International Journal of Computing and Network Technology
ISSN (2210-1519)
Int. J. Com. Net. Tech. 4, No. 2 (May-2016)

Performance Analysis of Mobility in the Integrated UMTS and WLAN Network for Interactive Service

Shashank Tripathi[1] and A K Jain[2]

[1,2]Department of Instrumentation and Control Engineering, Dr B R Ambedkar National Institute of Technology Jalandhar, Jalandhar, India-144011

Received: 8 Jan. 2016, Revised: 10 Apr. 2016, Accepted: 15 Apr. 2016, Published: 1 May 2016

Abstract: The Next Generation Networks (NGNs) have a responsibility to provide a satisfactory level of QoS to its mobile user during handoff. The seamless mobility is the solution belongs to this problem in these networks. In this category, the Integrated UMTS and WLAN network is most eligible NGN. The paper focuses on the handoff analysis with two different mobility models using Constant Bit Rate (CBR) interactive service. Finally, the paper concluded by presenting comparative mobility performance over QoS matrices in the presence of different handoff prediction algorithms.

Keywords: Integrated UMTS and WLAN network, QoS, Vertical Handoff Prediction Algorithms, File-based Mobility Model, Random Waypoint Mobility Model.

1. INTRODUCTION

The Universal Mobile Telecommunications System (UMTS) mobile provides arbitrary mobility at relative low bandwidth service to its mobile user, where Wireless Local Area Network (WLAN) offers high bandwidth service with relatively low mobility. By efficient sharing of resources between these two networks, the Quality of Service (QoS) and the capacity of networks can be improved [1]. In Third Generation Partnership Projects (3GPP) Release 6 specifications, architecture of the Integrated UMTS and WLAN network was propped [2]. During handoff between UMTS and WLAN, the integrated network faces serious handoff latency problems due to unpredicted link interruption [3]. To minimize handoff latency and achieving seamless mobility is a big issue in Integrated UMTS and WLAN networks [4]. The selection of the suitable handoff prediction algorithm is necessary to avoid unpredicted radio link interruption during handoff in the integrated network [5].

The handoff is a process to ensure mobile station radio connection active while moving from one Base Station (BS) /Access Point (AP) to another [6]. This process supports mobility of the User Equipment (UE) by replacing the existed connection from already established BS/AP with a new one and from new one to the other. The handoff within the UMTS and the WLAN networks is called as horizontal handoff, where the handoff between these networks is known as vertical handoff [7]. In this paper, all simulations carried out under CBR traffic scenario to provide interactive services. The interactive service is generally non real-time asymmetric class service, used for voice messaging, web-browsing, e-commerce, e-mail server access, etc [8]. The QoS in interactive application depends on QoS parameters, e.g., delay, jitter, packet loss, throughput, etc. In this paper, the CBR traffic generator parameters have been modelled according to voice messaging service QoS expectations [9]. For better utilization of radio resources in asymmetric interactive service, UMTS is used with High Speed Downlink Packet Access (HSDPA) that have high-speed downlink shared channel [10].

This paper includes two different vertical handoff prediction algorithms with two different mobility models, namely: the file-based mobility model, the random waypoint mobility model. Algorithms are based on measured parameters periodically gathered by mobile station such as Received Signal Strength (RSS), speed, direction and location.

The rest of this paper is organized as follows: Section II discusses salient features of Integrated UMTS and WLAN network, section III introduces vertical handoff strategy, section IV introduces scenario configuration and section V introduces simulation results and analysis. Finally, Section VI concludes this paper.

E-mail: shashankt.ic.12@nitj.ac.in, jainak@nitj.ac.in

2. SALIENT FEATURES OF INTEGRATED UMTS AND WLAN NETWORK

Various UMTS/WLAN interworking architectures have been proposed in literature with different integration scheme [11].This paper discusses on tight-coupled integration architecture between UMTS and WLAN access networks. In the Integrated UMTS and WLAN network, WLAN traffic passes through the UMTS core network and it functions as another access network of the UMTS core network [12]. Integrated UMTS and WLAN network is a combination of UMTS and WLAN access network.

In the concern of UMTS, 3GPP based standard used in simulations, which uses Wideband Code Division Multiple Access (WCDMA) technology along with Frequency Division Duplex (FDD). UMTS Public Land Mobile Network (PLMN) is divided into UE, UMTS core network and UMTS access network. UE is generally recognized as a mobile station, which have the Universal Subscriber Identity Module (USIM). Serving GPRS Support Node (SGSN), Gateway GPRS Support Node (GGSN) and Home Location Register (HLA) are the main part of the UMTS core network. The UMTS access network is also known as UMTS Terrestrial Radio Access Network (UTRAN) is formed by the base station (Node B) and Radio Network Controller (RNC) [10, 13].

In Integrated UMTS and WLAN network, the WLAN is another access network that uses IEEE 802.11g physical layer model and provide data rate up to 54 Mbps in the 2.4 GHz frequency unlicensed Industrial, Scientific and Medical (ISM) band. The WLAN works in the infrastructure and the adhoc mode. The paper uses WLAN with infrastructure mode. In this mode, all the stationary and mobile stations can communicate through the AP at a given time period [14]. The connection from a station to one AP is obtained after completing the scanning which can be either active or passive. In the passive scanning, AP continuously broadcasts periodic beacon frames and the station remain on a channel until getting the beacon frame. In the active scanning situation, the station who wants to connect with an AP broadcasts a probe request and waits a few milliseconds until it gets a probe response in reply from the AP [15]. In association of an AP to the station, the active scanning is faster than the passive scanning. The handoff between APs can be performed on the basis of RSS and threshold after completing scanning process.

3. VERTICAL HANDOFF STRATEGY

The Vertical handoff strategy is very important for mobile users to support UMTS-WLAN interworking services from the same operator in hot-spots area. Vertical handoff is classified into two sub-categories, namely: upward and downward vertical handoff [16]. An upward vertical handoff is a handoff which perform in the Integrated UMTS and WLAN network during mobile station move from WLAN to UMTS with usually lower bandwidth per unit area and a larger cell size, whereas a downward vertical handoff is a handoff in the Integrated UMTS and WLAN network from UMTS to WLAN with usually higher bandwidth per unit area and a smaller cell size. Handoff prediction algorithms are very important for minimizing handoff latency and packet loss during mobile station gets in and gets out from WLAN coverage in integrated UMTS and WLAN network [17]. This section is going to discuss different handoff prediction algorithms which included RSS with thresholds and Movement Extrapolation (ME).

A. Handoff Prediction Algorithm based on RSS with threshold

In literatures [7, 18, 19], the RSS based handoff prediction algorithm has been well discussed and it is very famous. In Integrated UMTS and WLAN Network during the upward handoff, a mobile station continuously measures the RSS from the current AP of WLAN and compares the current RSS value with a fixed predefined threshold value. In the result, if current RSS is found below the threshold, it discovers new AP with strongest RSS and mobile station initiates handoff to this new AP. However, on the absence suitable AP, mobile station initiates the handoff to UMTS Node B with strong RSS than other Node B. In the downward handoff, a mobile station continuously measures the RSS from the current Node B and compares the current RSS value with a fixed predefined threshold value. In the result, if current RSS is found below the threshold, it searches neighbouring Node B with strongest RSS and mobile station initiates handoff to this new Node B. However, on the presence of WLAN APs, mobile station initiates the handoff to AP with strong RSS than other AP. The RSS based prediction algorithm is well suited for horizontal handoff and its works efficiently in small coverage but faces ping-pong problems.

B. Handoff Prediction Algorithm based on ME

In literatures [5, 18, 20], the handoff based on the movement of a mobile station has been discussed. The prediction algorithm extrapolates the movement of the mobile station by using the current placement, direction, and velocity of the mobile station and expects its next location at a specific distance from its current location after certain periods. The process discovers a new AP of the next location and if this AP is better from the current, AP then initiated the handoff from current to new AP. In absence of proper serving AP of WLAN, the handoff from AP of WLAN to Node B of UMTS will initiated. The handoff from Node B of UMTS and AP of WLAN in Integrated UMTS and WLAN Network also performed under same above process.

4. SCENARIO CONFIGURATION

For mobility analysis, two different scenarios of the Integrated UMTS and WLAN network are designed for downward and upward vertical handoffs. In both scenarios, mobility of the mobile station act according to the file-based and random waypoint mobility model. The mobile station participates in the handoff process corresponding to both wireless technologies with dual interface. The network parameters of integrated scenario is given in table I, which has been configured according to the IEEE 802.11a/g PHY Model and the 3GPP UMTS technical specifications release 7 standards.

In the random waypoint model, the mobile station randomly selects new location and moves to selected location within the simulation area in each several milliseconds with constant velocity and variable speeds [5, 21, 22]. In each random waypoint model, the velocity of the mobile station is constant and the maximum speed is set to 5m/s, 10m/s, or 25m/s where the minimum speed is set to 2m/s with specific simulation time so that it covered a distance of 1700 meters ± 10 meters.

TABLE I. NETWORK PARAMETERS OF INTEGRATED SCENARIO

Parameter	UMTS-HSDPA	WLAN
Terrain	3000×3000 sq. meters	
No. of channels	03	
	1.95 GHz UL 2.15 GHz DL	2.4 GHz
Path-loss model	Two-ray	
Antenna model	Omni-directional	
	PHY Layer	
Radio Type	Cellular PHY- UMTS PHY	802.11a/g radio
Maximum transmission power	30dBm	20dBm
Maximum data rate	-----	6 Mbps
Channel access scheme	FDD	CSMA/CA
Modulation scheme	QPSK	OFDM
	MAC Layer	
MAC protocol	UMTS LAYER 2 – Cellular MAC	802.11

In the file based mobility model, the mobile station selects a new location using mobility flag, and moves to selected location within the simulation area using shortest path with constant speed [19, 21]. Speed between two mobility flags can be set by modifying the arrival time in each of these. In this mobility model, the speeds of the mobile station are set to 5m/s, 10m/s, or 25m/s using 50 meters space between two adjacent mobility flags with specific simulation time so that it spread over a distance of 1700 meters ± 10 meters. In each scenario, the distance between the Node B and the Access Point (AP) is set to 1000 meters. All the handoff algorithms have been implemented using Visual C++ and simulated them on the QualNet 5.0.2 platform.

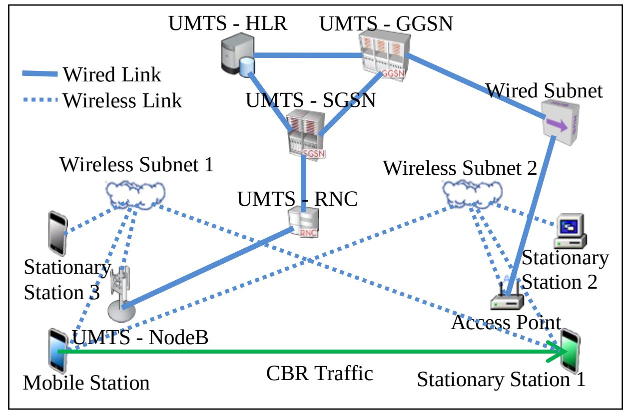

Figure 1. Scenario for vertical handoff from UMTS to WLAN

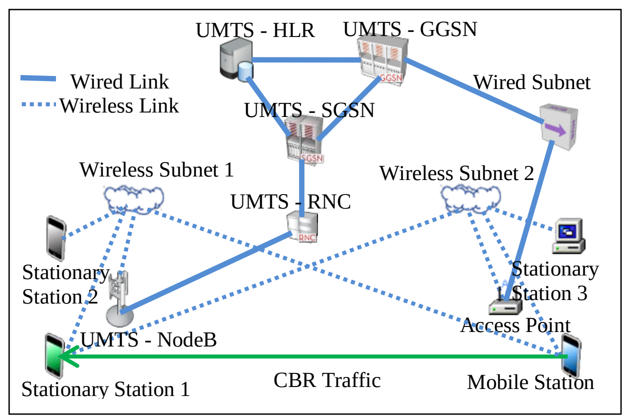

Figure 2. Scenario for vertical handoff from WLAN to UMTS

The first scenario dedicated for downward vertical handoff from UMTS to WLAN is illustrated in Figure 1.The handoff in tightly coupled Integrated UMTS and WLAN Network act according to RSS and ME based handoff prediction algorithms. The integrated network comprises the primary architectural elements: a mobile station, three stationary stations, one Node B, one AP, a HLR, a GGSN, a SGSN and a RNC.

The second scenario dedicated for upward vertical handoff from WLAN to UMTS is illustrated in Figure 2.The handoff in tightly coupled Integrated UMTS and WLAN Network act according to RSS and ME based handoff prediction algorithms. The integrated network comprises the primary architectural elements: a mobile station, three stationary stations, one Node B, one AP, a HLR, a GGSN, a SGSN and a RNC.

5. Simulation Results And Analysis

The voice massaging interactive application are used in this paper which is simulated by QualNet with Constant Bit-Rate (CBR) traffic generator. In all scenarios, the mobile station and stationary stations are placed under healthy coverage range of network BS/AP. The simulation setup for both scenarios is given in Table II.

TABLE II. Simulation Setup

Parameter	Simulation Setup
Packet Size	64 Byte
Packet Rate	25 Packets/s
Packet Transmission Time Interval (TTI)	40 ms

Mobility performance of the Integrated UMTS and WLAN network have been analysed by QoS parameters. In this paper, End-to-end delay, jitter, packet loss and throughput are used as QoS parameters. The result of the simulations is presented in following sub-sections.

A. *Simulation Setup - I (File-based Mobility Model)*

1) ***Effect of mobility on end-to-end delay with file-based mobility:***

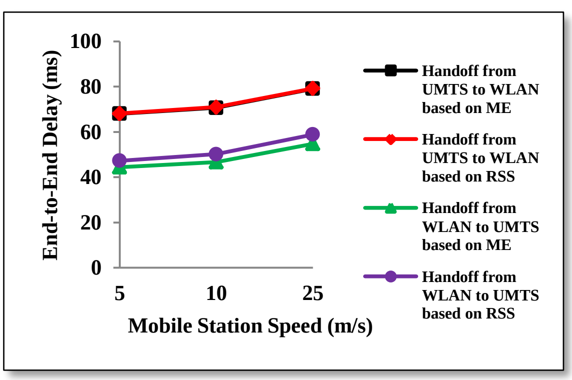

Figure 3. End-to-end delay versus various speeds of mobile station

In figure 3, the end-to end delay against various speeds of mobile station for upward and downward scenarios in pursuance of vertical handoffs prediction algorithms based on RSS and ME along with file-based mobility is illustrated. From figure 3, increase in end-to-end delay against the increase in speeds of the mobile station is observed. In perspective of best QoS performance, ME based vertical handoff prediction algorithm using for WLAN to UMTS handoff is having lowest average value of delay. In this case, the 44.45918ms delay observed at the 5 m/s speeds and increases to 46.7036ms, 54.7679ms with 10 m/s, 25 m/s speeds of the mobile station, respectively.

2) ***Effect of mobility on jitter with file-based mobility:***

In Figure 4, the jitter against various speeds of mobile station for upward and downward scenarios in pursuance of vertical handoffs prediction algorithms based on RSS and ME along with file-based mobility is illustrated. From the figure 4, increase in jitter against the increase in speeds of the mobile station is observed. In perspective of best QoS performance, RSS based vertical handoff prediction algorithm using for UMTS to WLAN handoff is having lowest average value of jitter. In this case, the 0.195054ms jitter observed at the 5 m/s speeds and increases to 0.324824ms, 0.524189 ms with 10 m/s, 25 m/s speeds of the mobile station, respectively.

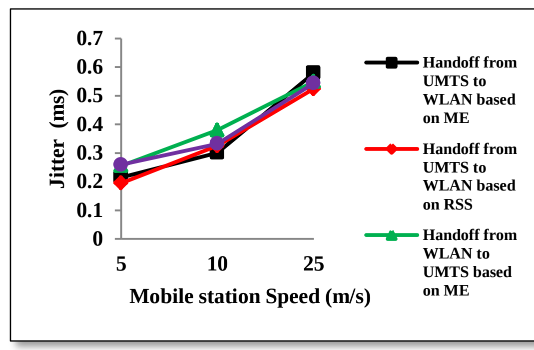

Figure 4. Jitter versus various speeds of mobile station

3) ***Effect of mobility on packet loss with file-based mobility:***

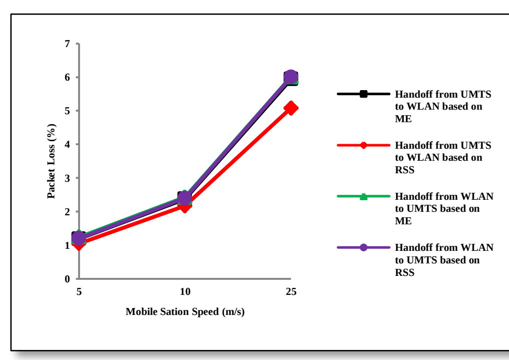

Figure 5. Packet loss versus speed of mobile station

In Figure 5, the packet loss against various speeds of mobile station for upward and downward scenarios in pursuance of vertical handoffs prediction algorithms based on RSS and ME along with file-based mobility is illustrated. From the figure 5, increase in packet loss against the increase in speeds of the mobile station is observed. In perspective of best QoS performance, RSS based vertical handoff prediction algorithm using for UMTS to WLAN handoff is having lowest average value of packet loss. In this case, the 1.050461% packet loss observed at the 5 m/s speeds and increases to 2.168627%, 5.076471% with 10 m/s, 25 m/s speeds of the mobile station, respectively.

*4) **Effect of mobility on throughput with file-based** mobility:* In Figure 6, the throughput against various speeds of mobile station for upward and downward scenarios in pursuance of vertical handoffs prediction algorithms based on RSS and ME along with file-based mobility is illustrated. From the figure 6, increase as well as decrease in throughput against the increase in speeds of the mobile station is observed. In perspective of best QoS performance, RSS based vertical handoff prediction algorithm using for UMTS to WLAN handoff is having highest average value of throughput. In this case, the 12827bits per second throughput observed at the 5 m/s speeds and increases to 12855bits per second, 12944bits per second with 10 m/s, 25 m/s speeds of the mobile station, respectively.

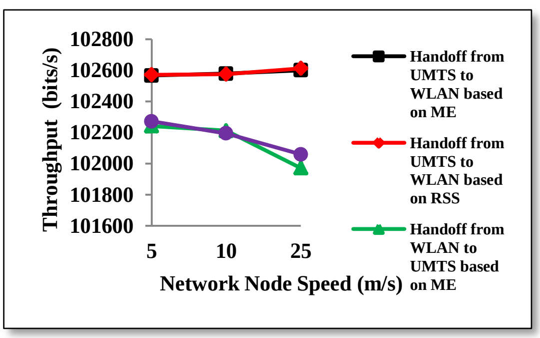

Figure 6. Throughput versus speed of mobile station

B. Simulation Setup - II (Random Waypoint Mobility Model)

*1) **Effect of mobility on end-to-end delay with random waypoint mobility**:*

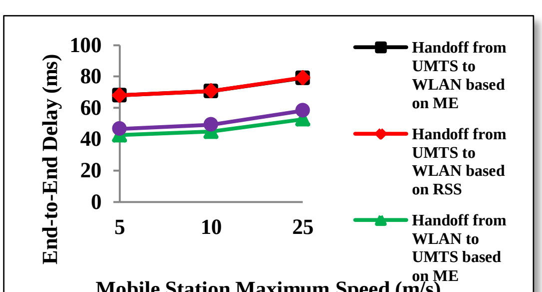

Figure 7. End-to-end delay versus speed of mobile station

In Figure 7, the end-to end delay against various speeds of mobile station for upward and downward scenarios in pursuance of vertical handoffs prediction algorithms based on RSS and ME along with random waypoint mobility is illustrated. From the figure 7, increase in end-to-end delay against the increase in speeds of the mobile station is observed. In perspective of best QoS performance, ME based vertical handoff prediction algorithm using for WLAN to UMTS handoff is having lowest average value of delay. In this case, the 42.64476ms delay observed at the 5 m/s maximum speed and increases to 44.85289ms, 52.7679ms with 10 m/s, 25 m/s maximum speeds of the mobile station, respectively.

2) Effect of mobility on jitter with random waypoint mobility: In Figure 8, the jitter against various speeds of mobile station for upward and downward scenarios in pursuance of vertical handoffs prediction algorithms based on RSS and ME along with random waypoint mobility is illustrated. From the figure 8, increase in jitter against the increase in speeds of the mobile station is observed. In perspective of best QoS performance, RSS based vertical handoff prediction algorithm using for UMTS to WLAN handoff is having lowest average value of jitter. In this case, the 0.185222ms jitter observed at the 5 m/s maximum speed and increases to 0.294792ms, 0.524152ms with 10 m/s, 25 m/s maximum speeds of the mobile station, respectively.

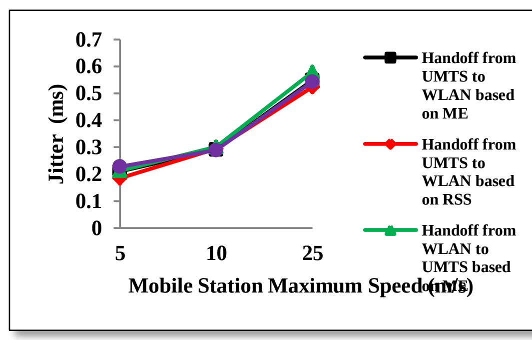

Figure 8. Jitter versus speed of mobile station

*3) **Effect of mobility on packet loss with random waypoint mobility:***

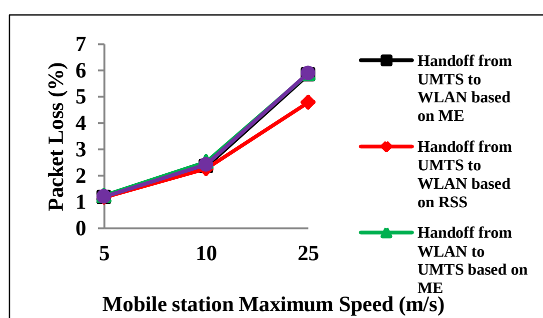

Figure 9. Packet loss versus speed of mobile station

In Figure 9, the packet loss against various speeds of mobile station for upward and downward scenarios in pursuance of vertical handoffs prediction algorithms based on RSS and ME along with random waypoint mobility is illustrated. From the figure 9, increase in packet loss against the increase in speeds of the mobile station is observed. In perspective of best QoS performance, RSS based vertical handoff prediction algorithm using for UMTS to WLAN handoff is having lowest average value of packet loss. In this case, the 1.18504% packet loss observed at the 5 m/s maximum speeds and increases to 2.268322%, 4.786471% with 10 m/s, 25 m/s maximum speeds of the mobile station, respectively.

*4) **Effect of mobility on throughput with random waypoint mobility:*** In Figure 10, the throughput against various speeds of mobile station for upward and downward scenarios in pursuance of vertical handoffs prediction algorithms based on RSS and ME along with random waypoint mobility is illustrated. From the figure 10, increase as well as decrease in throughput against the increase in speeds of the mobile station is observed. In perspective of best QoS performance, RSS based vertical handoff prediction algorithm using for UMTS to WLAN handoff is having highest average value of throughput. In this case, the 12828bits per second throughput observed at the 5 m/s maximum speed and increases to 12852bits per second, 12952bits per second with 10 m/s, 25 m/s maximum speeds of the mobile station, respectively.

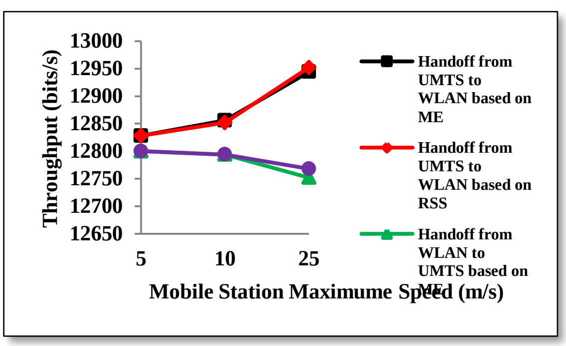

Figure 10. Throughput versus speed of mobile station

6. Conclusion

The mobility performance analysis of the Integrated UMTS and WLAN Network over two different mobility models has been studied using CBR interactive class service. Overall QoS performance is continuously decreasing due to increase in the speeds of mobile station that can be seen in simulation results. According to results, integrated network have little better, but comparable QoS in the random waypoint mobility model than the file-based mobility model. The effect of RSS and the ME based handoff prediction algorithms in the Integrated UMTS and WLAN network have been observed over various QoS parameters at three different speeds of the mobile station. The ME based prediction algorithm is better from the RSS because of minimum handoff latency while experiencing higher packet loss, higher jitter and lower throughput but comparable.

References

[1] Z. Zabanoot and G. Min, "Modelling of prioritised vertical handoff scheme in integrated UMTS/WLANs," IEEE 11th Int. Conf. rust, Secur. Priv. Comput. Commun., pp. 1654 – 1660, June 2012.

[2] 3GPP TS 23.934; "3GPP system to Wireless Local Area Network (WLAN) interworking; Functional and Architectural Definition (Release 6)," 3GPP TSG SA, Aug. 2002.

[3] H. Y. Jung, E. A. Kim, J. W. YI, and H. H. Lee, "A scheme for supporting fast handover in hierarchical mobile IPv6 networks," ETRI J., vol. 27, no. 6, pp. 798–801, Dec. 2005.

[4] H. Kwon, K.-Y. Cheon, and A. Park, "Analysis of WLAN to UMTS handover," IEEE 66th Conf. Veh. Technol., pp. 184 – 188, Sept. 2007.

[5] H. Kwon, M.J. Yang, A.S. Park, and S.Venkatesan, "Handover prediction strategy for 3G-WLAN overlay networks," Netw. Oper. Manag. Symp. IEEE, pp. 819 – 822, Ap. 2008.

[6] D. S. Deif, H. EI-Badawy, and H. EI-Hennawy, "Toplogy based modeling and simulation of UMTS-WLAN wireless heterogeneous network," Seventh IEEE Int. Conf. Wirel. Opt. Commun. Networks (WOCN), pp. 1 – 5, Sept. 2010.

[7] M. Z. A. Syuhada, I. Mahamod, and W. A. W. N. S. Firuz, "Performance evaluation of vertical handoff in fourth generation (4G) networks model," IEEE 6th Natl. Conf. Telecommun. Technol. / 2nd Malaysia Conf. Photonics, pp. 392 – 398, Aug. 2008.

[8] S. Tripathi and A. K. Jain, "Performance of inter-domain routing protocols for interactive srvices under QoS guarantee in a UMTS-HSDPA and WLAN Ad-Hoc networks," Journal Instrum. Technol. Innov., vol. 5, no. 3, pp. 1–17, 2015.

[9] 3G TS 22.105v3.9.0, "Univarsal Mobile Telecommunications System (UMTS), service aspects, services and service capabilities," June 2000.

[10] M. Rahnema, "UMTS network planning, optimization, and inter-operation with GSM," John Wiley & Sons (Asia) Pte Ltd, 2008, pp. 1–327.

[11] T. Soungalo, L. Renfa, Z. Fanzi, and H. N. Waita, "Performance analysis of interworking between WLAN and 3G networks based on three approaches," Int. Work. Inf. Electron. Eng. Elsevier B.V., vol. 29, pp. 1126–1132, 2012.

[12] S. Rizvi, A. Aziz, N. M. Saad, N. Armi, and M. Z. Yusoff, "Tight coupling internetworking between UMTS and WLAN: challenges, design architectures and simulation analysis," Int. J. Comput. Networks, vol. 3, no. 2, pp. 116–134, 2011.

[13] 3GPP TS 25.301 version 7.5.0; "Universal Mobile Telecommunications System (UMTS); radio interface protocol architecture (Release 7)," Jun. 2010.

[14] IEEE 802.11; "IEEE standard for information technology telecommunications and information exchange between systems local and metropolitan area networks specific requirements part 11: Wireless Medium Access Control (MAC) and Physical Layer (PHY) specifications," 2004

[15] R. J. Bartz, "Mobile computing deployment and management: real world skills for comptia mobility+certification and beyond," John Wiley Sons, pp. 1–744, Feb. 2015.

[16] M. Lott, M. Siebert, S. Bonjour, D. von Hugo, and M. Weckerle, "Interworking of WLAN and 3G systems," Commun. IEE Proc., vol. 151, no. 4, pp. 507 – 513, 2004.

[17] X. Yan, Y. A. Sekercioglu, and S. Narayanan, "A survey of vertical handover decision algorithms in fourth generation heterogeneous wireless networks," Comput. Networks, Elsevier B.V., vol. 54, pp. 1848–1863, 2010.

[18] G. . Pollini, "Trends in handover design," Commun. Mag. IEEE, vol. 34, no. 3, pp. 82 – 90, 2002.

[19] A. E. I. Pastrav, A.-I. Grapa, T. Palade, and E. Puschita, "Performance analysis of mobility in 3G cellular UMTS and WLAN networks," 4th IEEE Int. Symp. Electr. Electron. Eng., pp. 1 – 6, 2013.

[20] A. Jayasuriya and J. Asenstorfer, "Mobility prediction model for cellular networks based on the observed traffic patterns," Proc. IASTED Int. Conf. Wirel. Opt. Commun., pp. 386–391, July 2002.

[21] "Mobility Models," in QualNet 5.0.2, Wireless Model Library, 2010, pp. 252–268.

[22] E. Hyytia, P. Lassila, and J. Virtamo, "Spatial Node Distribution of the Random Waypoint Mobility Model with Applications," IEEE Trans. Mob. Comput., vol. 5, no. 6, pp. 680–694, June 2006.

Shashank Tripathi was born in Allahabad, Uttar Pradesh, India on July 30th, 1985. He received B.Tech Degree in Electrical & Electronics Engineering from Skyline Institute of Engineering & Technology, Greater Noida, Uttar Pradesh, India in 2007 and M.Tech Degree in Control & Instrumentation Engineering from Dr. B. R. Ambedkar National Institute of Technology, Jalandhar, Punjab, India in 2010. He is Research Scholar at Department Of Instrumentation and Control Engineering, Dr. B. R. Ambedkar National Institute of Technology, Jalandhar, Punjab, India. He was Assistant Professor at Department Of Instrumentation and Control Engineering, Dr. B. R. Ambedkar National Institute of Technology, Jalandhar, Punjab, India from August 2010 - July 2012. His research area of interest is modelling and simulation of wireless networks.

A.K.Jain received his B.E and M.E both from IIT, Roorkee, (erstwhile University of Roorkee, Roorkee) India in 1981 and 1987 respectively and received his Ph.D. degree on Quality of Service in High Speed Networks from the Dr. B. R. Ambedkar National Institute of Technology, Jalandhar, India in 2009.He has published over sixty research papers in national and international journals/conferences. He is presently working as Professor in the Department of Instrumentation and Control Engineering, Dr. B. R. Ambedkar National Institute of Technology, Jalandhar, India. He is guiding PhD and M.Tech students in the area of Wireless Networks. Before joining N.I.T, Jalandhar, he has served at TIET Patiala, IET Lucknow, and NIT Hamirpur (Erstwhile REC Hamirpur) in various capacities. His research interests include quality of service in wireless networks, medium access protocols for mobile computing, and mesh networks. Dr. Jain is life member of ISTE India.