Tight Coupling Internetworking Between UMTS and WLAN: Challenges, Design Architectures and Simulation Analysis

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Abstract

To provide seamless internet connectivity anywhere at any time to the mobile users, there is a strong demand for the integration of wireless access networks for all-IP based Next Generation Networks (NGN). The Wireless Local Area Network (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, however, cost is high and the provided data rate do not fulfill the requirements of bandwidth intensive applications. By integrating these two promising technologies; UMTS and WLAN several benefits can be achieved, i.e., load balancing, extension of coverage area, better Quality of Service (QoS), improved security features, etc. Therefore, the integration of these two technologies can provide ubiquitous connectivity and high data rate at low cost to wireless clients. In this paper different integration mechanisms of UMTS and WLAN are investigated. More precisely, an integrated mechanism for the integration of UMTS and WLAN based on two different variations of tight coupling, i.e., interconnecting WLAN with Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN) is designed and analyzed. The simulated results reveal that the GGSN-WLAN integration performance is better than the SGSN-WLAN integration for all the applied applications and measurement parameters.

Keywords: Vertical Handoff, Heterogeneous Networks, UMTS-WLAN Integration, Tight Coupling Integration, Loose Coupling Integration.

1. INTRODUCTION

Widespread acceptance and technology advancement in internet usage and mobile communication has changed the shape of the telecommunication world. At the time when the internet was launched, internet usage was considered limited to research, scientific and academic institutions. In a similar manner, mobile communications was limited because of its high cost and low coverage area. Nowadays, the World Wide Web (WWW), file transfers, and communications through the internet are deemed necessary in daily life and not only limited to the business purposes [1]. In the mid-1980s, first commercial mobile network has been launched. Since then, the communication world has been witnessing drastic changes and significant improvements of services offered by the cellular networks. The evolution from 1G to 4G networks is clearly indicating the fulfillment of customer's demands and better enhanced services provided by the cellular networks. These facts represent a clear success story of cellular communication [2].

Network	**Coverage**	**Data Rates**	**Cost**
Satellite	World	Max. 144kb/s	High
GSM/GPRS	Approx. 35 km	9.6 kb/s up to 144kb/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 300m	25 Mb/s	Low
IEEE 802.11a	50 up to 300m	54 Mb/s	Low
IEEE 802.11b	50 up to 300m	11 Mb/s	Low
Bluetooth	10m	Max. 700 kb/s	Low

TABLE 1: Diversity in existing and emerging wireless technologies [3].

At present, there are number of wireless access networks providing services to the end user. However, as illustrated in Table 1 [3], every access network has some inherent limitations and ranges in terms of data rate, coverage area, cost of services, etc. To provide services anywhere at any time, integration of wireless networks is a milestone. In the integrated unified network scenario, a user can be facilitated by the best features of each integrated wireless access network for the same data session.

The vision of 4G wireless networks is to integrate different wireless access networks to form a unified network that can provide services anywhere at any time. It is speculated that 2G, 3G, UMTS, WLAN, Worldwide Interoperability for Microwave Access (WiMAX), etc., would be operated under a unified integrated 4G network. In addition, ad hoc and wireless sensor networks would also be the part of integrated 4G networks. These heterogeneous wireless access networks will be interconnected with each other via an Internet Protocol (IP) network back bone and the internet. Such a unified network of heterogeneous wireless access networks is illustrated in Fig. 1. The main drivers of such integrated heterogeneous wireless access networks are excellent mobility supports and extensive supports of IP-based traffic [4].

Intensive research has been ongoing to integrate two most promising wireless technologies, i.e., UMTS and WLAN, to provide ubiquitous connectivity and high data rate to the wireless client. WLAN provides high data rate; however, it serves a small geographical area. IEEE 80.11b operates in license-exempt band i.e., 2.4 GHZ and provides a data rate up to 11Mbps [5]. Whereas, 802.11a and 802.11g operate at license-exempt band i.e. 5GHZ and 2.4GHZ, respectively, and provide data rate up to 54Mbps[6]. Although, WLAN coverage ranges are limited to 300 meters. On the other hand, UMTS provides global coverage; however, the data rate is limited to the maximum of 2Mpbs at high operational costs. The major limitation of UMTS networks is that they cannot serve indoor, small and densely populated areas, i.e., hotspots [7]. A WLAN network is an optimal network to provide high data rate at a very low operational cost to serve such dense and bounded regions.

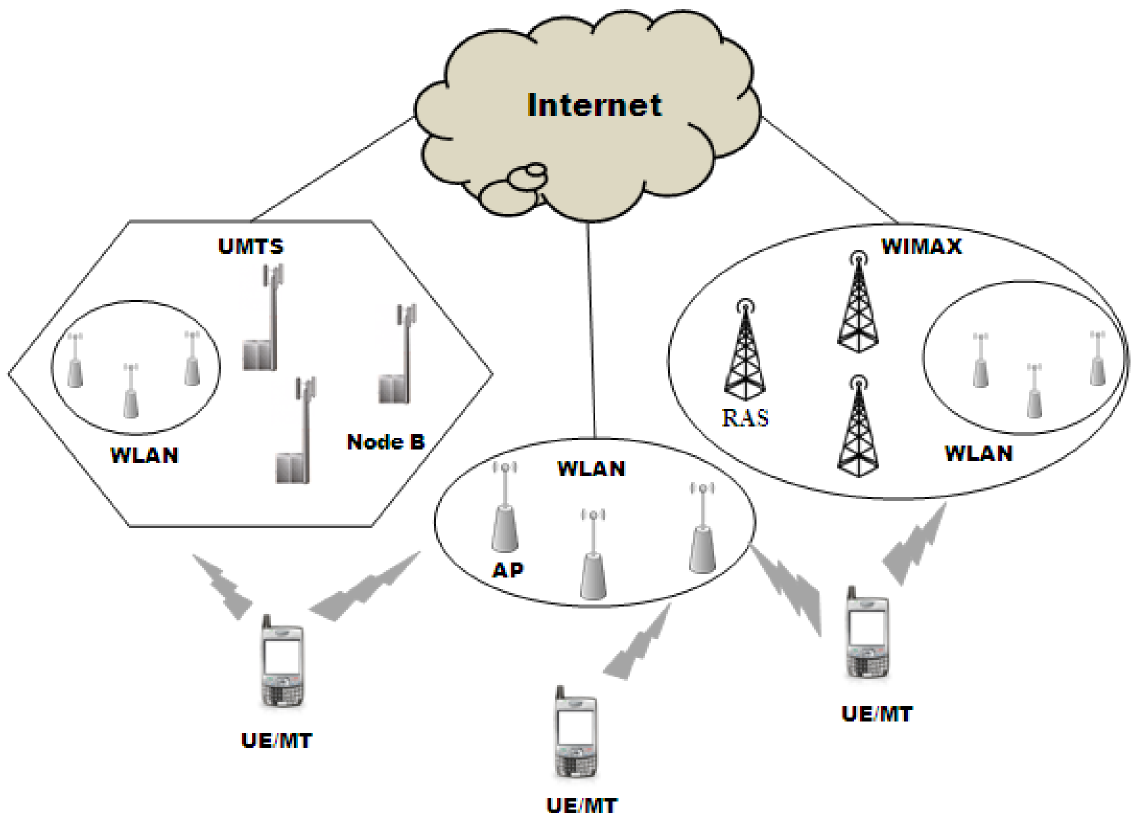

FIGURE 1: Integration of heterogeneous wireless access networks.

Therefore, the integration of UMTS and WLAN networks offers the wireless client best services experience at hotspot areas where bandwidth intensive applications are more demanding. For example, if a user is moving from the UMTS network towards a hotspot region that is being served by the WLAN network, then the same running session can be facilitated with the high data rate and low cost WLAN network. In contrast, if the user is moving away from the hotspot then the overlaid WLAN network data session can be facilitated by the UMTS. Consequently, discontinuing the running session on the Mobile Terminal (MT), due to an “out of coverage” constraint, can be eliminated by the integrated overlaid wireless network.

For the integration of UMTS/WLAN network, six scenarios have been proposed [8] [9] [10]:
I. Simplest form of integration: Common Customer Care and Billing.
II. 3G-Based Charging and Access Control.
III. Access to 3G Packet Switched (PS) services.
IV. Access to 3G PS services with the Service Continuity maintenance.
V. Access to 3G PS services with Seamless Service Continuity.
VI. Access to 3G Circuit Switched (CS) services with Seamless mobility.
These scenarios play a major role in defining the way of coupling or the integration technique. Broadly, coupling schemes are divided into three classes: open coupling, loose coupling and tight coupling.

This paper mainly focuses on the tight coupling integration scheme of UMTS and WLAN. Both variations of the tight coupling architecture, GGSN-WLAN and SGSN-WLAN, have been analyzed with respect to different services and parameter values. The remainder of the paper is organized as follows. Section 2 describes the technical challenges and issues related to the integration of the wireless heterogeneous networks. Section 3 illustrates the advantages of the 4G heterogeneous wireless environment from users’ and network operators’ point of view, and the advantages of the integration of UMTS-WLAN networks. Section 4 discusses the related works and associated contribution for the integration of wireless networks. In Section 5, we demonstrate the different approaches for the integration of wireless networks and their advantages and disadvantages. Simulated network architecture and results obtained are represented in Section 6. Finally, conclusion drawn from the paper and future work are discussed in Section 7.

2. TECHNICAL CHALLENGES

The integration of UMTS and WLAN networks brings a lot of technical challenges and problems. UMTS and WLAN are two different technologies that came into existence to serve different goals and to fulfill different service demands [11]; the implemented protocols, algorithms, data rate, authentication mechanisms, handoff mechanism, coverage ranges, etc., are dissimilar. In the same fashion, an integrated user terminal mechanism that equips the user terminal with multiple wireless access networks is required. To support seamless mobility among heterogeneous wireless networks, sophisticated mechanisms and vertical handoff decision algorithms are required.

In vertical handoffs (VHO), i.e., handoffs between radio access networks which are representing different technologies, an additional delay is occurred to disconnect from the current serving radio access network, and to connect to the target radio access network. Therefore, correct time to initiate a VHO request and selection of the best available target network among the range of available network are crucial. Moreover, minimizing the vertical handoff delay is an important factor to avoid packet loss and degradation of services during VHO.

Vertical handoff can be categorized as downward VHO (handoff towards high data rate network with smaller coverage area, from a low data rate network with larger coverage area, e.g., from UMTS to WLAN) and upward VHO (handoff towards low data rate network with larger coverage area, from a high data rate network with smaller coverage area, e.g., from WLAN to UMTS). Downward VHO are basically opportunity based VHO; i.e., User Equipment (UE) performs VHO to the target network, e.g., from UMTS to WLAN network, even when the current network is still available. Such VHO is performed to achieve high data rate and low cost services. Handoff timing is not often crucial in downward VHO. In upward VHO, UE is currently served with the high data rate and low cost network; it needs to perform VHO because it is moving away from the current network coverage area, e.g., from WLAN to UMTS network. Hence, in such type of VHO timing is crucial. An early handoff results in unnecessarily high cost and low data rate services of the target network, whereas a late VHO results in packet loss and degradation of service [12]. Downward and upward VHOs are illustrated in Fig. 2.

Similarly, a unified protocol stack is required to make networks compatible among one another. Seamless mobility, QoS, Authentication Authorization and Accounting (AAA), vertical handoffs etc., in such heterogeneous environment are still under intense research. Before answering these issues the robust integration of these promising technologies would never exist.

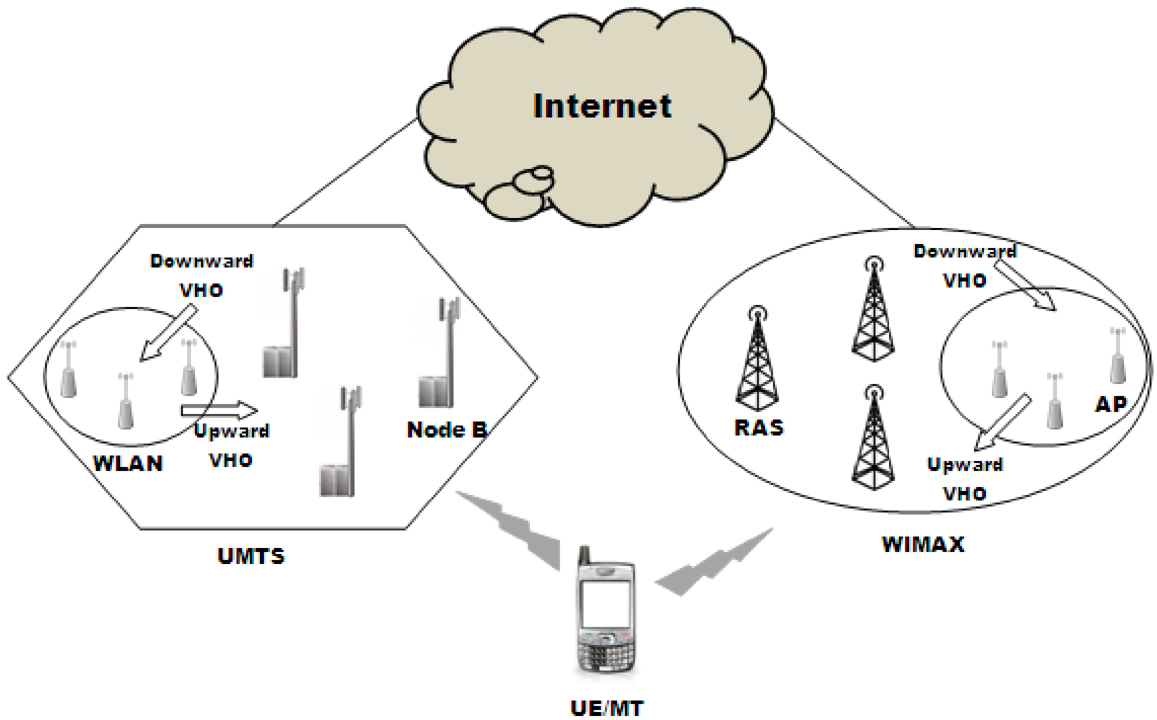

FIGURE 2: Downward and upward VHO in wireless heterogeneous networking environment.

3. ADVANTAGES OF UMTS AND WLAN INTEGRATION

The 4G networks will provide several benefits to the user and service providers [13, 14].From the users' point of view; they will have an opportunity to select a network among all the integrated networks. Therefore, the issues such as being out of coverage and limited capacity offered by some specific network will no longer exist. Moreover, 4G networks will allow them to seamlessly connect to the network that is providing a large number of available resources. Therefore, the concept of "anywhere, at any time, and always connected with the best network" can be provided to the user. From network operators' point of view, such integrated wireless heterogeneous networks will provide efficient utilization of available network resources of each wireless network. Furthermore, already deployed networks can be reused to provide anywhere at any time and always-on services, global coverage, low cost for the running session of mobile terminal and best services.

Moreover, the integration of UMTS-WLAN networks leads to achieve [7]:

- 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 achieved.
- extension 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 facilitated by the UMTS network when he/she moves away from WLAN coverage region.
- better QoS for the running application of the MT.
- improved security features, as the WLAN security features are not robust to provide the required networks security from the network attacks. Therefore, in an integrated UMTS-WLAN network, UMTS security features can be reused for the WLAN.
- interference avoidance and less power consumption, as the far user of the UMTS can use the WLAN as the relay network which consequently, improves network capacity.

4. RELATED WORKS

Intensive research has been conducted by the various parties to integrate 3G and WLAN networks. Tsao et al. [15], analyzed different UMTS and WLAN network integration approaches namely gateway, Mobile IP and emulator schemes. 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. The emulator approach is the most difficult approach among the three applied approaches as networks are tightly coupled; however, it provides the lowest handoff latency among all of the analyzed approaches.

In [16], Apostolis proposed and discussed some 3G-WLAN integration architectures which will enable high throughput at hotspot locations for 3G subscribers. In [7], Fauzi and Mohammad proposed architecture for WLAN-UMTS integration and discussed a protocol to reserve resources for handoff.

In [17], F. Siddiqui et al. proposed and implemented architecture for a dual interface mobile terminal that switches its active data transmission, and evaluated handoffs performance in between UMTS and WLAN networks. In [18], Yu Zhou et al. designed a dual-mode mobile terminal module for the integrated UMTS-WLAN network and proposed a utility-based access selection algorithm for the load balancing in between them. Usman et al. [19], proposed a scheme for the authentication of a mobile node in a heterogeneous wireless environment. While switching its current running application from one network to another network when GRPS-WLAN networks are tightly coupled [19], MT shows its authentication certificate to the target network. This authentication certificate is given to the MT when it authenticates for the first time. This authentication certificate is used for re-authentication whenever MT performs vertical handoff.

M. Shi et.al [20], proposed an agent based scheme for a WLAN-cellular network. This scheme supports relevant authentication and event tracking for billing. Moreover, it does not require peer-to-peer roaming agreements between different wireless networks. In [21], the authors proposed an analytical mobility model for soft handoff regions. It is analyzed that the proposed model reduces call blocking and dropping probabilities when a user is moving in between the loosely coupled 3G-WLAN networks.

In contrast to the above mentioned research efforts, the prime concern of this paper is to study the effects of two tight coupling architecture variations on different applications and services. When WLAN is connected to the SGSN and when it is connected with the GGSN. These variations are termed as SGSN-WLAN (when WLAN is connected to SGSN) and GGSN-WLAN (when WLAN is connected to GGSN).

5. INTEGRATION SCHEMES

In the literature, several types of integration schemes have been proposed [5], [6], [22] [23], [24]. European Telecommunication Standards Institute (ETSI) has defined two generic approaches for the integration of UMTS and WLAN; namely, these are 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. In such an internetworking scenario, WLAN appears as another access network of the UMTS core network. Signalling and data traffic traverse through UMTS network. 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.

5.1 Loose Coupling

In the loose coupling inter-networking, networks are deployed and interconnected to each other independently. The WLAN is connected to the Internet Protocol (IP) network to maintain an indirect link with the UMTS network. From the UMTS network point of view, this inter-connecting point exists after the GGSN. For the mobility management, networks use the Mobile IP mechanism [25, 26].

As illustrated in Fig. 3, three promising wireless technologies, i.e., UMTS, WLAN and WiMAX, are integrated to form a unified network. To maintain interconnection, interconnecting devices such as WiMAX and WLAN gateways are required for roaming purposes. These gateways are used for the support of billing and authentication purposes. Mobile IP is used to support mobility among UMTS, WLAN and WiMAX networks [27]. Both gateways are connected to UMTS AAA server which in turn connects them to the internet. Hence, no direct connection between UMTS and WLAN/WiMAX exists. Subsequently, WiMAX and WLAN data traffic directly traverse to the internet instead of traversing through the UMTS core network. This approach enables a UMTS service provider to collect accounting records of WLAN and WiMAX and generate a combined billing statement for all integrated networks.

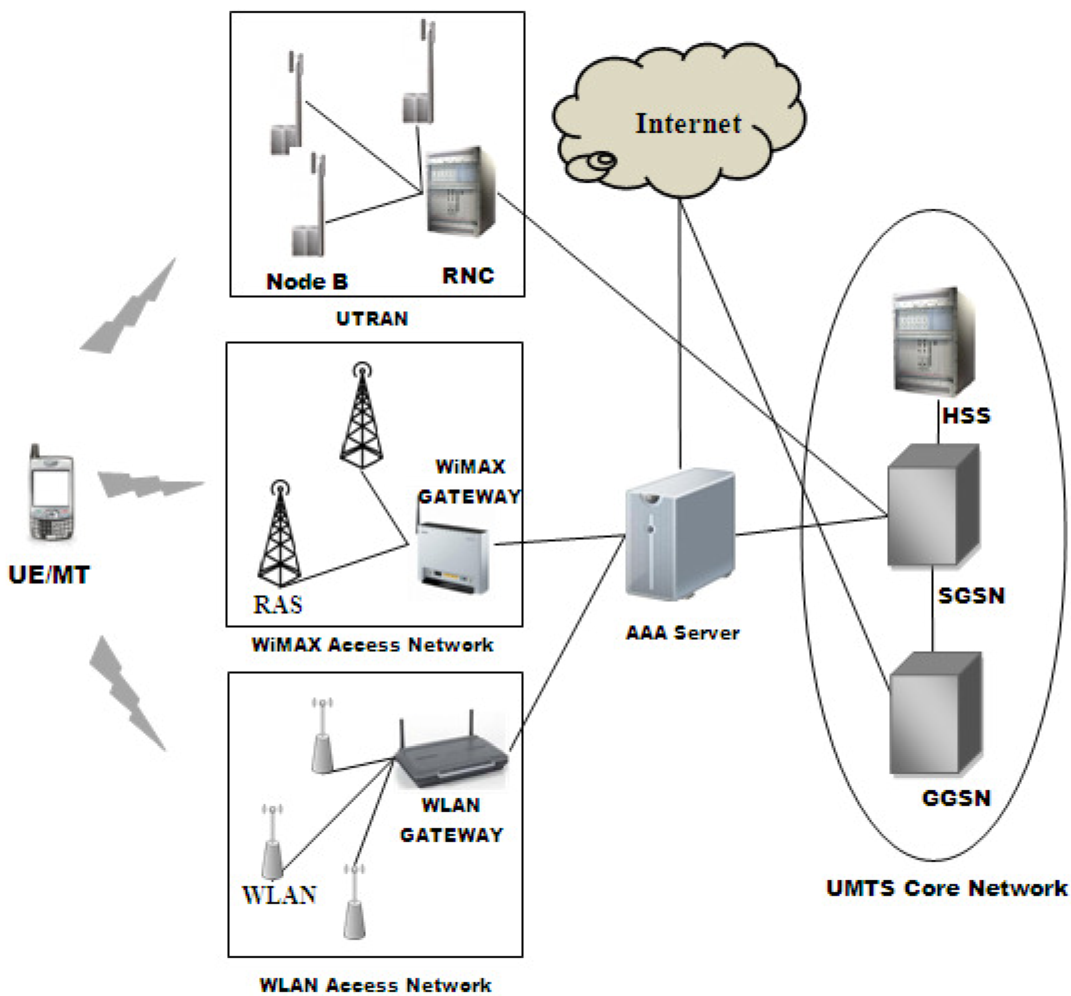

FIGURE 3: Loosely coupled integrated networks.

The main advantage of using the loose coupling scheme is that it allows the independent deployment and operation of networks. This allows the network service providers to take advantage of other provider's already deployed networks. Moreover, minimal enhancements in deployed network devices are required; hence integration does not require major investments. Subscribers can use all integrated wireless access networks while subscribing to only one service provider. For example, a UMTS subscriber can reuse its Subscriber Identity Module (SIM) or User Service Identity Module (USIM) for WLAN or WiMAX multimedia services [28].

The main disadvantage of this approach is that two networks are integrated via the internet. Therefore, signal traffic needs to traverse long paths which cause high handoff latency. As defined in [29], average handoff duration reaches 400ms; therefore, real-time services are highly affected.

5.2 Tight Coupling

In the tight coupling internetworking approach, WLAN and WiMAX are connected directly to the UMTS core network. In such an internetworking scenario, WLAN or WiMAX gateways are connected with the UMTS network in the similar manner as it is another UMTS Radio Access Network (RAN). A UMTS network deals with WLAN and WiMAX as its own RAN and finds no difference between UMTS and WLAN/WiMAX access networks, as illustrated in Fig. 4. Therefore, UMTS features such as mobility management, security, authentication, etc., can be applied to WLAN and WiMAX networks. For internetworking, each network needs to modify its services,

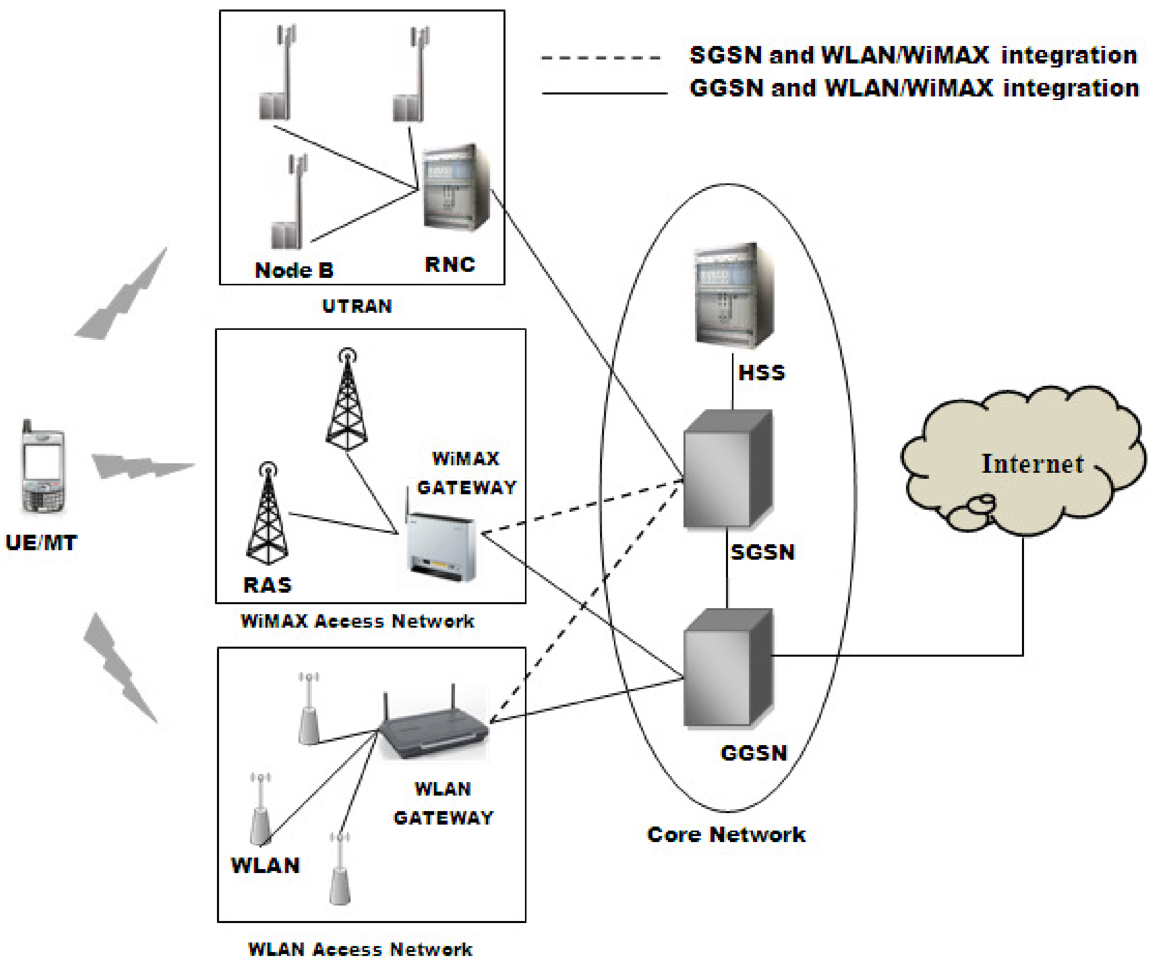

FIGURE 4: Tightly coupled integrated networks.

protocols and interfaces. WLAN or WiMAX data traffic traverse through the internet via the UMTS network. The tight coupling approach can be achieved by connecting the WLAN/WiMAX network either to UMTS' SGSN or UMTS' GGSN.

The main advantage of the tight coupling mechanism is the efficient mobility management; i.e., UMTS mobility management features are applied to the integrated networks. It offers service continuity, which includes billing and AAA services. Therefore, inter-domain seamless mobility can be achieved, while reducing handoff latency. Hence, packet loss can be reduced by minimizing the service degradation during vertical handoffs. Furthermore, UMTS core network resources, subscriber data base, billing system, authentication mechanism, etc., are reused. This reuse of resources leads to low cost deployment [25, 28].

The disadvantage of the tight coupling approach is that, as the data traffic of WLAN and WiMAX traverse via the UMTS network, they potentially create a bottle neck in the UMTS network. Moreover, this technique is considered more complicated than the loose coupling technique, because different wireless network protocol stacks need to be compatible for such type of integration. As the WLAN/WiMAX is directly connected with the UMTS network, the same operator needs to own the UMTS and WLAN/WiMAX networks. Therefore, the subscriber under the coverage of such WLAN/WiMAX networks which do not have the physical connection with the UMTS core network cannot be facilitated by the UMTS services and features.

6. SIMULATED NETWORK DESIGN

In this section, we are defining our simulation network design and parameters for the integration of UMTS and WLAN networks. Two variations of the tight coupling architecture are implemented and analyzed; in other words, one proposal is to interconnect WLAN with the GGSN of the UMTS core network, while the other mechanism is by interconnecting WLAN with the UMTS core networks' SGSN. The integrated network was designed on OPNET Modeler tool.

The network design consists of three major parts: UMTS network, WLAN network and Internet Service Provider (ISP). In this network design, only PS domain is considered and CS domain of the UMTS network is neglected for simplicity. A UMTS network is composed of Node-B, Radio Network Controller (RNC), SGSN, GGSN, UE, etc. A WLAN network is composed of WLAN AP router, which is connected either with SGSN or GGSN, and a MT. At the back of internet cloud FTP, Voice, HTTP and E-mail servers are located to provide services to the MT or UE. UE is located under the coverage of UMTS. Whereas, MT is located under the coverage of WLAN. The WLAN is located within the UMTS cell coverage area. This simulation scenario reflects a real-world scenario where WLAN is operated as a hotspot under the coverage of UMTS cell. Such hotspot serves airports, campuses, buildings, train stations, hotels, etc.

In our simulation scenario, RNC is connected with the Node-B and SGSN with the ATM OC-3 link that supports data rate up to 155.52 Mbps. The GGSN is connected to the SGSN with the PPP DS-3 bi-directional link that supports data up to 44.736 Mbps. For both GGSN-WLAN and SGSN-WLAN integration cases, WLAN AP is connected to the PPP DS-3 bi-directional link with GGSN or SGSN.

In the case of SGSN-WLAN integration [30], as illustrated in Fig. 5, WLAN does not appear as an external packet data network. Instead, it appears as another UMTS RAN. For the SGSN-WLAN integration, WLAN needs to be capable of processing UMTS messages. Therefore, some additional features in WLAN AP need to be added to make it capable of processing UMTS messages. The WLAN MT first updates its location and then establishes a packet switched signalling connection to the SGSN by using GPRS Mobility Management (GMM) attach procedure. The WLAN AP is responsible for sending these messages to the SGSN on behalf of MT. The WLAN MT is authenticated to the UMTS network after completing the GMM attach procedure.

In the case of GGSN-WLAN integration [30], as illustrated in Fig. 5, WLAN appears as an external packet data network to the UMTS network. First, UE needs to establish a Packet data protocol (PDP) context to the core network of UMTS to make itself known to the WLAN. If UE wants to communicate with the WLAN MT, then the user data are transferred between them using the encapsulation and tunneling techniques. GPRS Tunneling Protocol (GTP) is used for such encapsulation and tunneling mechanisms to send data transparently. For GGSN-WLAN integration, the WLAN does not need to process UMTS messages. Thus a simple WLAN AP is used for such type of integration.

6.1 MT Communication With ISP Servers

As illustrated in Fig. 5, WLAN access point is connected either to the SGSN or GGSN of the UMTS core network. Different types of services were used for the simulation. This includes Voice over IP (VoIP), FTP, E-mail and HTTP (web browsing). In this simulation scenario, MT communicates with the internet FTP, HTTP, Voice and E-mail servers. Table 2 represents application and measurement parameters tested for the integrated UMTS/WLAN networks.

These applications match different QoS classes of UMTS; i.e., a conversational class represents real time traffic flows such as VoIP. More precisely, PCM and GSM encoded voices have been analyzed in this paper, interactive class represents Web browsing (HTTP) and background class represents the both i.e. FTP and E-mail services.

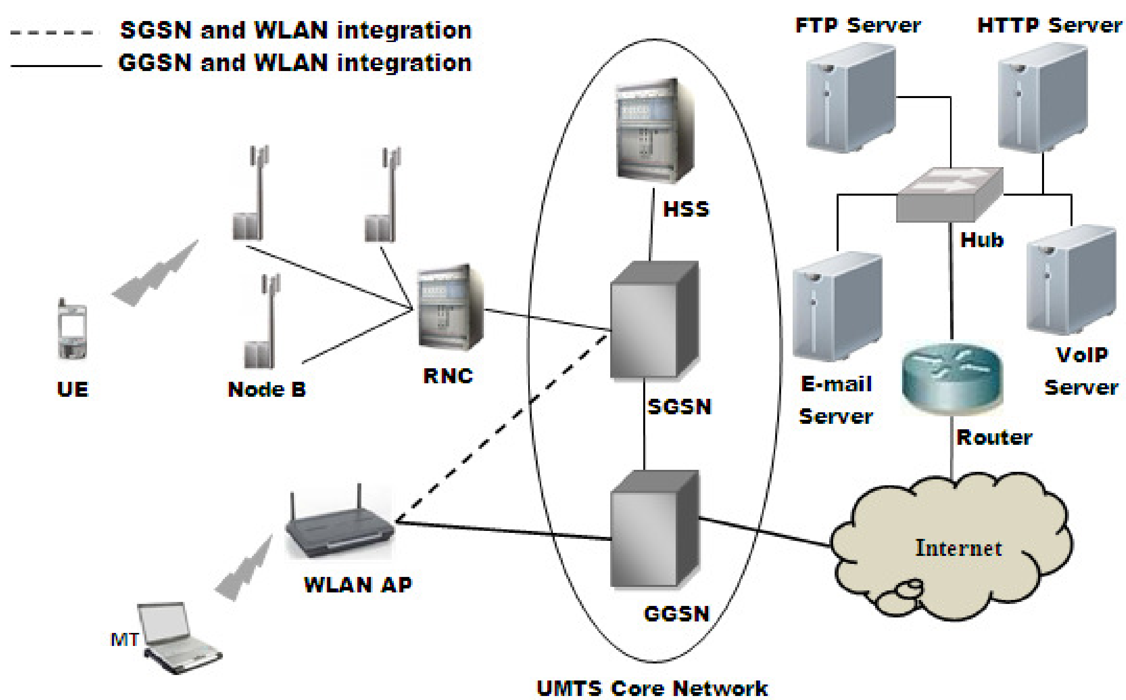

FIGURE 5: MT communicating with ISP servers in GGSN/SGSN integrated simulation scenario.

Application	QoS Class	Measurement Parameter	Size	Protocol	Figure
PCM encoded voice	Conversational	Packet Delay Variation	80 Bytes	UDP	Fig. 6
GSM-FR encoded voice	Conversational	Packet Delay Variation	33 Bytes	UDP	Fig. 7(a)
GSM-FR encoded voice	Conversational	Jitter	33 Bytes	UDP	Fig. 7(b)
E-mail	Background	Download Response time	1000 Bytes	TCP	Fig. 8(a)
E-mail	Background	Upload Response time	2000 Bytes	TCP	Fig. 8(b)
HTTP	Interactive	Downloaded Pages	500 Bytes	TCP	Fig. 9(a)
HTTP	Interactive	Object Response Time	500 Bytes	TCP	Fig. 9(b)
HTTP	Interactive	Page Response Time	500 Bytes	TCP	Fig. 9(c)
FTP	Background	Download Response Time	8000 Bytes	TCP	Fig. 10(a)
FTP	Background	Upload Response Time	8000 Bytes	TCP	Fig. 10(b)

TABLE 2: Description of the application and measurement parameters tested.

The PCM encoded voice is considered for VoIP service evaluation. Fig. 6 illustrates the simulation run times with the corresponding packet delay variation, when the user is communicating with the voice server. The voice server is located behind the internet. Throughout the simulation run time, it can be observed that the packet delay variation in the case of SGSN-WLAN integration is higher than those in the GGSN-WLAN integration.

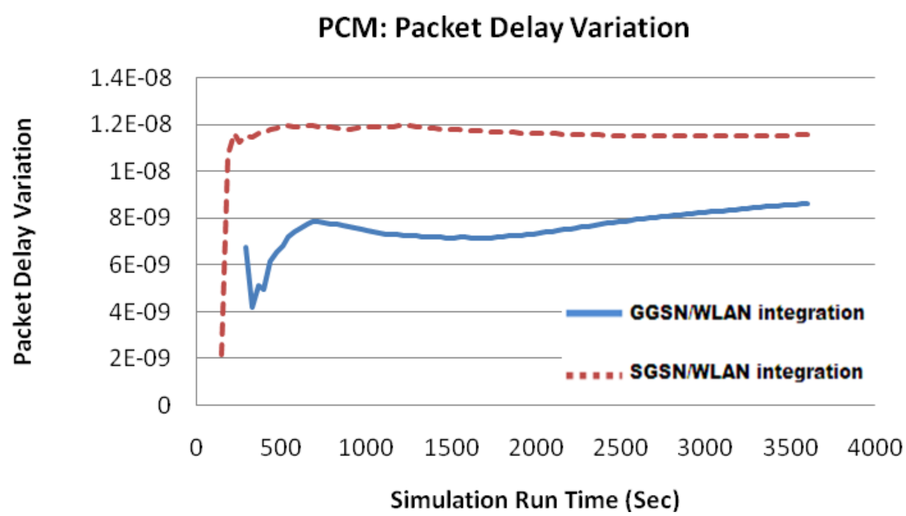

FIGURE 6: PCM packet delay variation.

Similarly for VoIP services, we consider the GSM-FR encoded voice. Fig. 7(a) and Fig. 7(b) illustrate the simulation run times with the corresponding packet delay variation and jitter, respectively. Throughout the simulation run time, it can be observed that the packet delay variation and jitter in the case of SGSN-WLAN integration is higher than those in the GGSN-WLAN integration.

Fig. 8(a) and Fig. 8(b) illustrate the simulation run times with the corresponding download and upload e-mail response time, respectively. For the diversity purpose, 1000 bytes and 2000 bytes e-mail size are used for downloading and uploading cases, respectively. It is observed that for both cases i.e. download and upload email response time, GGSN-WLAN and SGSN-WLAN integration results are initially high. However, as the simulation progresses, rapid responses can be observed. It is speculated that initially it take a longer time for the networks to negotiate with the server, and after the negotiation with the servers, email retrieval time becomes lower. The GGSN-WLAN integration represents more rapid responses in both download and upload cases compared to the responses in the SGSN-WLAN integration.

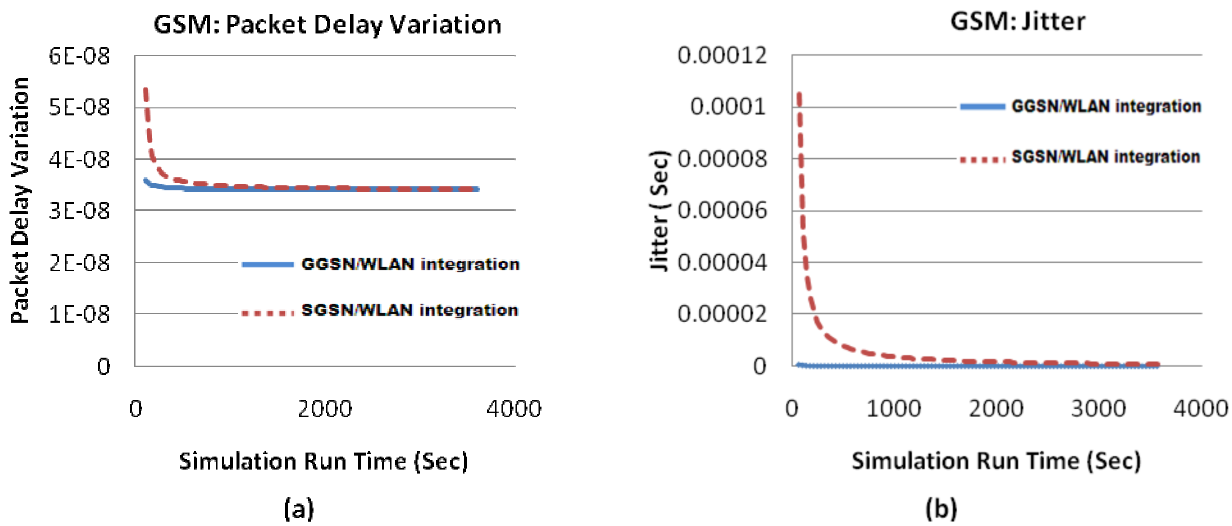

FIGURE 7: GSM encoded voice: (a) Packet delay variation, (b) Jitter.

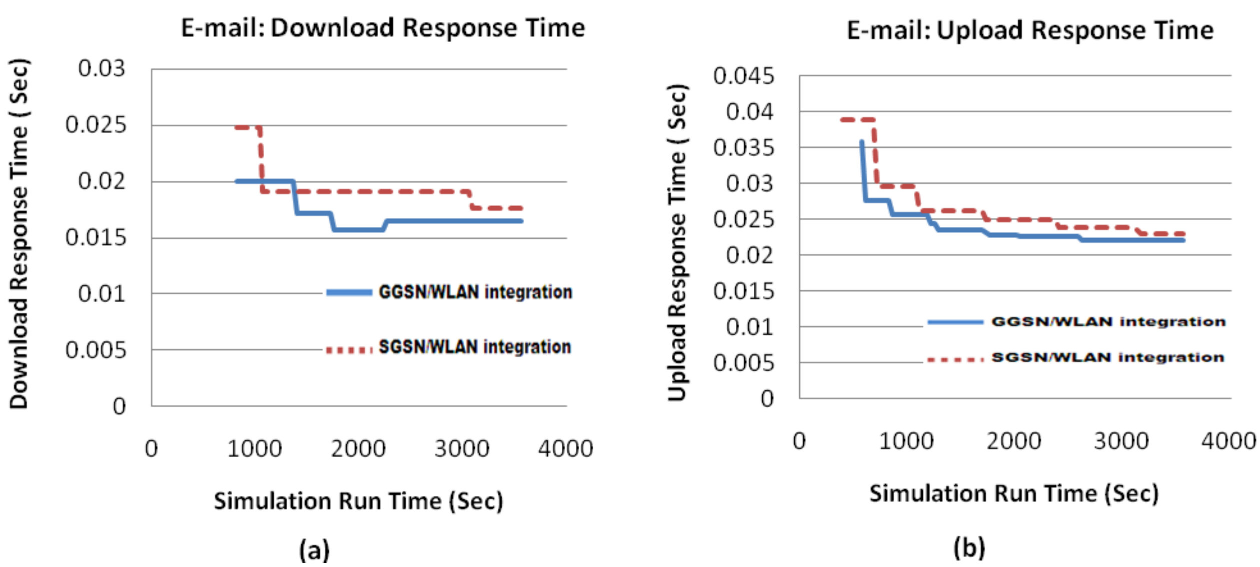

FIGURE 8: E-mail: (a) Download response time, (b) Upload response time.

For HTTP, throughout the simulation run time the GGSN-WLAN integration shows better performance than the SGSN-WLAN integration in terms of number of downloaded pages, object response time and page response time, as illustrated in Figs. 9 (a), 9 (b) and 9 (c), respectively. The page and object sizes are 500 bytes.

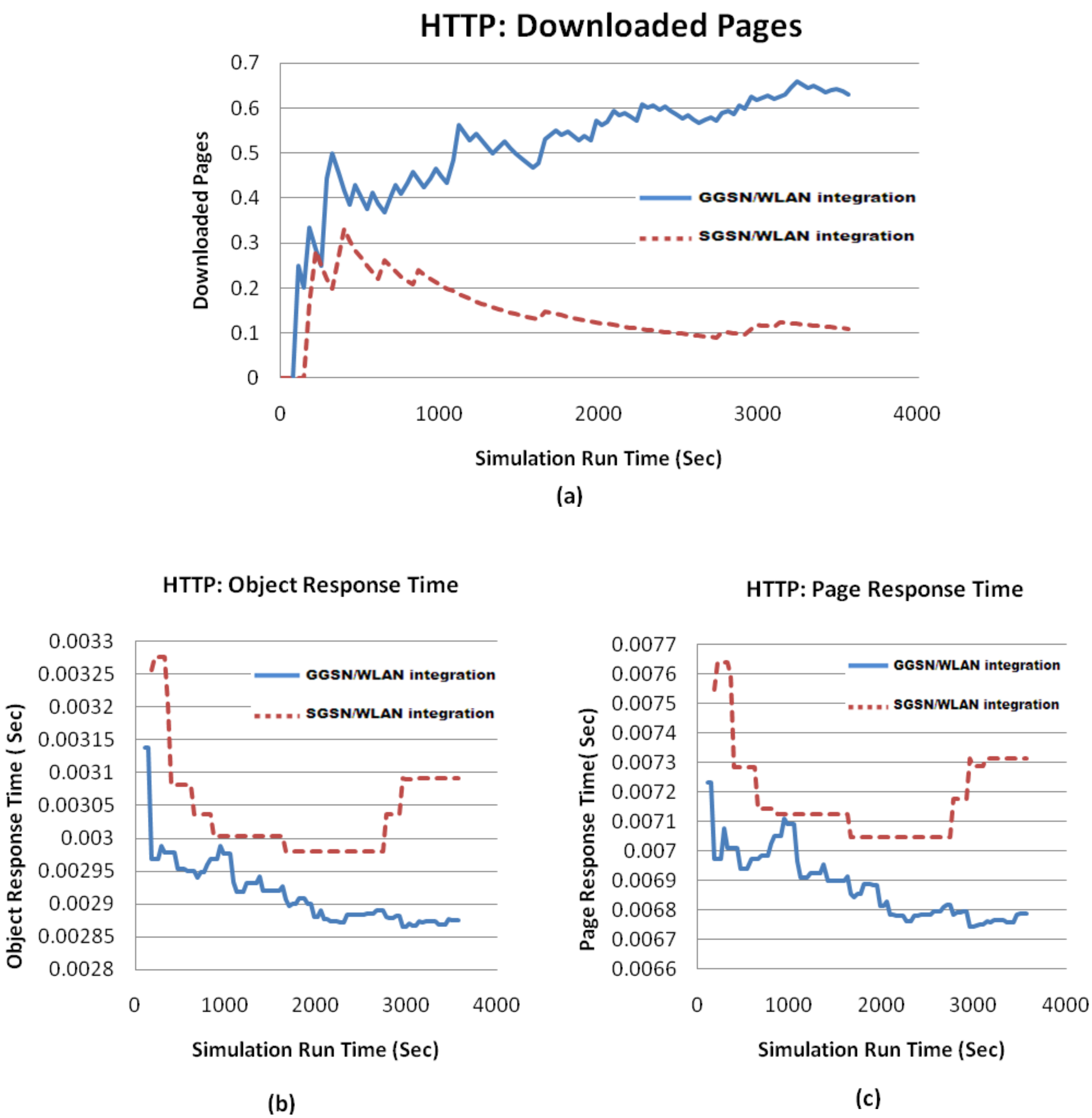

FIGURE 9: HTTP (a) Downloaded pages, (b) Object response time, (c) Page response time.

For FTP, Figs. 10(a) and 10 (b) illustrate the simulation run times the with the corresponding download and upload response time, respectively, when downloading an 8000 byte file by the MT from the FTP server located behind the internet. It can be observed that the overall performance of the GGSN-WLAN integration is better than that in the SGSN-WLAN integration, throughout the simulation run time for both cases.

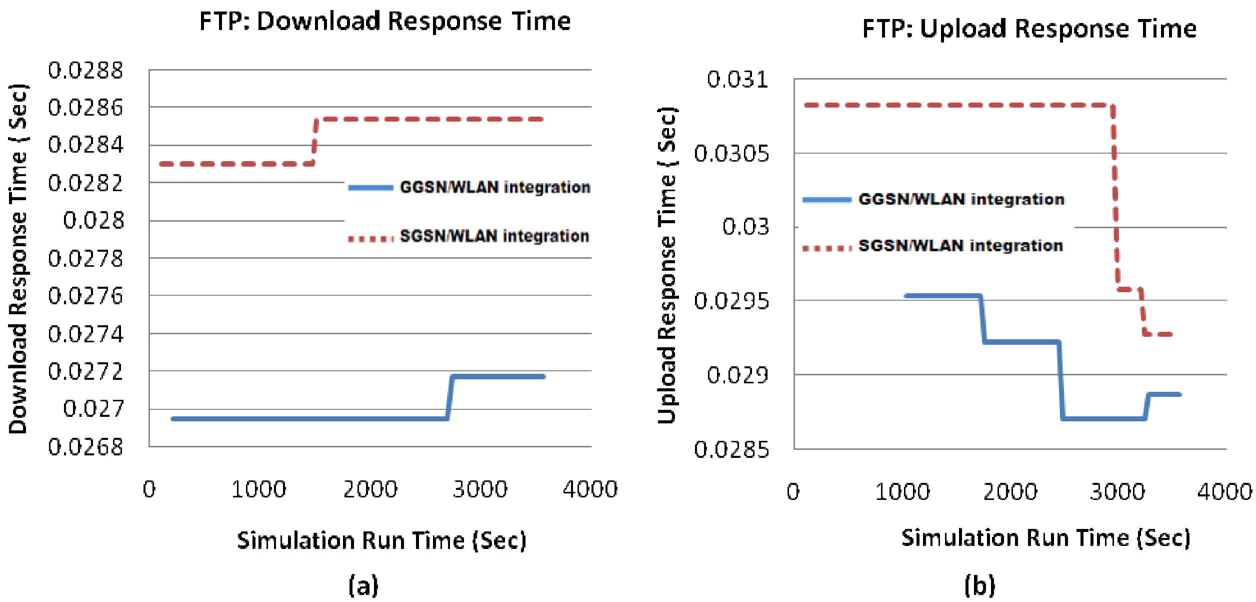

FIGURE 10: FTP: (a) Download response time, (b) Upload response time.

6.2 MT Communication With UE

As illustrated in Fig. 11, WLAN access point is either connected with the SGSN or GGSN of the UMTS core network. Different types of services were used for the simulation; these are summarized in Table 3. In this simulation scenario, MT is communicating with the UE. Therefore, it is dissimilar the simulation scenario discussed previously, in which MT is communicating with the ISP servers.

Application	QoS Class	Measurement Parameter	Size	Protocol	Figure
PCM encoded voice	Conversational	Packet Delay Variation	80 Bytes	UDP	Fig. 12 (a)
GSM-FR encoded voice	Conversational	Packet Delay Variation	33 Bytes	UDP	Fig. 12 (b)
HTTP	Interactive	Page Response Time	2000 Bytes	TCP	Fig. 13 (a)
HTTP	Interactive	Object Response Time	2000 Bytes	TCP	Fig. 13 (b)

TABLE 3: Description of the application and measurement parameters tested.

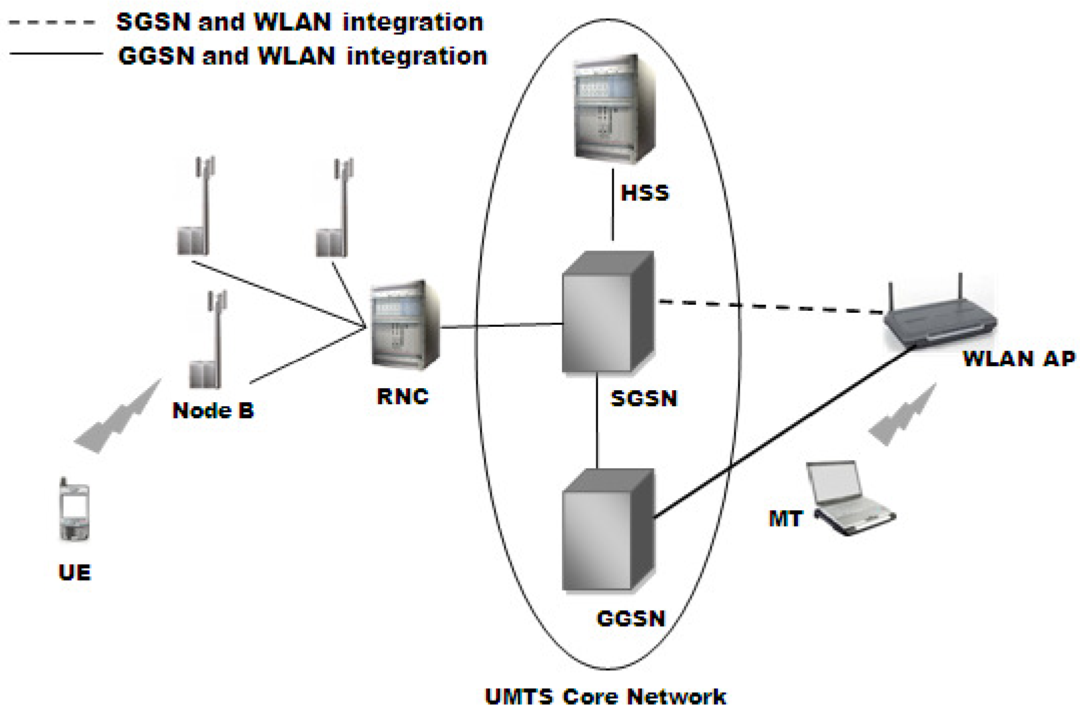

FIGURE 11: MT communicating with UE in GGSN/SGSN integrated simulation scenario.

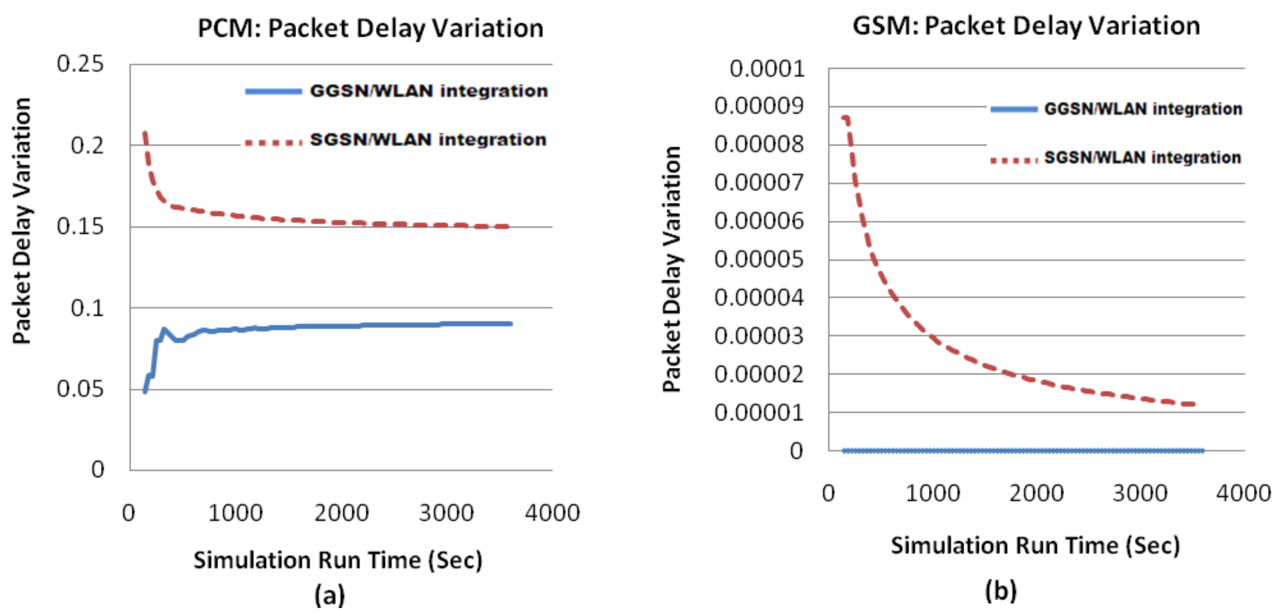

FIGURE 12: VoIP application: (a) PCM packet delay variation, (b) GSM packet delay variation.

For VoIP services, PCM encoded voice and GSM-FR encoded voice were considered, as illustrated in Figs. 12 (a) and 12 (b), respectively; the two figures represent the simulation run times with their corresponding packet delay variations. It can be observed that the packet delay variation in the case of SGSN-WLAN integration is higher than that in the GGSN-WLAN integration, throughout the simulation run time.

For HTTP, throughout the simulation run time, the GGSN-WLAN integration shows better performance in terms of page response time and object response time, compared to the SGSN-

WLAN integration, as illustrated in Figs. 13 (a) and 13 (b), respectively. The page and object sizes are 2000 bytes.

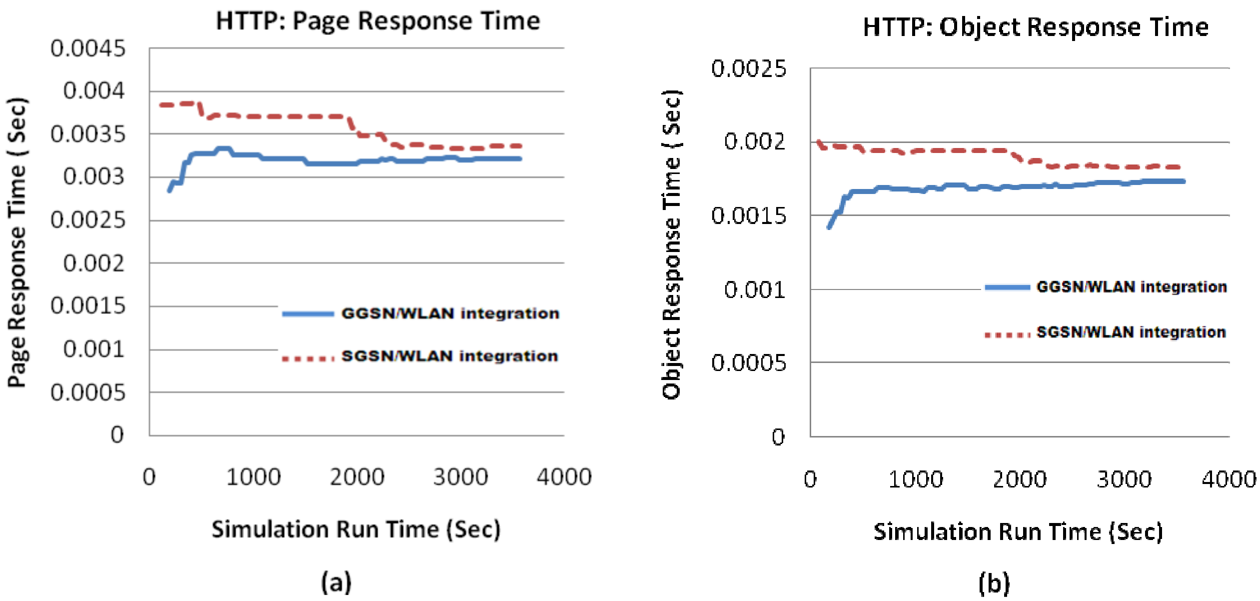

FIGURE 13: HTTP: (a) Page response time, (b) Object response time.

6.3 Discussion on Simulation Results

From the simulation results, it is apparent that the integration of the WLAN to the GGSN is of better-quality compared to the integration of WLAN to the SGSN, for all the applied applications. In the case of VoIP using either GSM or PCM encoded voice; the packet delay variation and jitter are higher in SGSN-WLAN integration compared to those in GGSN-WLAN. Similarly, in the case of E-mail, HTTP and FTP, for all applied measurement parameters, the performance of UMTS and WLAN integration is far better in the GGSN-WLAN integration than in the SGSN-WLAN integration.

In the case of SGSN-WLAN integration, this difference in the performance is due to the additional processing time required by the WLAN access point, to process the UMTS messages and establish compatibility with the UMTS network. The WLAN AP is performing dual tasks, i.e., at one time operating as a RAN to manage the compatibility to the UMTS network, and on the same communication session, operating as an AP for the MT. Therefore, it requires longer time to establish the session and has to process more messages for communication. For the authentication of MT to the UMTS network, it has to perform a GMM attach procedure with the UMTS network. On the other hand, for the GGSN-WLAN integration, WLAN AP is a simple IEEE 802.11b access point which requires no additional capabilities for processing the UMTS messages. The straightforwardness of the GGSN-WLAN integration, leads to the lower latency and low processing requirement for the communication, as no additional task needs to be performed.

Consequently, in the case of GGSN-WLAN integration, improvement in the performance for all applied applications and their parameters are achieved. For VoIP using either GSM or PCM encoded voice; improvement in the packet delay variation and jitter is achieved. For E-mail, download and upload response time is reduced. For HTTP, number of downloaded pages is noticeably high. Whereas, object and page response time is significantly reduced. For FTP, download and upload response time is considerably low etc. Therefore, the simplicity of communication without extra processing and additional tasks leads to the performance enhancements.

7. CONCLUSION AND FUTURE WORK

In this paper, we have reviewed several internetworking techniques for the integration of UMTS and WLAN networks. The inherent differences between WLAN and UMTS bring a lot of technical challenges that need to be resolved for the integrated Next Generation Wireless Networks. These differences are in terms of protocols, algorithms, data rate, authentication mechanism, handoff mechanism, coverage ranges, etc. To achieve an integrated heterogeneous wireless network, several techniques have been proposed in the recent literature. Moreover, we have comprehensively investigated two different techniques of tight coupling schemes for the integration of the UMTS and WLAN, namely GGSN-WLAN and SGSN-WLAN.

The network model has been designed on OPNET modeler tool. For simplicity, only the PS-domain of the UMTS core network is considered in the designed model, while neglecting the CS-domain. Comprehensive results have been obtained by designing two different simulation scenarios, i.e., MT is communicating with the ISP server and MT is communicating with the UE. For both cases, our results demonstrate that the performance of the integrated UMTS and WLAN is far better in the case of GGSN-WLAN than that of SGSN-WLAN internetworking, for all of the applied applications and measurement parameters. This is because the WLAN AP needs to have some additional capabilities to process UMTS messages; the SGSN-WLAN integration requires more processing and latency for the communication. Whereas for GGSN-WLAN, a simple IEEE 802.11b WLAN AP is required; therefore, GGSN-WLAN requires no additional tasks for communication. Our future research focuses on the evaluation and optimizations of the vertical handoff decision algorithms and the maintenance of a seamless mobility, when the user is moving across the heterogeneous wireless networks.

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