi-MAX, and Wi-Fi) [1]. Mobile cellular networks are run by classical Telecommunication Service Providers (TSPs) with the “intelligence” located in the network, rather than on the end-devices (usually mobile phones), which means the network is responsible for control functions such as handover, session setup, among others. Wireless access technologies utilizes the license frequency bands and are regulated by public authorities. Mobile cellular networks are densely deployed and have cell sizes between 500m-35km diameter [2].on the other hand, wireless data networks, are sparsely deployed by minor Internet Service Providers (ISPs) who rely on the Internet for wide-area connectivity. As backbone support. In this network, access and core networks are purely packet-switched and the “intelligence” is in the end-devices, rather than in the network. They cover a distance of about 50m, and utilize the Industrial, Science, and Medicine (ISM) frequency bands as such not requiring any license for operation.

Current research seeks to enhance handover mobility in this diverse network scenario. In this study, we focus on integrating the UMTS (mobile cellular network) and WLAN (wireless data network) architectures in a bid to harness the inherent benefits of both technologies.

Universal Mobile Telecommunications System (UMTS), often referred to as a 3G mobile communication system, has it core network divided into two parts. Foremost, is the part that is responsible for the circuit switched services (CS-domain) and the other manages packet switched services (CS-domain) [3]. While the CS-domain manages voice calls, the PS-domain on the other handle cater for data connections like connections from a mobile device (called user equipment (UE) in UMTS) to the internet.

UMTS is designed to provide global access and world-wide roaming. It supports multimedia, web, email and other data services in a broadband wireless network. It uses WCDMA (Wideband Code Division Multiple Access) technology as the underlying air interface for transmission and offers data rates up to 2-Mbps [4, 5]. Similarly, in Wireless Local Area Network (WLAN), different nodes communicate with each other on the basis of radio waves with WLAN signals broad casted to aid sharing among nodes in range. This, provides much flexibility to users who can easily change their positions without disconnection. This network support a data transfer rate of 1 to 54 Mbps, within a radius of 65 to 300 feet [5].Thus for mobile device to move from one coverage area to another of the same or different networks, handover becomes necessary if its connection is to be maintained. Handover (often referred to as handoff) entails the migration of mobile station (MS) from air interfaces of its current base station (BS) or access point (AP) to air-interfaces of adjacent BS or AP. It is unavoidably incurred when a cell is overloaded or a MS moves out of a BS`s signal coverage. Handovers can be divided into two types: Horizontal handovers and Vertical handovers. While the latter encompass homogeneous intra -network inter-cellular interaction, the former entails inter-network inter-cellular exchange [6].

While it is envisaged that the Next Generation Networks (NGN) will provide seamless vertical handovers (VHOs) to the mobile users, there is a strong demand for the integration of wireless access networks for all-IP based NGN. The European Telecommunications Standards Institute (ETSI) in this regard has defined two generic approaches for the integration of UMTS and WLAN; namely, loose coupling and tight coupling [7]. These two schemes differ in terms of the connecting point of WLAN with a UMTS network. In Tight coupling the WLAN is directly connected to the UMTS core network, i.e., either to SGSN (Serving GPRS Support Node) or GGSN (Gateway GPRS Support Node). Such an internetworking scenario, WLAN appears as another access network of the UMTS core network with signaling and data traffic traversing through UMTS network. On the contrary, loose coupling entails an internetworking scenario in which WLAN and UMTS networks are deployed independently; as WLAN is connected to the internet, it maintains indirect connectivity to the UMTS network.

In this work, we propose an integration mechanism for UMTS-WLAN integration. This is in a bid to realize easy network deployment, and seamless vertical handover (VHO) of mobile user. Ease of implementation is achieved by adopting a loose coupling integration mechanism that does not require significant protocol alteration or introduction of additional network components in existing UMTS and WLAN networks.

To be able to holistically present this work and its findings, the remaining sections of this paper are organized as thus: Section II gives an insight to the current state of art in this area, section III presents the proposed system model for the integration mechanism for UMTS and WLAN. While in section IV, the simulation results and finding are discussed. Finally in section V a general summary and conclusion is given.

2. STATE OF THE ART

Recent advances in Internet technology have changed the way people communicate. With the expeditious increase of wireless packet-switched networks, sending data through the Internet rather than the Public Switched Telephone Network (PSTN) has become the de facto option for users and service providers, thus, adding to huge growth of voice applications over IP networks. With emerging set of smarter devices such as iPhones, VoIP has become a de facto standard for voice applications in the Internet [1, 7]. Mobile phone users can ubiquitously make voice/video call via the Internet with better communication quality and less cost than PSTN. Internetworking of networks avails for better reliability and improved quality of services [8].UMTS a 3G mobile communication network led by Third Generation Partnership Project (3GPP) designed to provide a range of 3G services [9].It is a wireless protocol that is part of the International TelecommunicationsUnion's IMT-2000 vision of a global family of 3G mobile communications systems. The UMTS model suite allows for easy modeling of the network and ease evaluation of end-to-end service quality, throughput, drop rate, end-to-end delay, and delay jitter through the radio access network and core packet network. It can also be used to evaluate the feasibility of offering a mix of service classes given quality of service requirements. It uses Wideband Code Division Multiple Access (W-CDMA) access scheme which utilizes direct spread sequence at a chip rate of 3.84 Mbps and a nominal bandwidth of 5MHz (a pair of 5MHZ channel). The model supports one of W-CDMA's two duplex modes: Frequency Division Duplex (FDD). In FDD mode, uplink and downlink transmissions utilizes different frequency bands with radio frame of 10ms divided into 15 slots, and spreading factors varying from 256 to 4 for an FDD uplink and from 512 to 4 for an FDD downlink at a data rates of up to 2 Mbps [4, 8]. The frequency band defined for UMTS is 1885-2025MHZ for uplink and 2110- 2200MHZ for downlink.

The wireless broadband technologies were developed with the aim of providing services that matches those provided by the wire line networks. Wireless data networks are of two variant depending on their area of coverage. They are: Wireless Local Area network (WLAN) which has a cell radius up to hundred meters mainly used in home and office environments. Wireless Metropolitan Area Network (WMAN) which generally covers wider areas as large as entire cities. Wireless Wide Area Network (WWAN) with a cell radius about 50 km, and covers areas larger than a city [9]. Wireless LANs avails user's high-speed data within a small geographical location. Wireless devices that access wireless LANs are typically stationary or moving at pedestrian speeds. All wireless LAN standards run on the unlicensed frequency bands. In order to provider user ubiquitous seamless Internet connectivity there is a strong demand for the integration of wireless access networks for all-IP based Next Generation Networks (NGN). Though WLAN is capable of providing high data rate at low cost, however, its services are limited to a small geographical area. Universal Mobile Telecommunications System (UMTS) networks provide global coverage, though with high cost and the provided data rates do not fulfill the requirements of bandwidth intensive applications of users. Thus the reason for integration as it promises, several benefits such as [10]:

i. Load balancing and avoidance of congestion. For example, in case of congestion in any specific network, user's data can be sent to multiple integrated wireless access networks. Therefore, by sending data to multiple networks, load balancing and avoidance of congestion can be achievedExtension in coverage area. In other words, cellular and WLAN coverage areas can be extended by the integrated UMTS-WLAN network. For example, a UMTS user can be facilitated by the WLAN in hotspot regions. Likewise, a WLAN user can be supported by the UMTS network when he/she moves away from WLAN coverage region.

ii. Improved QoS for the running application of the mobile terminal (MT);

iii. Improved security features, as the present WLAN security features are not robust enough to avail the required networks security from the network attacks. Therefore, in an integrated UMTS-WLAN network, UMTS security features can be reused for the WLAN;

iv. Interference avoidance and less power consumption, as the far user of the UMTS can utilize the WLAN as the relay network which consequently, improves network capacity.

Integrated WLAN and UMTS architecture encompasses issues such as QoS support, network architectures, mobility management and integrated architectures. For the integration of UMTS/WLAN network, several scenarios have been proposed [11] and these scenarios contribute greatly in defining the way what coupling or the integration techniques to be adopted. Broadly, three variants of coupling schemes abound namely: open coupling, loose coupling and tight coupling. The ETSI has defined two approaches for the integration of UMTS and WLAN; namely, loose coupling and tight coupling. These two schemes differ in terms of the connecting point of WLAN with a UMTS network. Tight coupling indicates that the WLAN is directly connected to the UMTS core network, i.e., either to SGSN or GGSN, with the WLAN appearing as another access network of the UMTS core network in such an internetworking scenario. On the contrary, loose coupling suggests an internetworking scenario in which WLAN and UMTS networks are deployed independently; as WLAN is connected to the internet, it maintains indirect connectivity to the UMTS network [12, 13].

The last decade, has been herald by several research outputs in this domain in a bid to derive maximum utility from the complementary services provided by UMTS and WLAN by the way of internetworking .Maarouf, in [11] juxtapose the open and loose coupling integration schemes using three possible handover solutions i.e., mSCTP, MIP, SIP. He analyzed that loose coupling, preferably using SIP prove to be better result than open coupling. In [27], integration of UMTS and WLAN founded on two variant of tight coupling, i.e., interconnecting WLAN with Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN) was designed and analyzed by Safdar Rizvi and et al. The authors' simulation results revealed that GGSN-WLAN integration outperforms the SGSN-WLAN integration for all the applied metrics of evaluation. [28] , investigated the performance of dual mode radio access protocol design through experimental simulations using various types of applications reflecting different QoS classes in GSM encoded format, FTP, and HTTP (web browsing). The parameters they measured regarding the integration problem included end-to-end packet delay, file upload time and HTTP page response time. Tsao et al. [29], and Anita et al. [30], analyzed gateway, Mobile IP and emulator schemes for UMTS and WLAN network integration. They concluded that Mobile IP is the easiest way to achieve the integration. Furthermore with the Mobile IP, networks can be deployed independently and standards are ready to use. However, the Mobile IP approach is not an appropriate solution for the real time services as the latency is too high during the handoffs. In the gateway approach, handoff latency is much lower compared to that in the Mobile IP approach. However, service and application mobility could not be supported. They also pointed out that the emulator approach is the most difficult approach among the three applied approaches as networks are tightly coupled; though it provides the lowest handoff latency among all of the analyzed approaches. Moreover, emulator approach lacks flexibility since the two networks are tightly coupled. The work of Wei Wu et al in [31] analyzed the handover problem using SIP. The authors provided numerical analysis regarding handover delays. They observed that the WLAN-to-UMTS handover acquires more delay than the UMTS-to-WLAN handover owing to error-prone and bandwidth-limited wireless links in the former situation.

Buddhikot et al. [32] described the realization of a loosely coupled integrated network that supports roaming between 3G and WLAN networks by using both, simple IP as well as mobile IP service. They explained that simple IP service causes service disruption while Mobile IP service increases the handoff end-to-end delay. In [33], Yu Zhou et al. On the other hand proposed a dual-mode mobile terminal module for the integrated UMTS-WLAN network and recommended an algorithm based on network access selection. In [14], Fauzi and Mohammad developed a method for WLAN-UMTS integration and debated a protocol to save resources for handover. In [34], Apostolis discussed some 3G-WLAN integration architectures which will facilitate high throughput at hotspot locations for 3G subscribers. M. Shi et.al [35], proposed an agent based scheme for a WLAN-cellular network. This scheme supports important authentication and event tracking for billing. Moreover, it does not require peer-to-peer roaming agreements between different wireless networks. In [36], an analytical mobility model for soft handoff regions was proposed. Analysis of the proposed model shows a reduction in call blocking and dropping probabilities when a user is moving in between the loosely coupled 3G-WLAN networks.

While several giant strides have been made in this domain in the last decade, none of the present reviewed literatures have explored the option of making tight-coupling integration mechanism less attractive because of its design complexity and high cost of deployment. We thus propose an integration mechanism in an effort to minimize handover latency in loose coupling integration mechanism without significant modification in its architectural simplicity.

3. SYSTEM MODEL

For the purpose of this work, we would be adopting a loose coupling internetworking. This is because in the loose coupling internetwork, the networks are independently deployed and interconnected. From the UMTS network point of view, as illustrated in the figure 3.1, this interconnecting point exists after the Gateway GPRS Support Node (GGSN), i.e., at the Gi interfaces. As such, the WLAN network bypasses the UMTS core network for the establishment of a direct connection with the external Packet Data Networks (PDNs) and at the same time maintains an indirect connection with the UMTS network. For the mobility management, networks often use the Mobile IP mechanism. The loose coupling scheme adopted for this work allows for independent deployment and operation of networks and this is one of its major advantages. This property permits the network service providers to take advantage of other providers’ existing networks .Though this scheme integrates two networks via Gi interface and as such, signal traffic needs to traverse a long path which causes high handoff latency. This set back obviously outweighs the challenge of the tight coupling scheme techniques which connect WLAN AP on Lu-ps interface of SGSN or Gn interface of GGSN and thus requiring the introduction of additional components, i.e., the SGSN Emulator (SGSNE) and the RNC Emulator (RNCE) or gateway device, for the protocols conversion and data routing between UMTS and WLAN networks. Such operations require intensive modifications in the existing protocols and network architecture which consequently increases the operational complexities and overall cost of network deployment. The Proposed Integration Mechanism (PIM) operates when WLAN AP is connected with the GGSN at Gi interface (loose coupling approach) and is able to realize easy network deployment and seamless vertical handover (VHO) of mobile user. PIM is able to attain seamless VHOs by introducing proactive received signal strength (RSS) VHO triggering mechanism in Dual Mode Mobile Terminal (DMMT). Therefore, seamless mobility is attained by sending most of the VHOs signaling messages to the target network in parallel with the already established data session with the previous network. This reduces the number of messages that will influence the overall VHO performance.

3.1 Dual Mode Mobile Terminal (DMMT) Protocol Stack

As shown in figure 2, DMMT protocol architecture for the PIM consists of UMTS and WLAN interfaces to maintain session continuity during vertical handover, and a full protocol stack between the application layer and IP layer. DMMT contains intelligent software known as convergence layer (CL) that operates below IP layer and above UMTS GMM and WLAN MAC layers. Packets coming from higher layer are switched to the intended UMTS or WLAN link layer by CL. For example, if the packets are intended to the UMTS radio access network then the convergence layer will route the packets to the UMTS GMM layer. The GMM appends the GMM signaling information which includes International Mobile Subscriber Identity (IMSI), International Mobile Equipment Identity (IMEI) and cell identity etc.

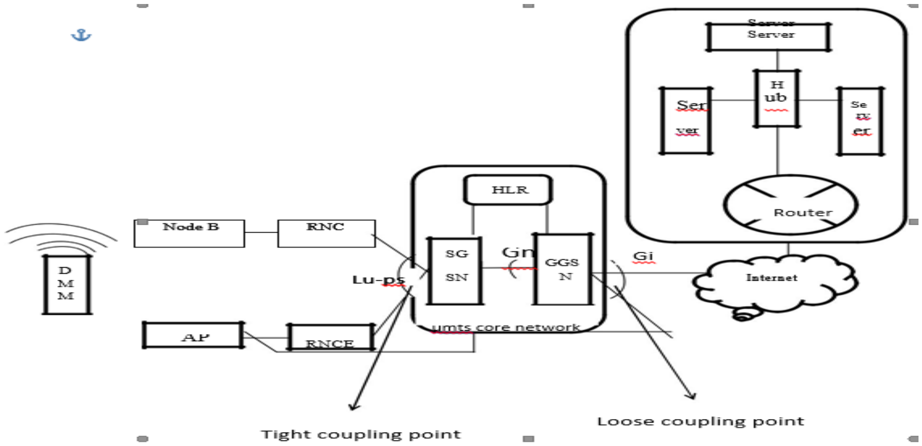

Fig.1: Architecture of the proposed UMTS-WLAN integration

Subsequently, all the packets will be sent to the UMTS RLC_MAC. Finally, the packets will be sent to UMTS radio access network via UMTS physical interface of DMMT. However, if the packets are intended to the WLAN radio access network, then the convergence layer will switch them to the WLAN MAC. The MAC layer will convert the packets into frames and add a MAC header in each frame thatcontains the source and destination MAC addresses information. Consequently, the data stream will be sent to the WLAN radio access network in the form of digital bytes and bits by the WLAN physical layer of DMMT. In addition, the CL continuously monitors the link layer RSS value of the WLAN interface for appropriate and proactive network switching decisions. The major difference in WLAN and UMTS workstations exist after the higher layers. Therefore, the proposed DMMT contains the MAC and physical layer of both UMTS and WLAN technologies.

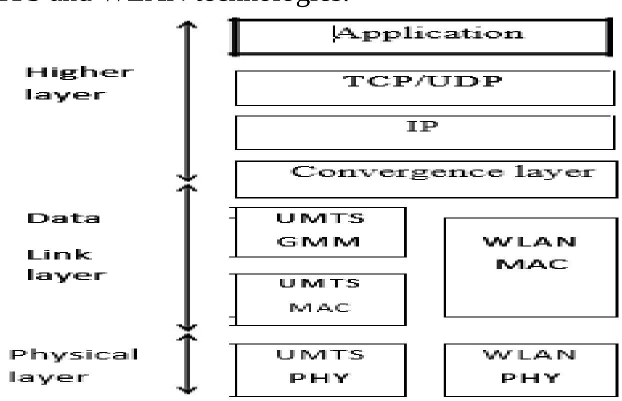

Fig.2: DMMT protocol stack

The simulation model was designed using OPNET Modeler tools. The network design consists of three major parts: UMTS network, WLAN network and Internet Service Provider (ISP). The parameters for investigation are presented in table 1.

Table 1. Simulation Parameters

Application	QoS Class	Protocol	Measurement Parameters	Size
PCM, GSM, G.7231encoded voice	Conversational	UDP	Handover delay and packet loss	80, 33, 20 bytes
FTP	Background	TCP	Download response time	1-100 kilobytes
HTTP	Interactive	TCP	Object response time	0.5-2 kilobytes

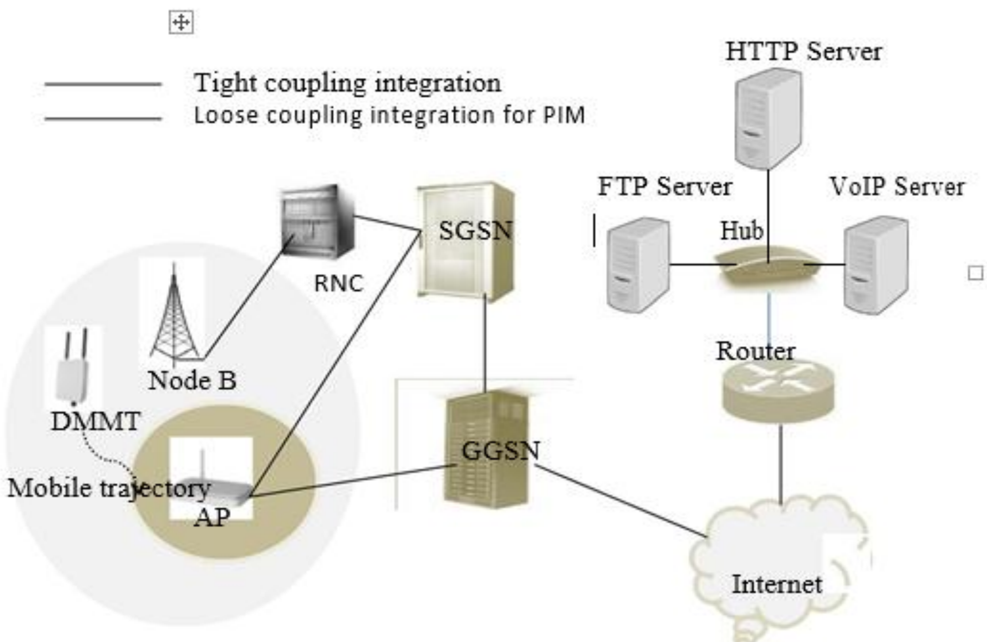

Fig.3 Simulation Parameter

4. SIMULATION RESULT

In this study, two different simulation scenarios have been designed and evaluated. To analyze the data service performance in an integrated UMTS/WLAN network only non-real time services were used by increasing the packet sizes. For the VHO delay and transient packet loss performance assessment, only real time services were used in the integrated UMTS/WLAN network. The downward VHO case was evaluated with all described codecs.

In order to evaluate the data services performance in the integrated UMTS/WLAN network, a static DMMT located inside the WLAN access network and accessing the internet servers by using the PIM and tight coupling mechanism is considered. Table 2 and figure 4 illustrate the average download response time metric investigation with the corresponding file sizes. The download response time represents the time elapsed between sending a request to the internet server (IS) and receiving the requested file from the IS. The connection setup signaling delay is also included in this time. FTP file sizes of 1, 5, 50, and 100 kilo-bytes that comprise of inter-request time of exponential distribution with the mean outcome of 3600, 720, 360 and 3600 seconds, respectively, have been used for the course of 3 h simulation run time. It was observed that PIM gives more rapid download response time compared with the tight coupling (TC) mechanism. For example, as illustrated in the Figure 4, for the small FTP file sizes, the value of the download response time of PIM and tight coupling mechanism are relatively closer. However, as the file size increases, it takes longer time to download the file with the tight coupling architecture compared tothe PIM. For example, for the file size of 1 kilo-bytes, it requires about 0.0119 sec to download the complete file using PIM. On the other hand, the same file can be downloaded in about 0.0120 sec for the user accessing the internet server by the tightly coupled integrated network. Conversely, for the FTP file size of 100 kilo-bytes download response time reaches to 0.271 and 0.292 sec for PIM and tight coupling (TC) mechanism, accordingly.

Table 2.FTP: Download response time (sec).

file size (kilo-byte)	PIM			TC		
	Min.	Max.	Average	Min.	Max.	Average
1	0.01167	0.01211	0.01189	0.01136	0.02770	0.019570
5	0.02330	0.09450	0.05890	0.04436	0.03615	0.075255
50	0.13830	0.15310	0.14570	0.14040	0.16680	0.153600
100	0.27070	0.27070	0.27070	0.26990	0.31420	0.292050

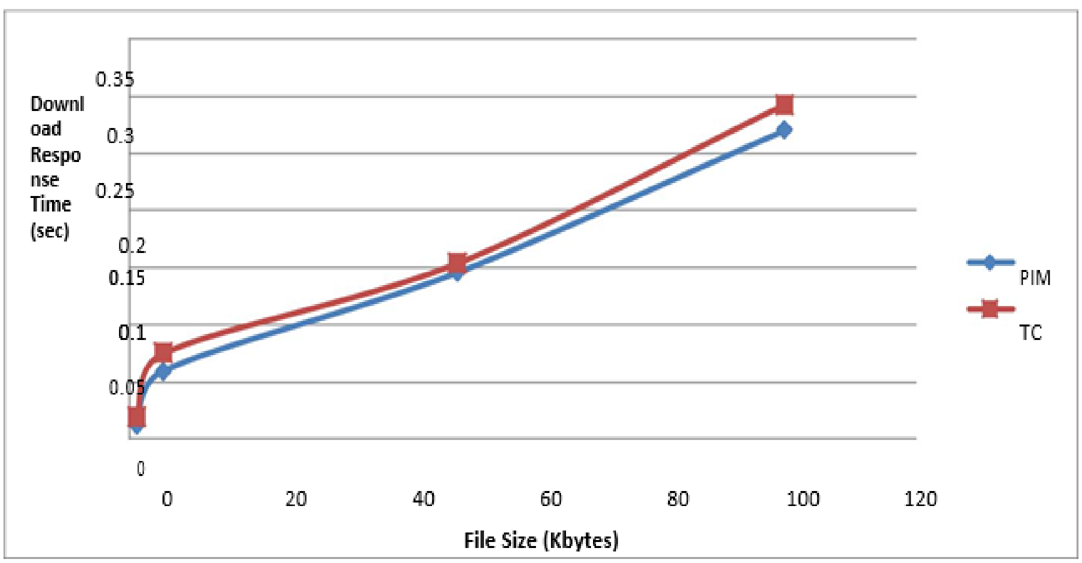

Fig. 4 FTP: Download Response Time

For web browsing, HTTP services have been simulated for the simulation run time of 3 h. As represented in table 3and Figure 5, several variations of web browsing have been used with the different parameters. This performance analysis uses three different variations of browsing i.e., light, heavy and image browsing. Light and heavy browsing contains the object size of 500 and 1000 bytes that consist of page inter-arrival time of exponential distribution having a mean outcome of 720 and 60 sec, respectively. Whereas, image browsing contains the object size of 1000 bytes that comprises of page inter-arrival time of exponential distribution having a mean outcome of 10 sec. In addition, the image browsing also uses medium and large size objects. The minimum and maximum of the medium size object ranges from 500to 2000 bytes. On the other hand, minimum and maximum range of large size object is 2000 to 10,000 bytes.

It can be observed from Figure 5 that the performance of the PIM mechanism is dominant over tight coupling architecture. In tight coupling architecture, downloading is quite slower than the proposed mechanism; therefore, the wireless client will have to wait longer to download the webpage.

Table 3.HTTP: Object response time (sec).

Object size (bytes)	PIM			TC		
	Min.	Max.	Average	Min.	Max.	Average
Light	0.006278	0.008948	0.007613	0.00697	0.01926	0.013115
Heavy	0.009310	0.017550	0.013430	0.00929	0.02007	0.014680
Image	0.036760	0.045910	0.041335	0.03787	0.04800	0.042935

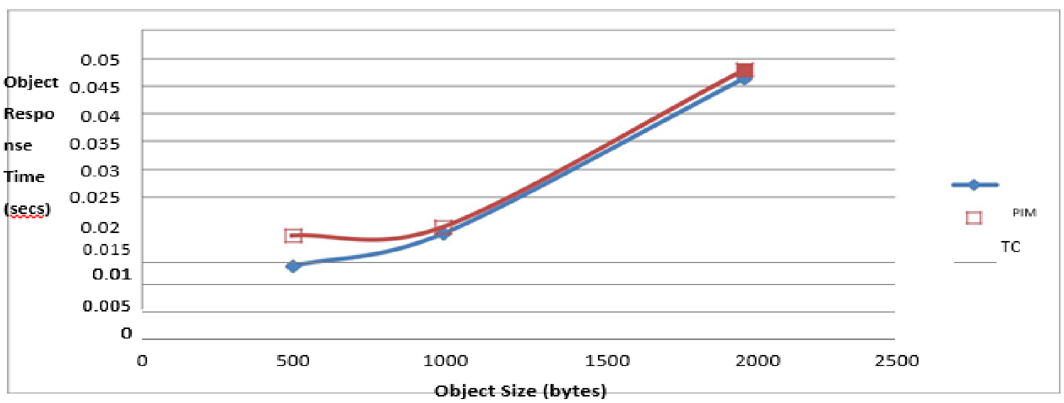

Fig.5 HTTP: Browsing type

These data service enhancements in data traffic scenario are achieved because of the optimal route selection and overhead free mechanism of the proposed protocol. It should be noted that tight coupling mechanism requires a RNC emulator to perform the integration of UMTS/WLAN networks. The RNC emulator performs dual task, i.e., at one time it works as the wireless access point and for the same communication session it operates like an UMTS RAN at its other interface. This format conversion requires additional processing time for every packet. In the case of PIM, no such packet conversion is required for the data session as a simple IEEE 802.11b AP is required to connect with the GGSN. The GGSN appears as a simple router which only route the packet to the intended destination without performing any additional functionality. This simplicity and straightforwardness lead to the low latency and processing requirement for the data session compared with the tight coupling mechanism.

The real time services performance is analyzed by the mean handoff delay of 60 minutes simulation run time as illustrated in Table 4 and Figure 6. It can be observed that the average vertical handoff delays for the UMTS to WLAN network switching, in case of tight coupling mechanism, is 108 milliseconds. On the other hand, by implementing the proposed integration mechanism, the average VHO delay is reduced to 80 milliseconds. Hence, the PIM requires less VHO delay for downward VHO case, compared to tight coupling mechanism because of the proactive RSS based protocol and less signaling and node processing cost requirement for the handoffs.

Table 4: Handoff delay (millisecond) UMTS to WLAN

Codec type	PIM	TC
G.731.1	100.50	150.31
GSM	80.66	102.37
PCM	60.62	72.83
Average delay	80.59	108.50

Fig.6 UMTS to WLAN

Table 5 and Figure 7 plot the size of packet loss with the corresponding codec mechanism used in UMTS to WLAN scenario switching. It can be seen that the packet losses increase with the faster packet arrival rate of data packets by different codecs. Since handoff delay is proportional to packet loss, the tight coupling mechanism incurs high VHO delays and therefore, suffers higher packet loss compared with the proposed integration mechanism.

Table 5.Size of Packet Loss (bytes) switching from UMTS to WLAN

Codec type	PIM	TC
G.731.1	67.00	100.21
GSM	133.09	168.91
PCM	232.65	279.52

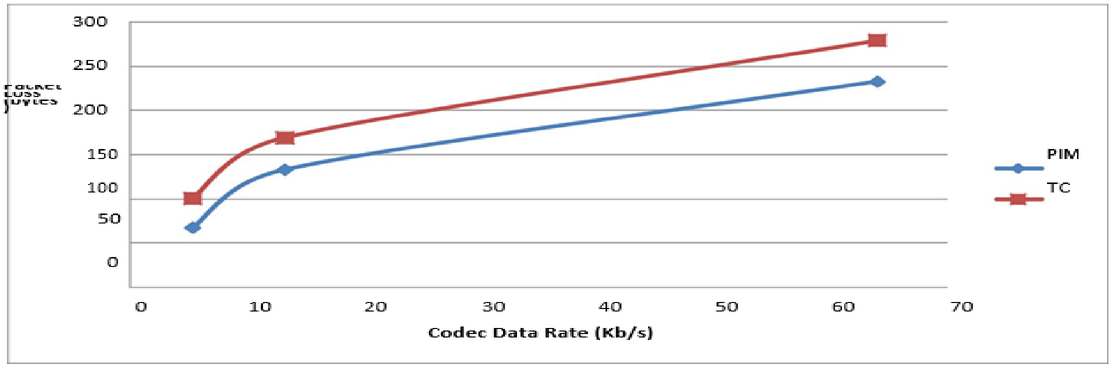

Fig.7 Size of Packet Loss against Codec Data Rate

5. CONCLUSION

Integrated WLAN and UMTS networks benefit users with both 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. In this thesis, several network coupling mechanisms for the integration of UMTS and WLAN networks have been reviewed. The loose coupling mechanism provides ease of network implementation; however it does not provide seamless mobility features and introduces high handoff delays and packet losses during handoff which are not acceptable for the real time services. The seamless mobility can be achieved by the tight coupling mechanism. Nevertheless, significant modification in the network topology and protocol design makes the tight coupling mechanism less attractive for the network service providers because it eventually increases the network design complexities and total cost of deployment. This work has been focused on the mechanism that bridges the gap between network implementation simplicity and seamless mobility. Therefore, the proposed integration mechanism (PIM) in this work meets the requirements of seamless mobility during vertical handover and ease of network deployment by avoiding significant alteration in the already existing technologies. The simulation results reveal that the PIM has less handoff delay and low packet losses during downward vertical handoff when compared with tight coupling mechanism. This has been made possible due to the proactive dynamic interface switching of DMMT based upon the received signal strength of the WLAN beacon signal. The technique enables smooth handoff process to take placewhile moving across heterogeneous networks by decreasing the signaling and processing cost of the network. It can also be observed that the size of packet lost is proportional to the packet arrival rateof a particular voice stream with PCM having the maximum packets lost and G.723.1 the minimum. Similar to the handoff delay, it is also noticed that the PIM gives less packet loss when different codecsare used than tight coupling integration mechanism.

When the DMMT is communicating with the internet servers through WLAN network, in contrast to the tight coupling mechanism, in which data session traffic follows: IS ↔ Internet ↔ GGSN ↔ SGSN ↔ RNCE ↔ DMMT, in PIM data session will traverse IS ↔ Internet ↔ GGSN ↔ AP ↔ DMMT. This means that not only SGSN is bypassed; moreover, the PIM provides an optimal routing mechanism by decreasing the number of network hops to/from internet servers. Unlike the tight coupling mechanism, no tunneling is required to be established between the network nodes forthe data transportation in the PIM. Thus, no tunneling overheads are required for the data session. As a result of the optimal routing technique and overhead free mechanism, data service performance improvements have been achieved in the PIM in terms of FTP download response time and faster web browsing.

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