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Handover Scenarios for Mobile WiMAX and Wireless LAN Heterogeneous Network

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Abstract

This paper presents proposed handover scenarios for a heterogeneous network comprising mobile worldwide interoperability for Microwave Access and Wireless Local Area Network segments. Homogenous handover scenarios for a mobile WiMAX network are also considered to allow a comparative analysis. A mobile node supporting voice traffic is analysed, when operating in a half-cell overlap coverage scenario, for both pedestrian and vehicular speeds. All proposed handover scenarios are assessed and validated through system-level Media Independent Handover network simulations. Results for both homogenous and heterogeneous handover show that the handover delay and jitter are within the acceptable values published by the WiMAX Forum. For heterogeneous handover, the packet loss is negligible for all cases; however, there were significant occurrences of packet loss in throughput for homogenous handover at vehicular speeds. This is due to the fact that the implementation of an adaptive channel scanning algorithm to allocate scanning intervals can limit communication disruptions.

Keywords: *broadband, wireless communication, handover schemes, mobile communication, VoIP*

1. Introduction

The ITU standardisation of mobile Worldwide interoperability for Microwave Access (WiMAX) as a third generation (3G) network has given network operators with the opportunity to provide a new means for the mobile user to gain access to low-cost broadband Internet services [1]. When combined with Wireless-Local Area Network (W-LAN) solutions, widely referred to as WiFi, it becomes possible to provide seamless wireless Internet access through an hierarchical heterogeneous network architecture that is independent of traditional cellular network solutions.

The literature contains several proposals for the architecture and performance evaluation criteria for WiMAX and WiFi integration [2-8]. A VHTC (Vertical Handoff Translation Centre) architecture for WiMAX and WiFi heterogeneous networks is proposed in [2] to improve the transmission quality of service (QoS) guarantees. This paper also introduces new approaches and architectures for packet translation, QoS mapping, bandwidth borrowing management and vertical handover protocols to achieve advanced seamless heterogeneous wireless networks. In [3], a new design for a WiMAX and WiFi adaptation layer is introduced to reduce the delay in the protocol layer.

A new user-centric algorithm for vertical handover in existing standard technologies, like 802.11 and 802.16, which combines a trigger to continuously maintain the connection and to maximise the user throughput is proposed in [4], while an integrated architecture utilising a novel WiMAX/WiFi Access Point (AP) device to effectively combine the WiMAX and WiFi technologies is studied in [5], where the WiMAX/WiFi AP device and the extended Media Access Control (MAC) functionality enable each WiFi hotspot to support connection-oriented transmissions and differentiated services.

Furthermore, the proposed QoS provisioning mechanisms for integrated WiMAX/WiFi systems are introduced in [6]. This work presents the modules required to provide an integrated QoS approach over the 802.16 network, and addresses main implementation results in terms of

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QoS performance and mobility with QoS support for converged networks comprising WiMAX and WiFi technologies.

A quantitative evaluation of integrating WiMAX and WiFi capacity is given in [7]. A resource management scheme for WiMAX and WiFi handover supporting voice over IP (VoIP) is proposed and analysed, based on the blocking probability of new calls while reducing the dropping probability of handover calls. While in [8], a proposed model for optimal pricing for bandwidth sharing in an integrated WiMAX/WiFi network is presented, where the licensed WiMAX spectrum is shared by WiFi APs/routers to provide Internet connectivity to mobile WiFi users.

The proposals for WiMAX and WiFi integration architecture and performance evaluation criteria previously mentioned are mostly analysed for fixed WiMAX and WiFi access network integration. To the best of our knowledge, however, no mobile WiMAX and WiFi handover scenario has been analysed.

In this paper, VoIP traffic is used as a user application model. Even for WiMAX technology primarily focused on mobile Internet services, special handling of VoIP traffic in the physical and MAC layers is required to maximise voice capacity. Also, the efficient support of voice traffic has always been one of the key metrics for evaluating and selecting radio access technologies [9].

The achievement of seamless mobility in an integrated mobile WiMAX/WiFi network will depend, to a large extent, on maintaining tolerable system throughput, delay, jitter and packet loss during homogenous and heterogeneous handover between networks at pedestrian and vehicular speeds. These performance criteria will form the basis of the simulation analysis presented in this paper.

The paper is organised as follows. In section two, the underlying technology and foundations of mobile WiMAX are considered. Section three discusses handover types in more detail with an emphasis on heterogeneous handover from a mobile WiMAX to a WiFi access network. The design of the handover scenarios and the simulation with voice traffic at different speeds for half-cell overlap coverage are carried out in section four. Section five analyses the simulation results and, finally, section six draws conclusions and indicates the intended direction of future research.

2. Research Method

2.1. Introduction

A system-level MIH network simulation for homogenous and heterogeneous handover scenarios with half-cell overlap coverage is used to study mobile WiMAX handover performance. Five cells are used in the simulation, with each cell’s coverage overlapping another by 250m. The distance between the centres of two overlapping cells is 750m and a cell’s diameter is 500m. The simulated traffic is constant bit rate voice with user datagram protocol as the transport layer protocol and with a voice packet size of 160 bytes (e.g. 5 voice packets = 800 bytes) and a voice packet interval of 0.02s. An MN supporting voice traffic is observed at a pedestrian speed (5km/h), low vehicular speed (60km/h) and high vehicular speed (120km/h). The MIH handover performance is assessed and analysed using the network simulator NS-2.

2.2. Handover Scenarios

2.2.1. Homogenous Handover

The homogeneous mobile WiMAX handover scenario is modelled as in Figure 1. Five BSs (defined as BS1, BS2, BS3, BS4 and BS5), an ASN-GW router and a CSN node involving a CN are modelled. An MN traverses the five BSs starting from the Home Network BS1 (HN BS1) to Foreign Network BSs (FN BSs), which are BS2 to BS5.

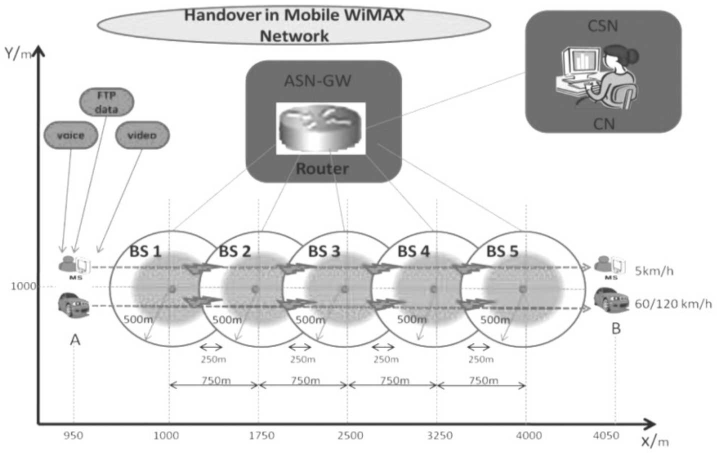

Figure 1. Homegeneous Handover Scenario at Half-cell Overlap Coverage

2.2.2. Heterogeneous Handover

This scenario is illustrated in Figure 2. At point “A” (i.e. within the coverage area of a WiFi AP (AP1)), a mobile user starts a voice session with another user in the CN using an MMT. From point “A” to point “B”, the user is at a pedestrian speed of 5km/h and experiences a handover to a WiMAX network in BS1. Then, the user moves from point “B” to point “C” at a speed of 60km/h, handing over from BS1 to BS2. Afterwards, from point “C” to point “D”, the user accelerates to 120km/h, handing over from BS2 to BS3 and maintains this speed to point “E” in BS4. The user then moves to point “F” handing over from BS4 to BS5 at 60km/h. At point “G”, the user’s speed reduces to 5km/h and hands over to AP2. In this scenario, it is assumed that WiFi and WiMAX services are offered by the same service provider.

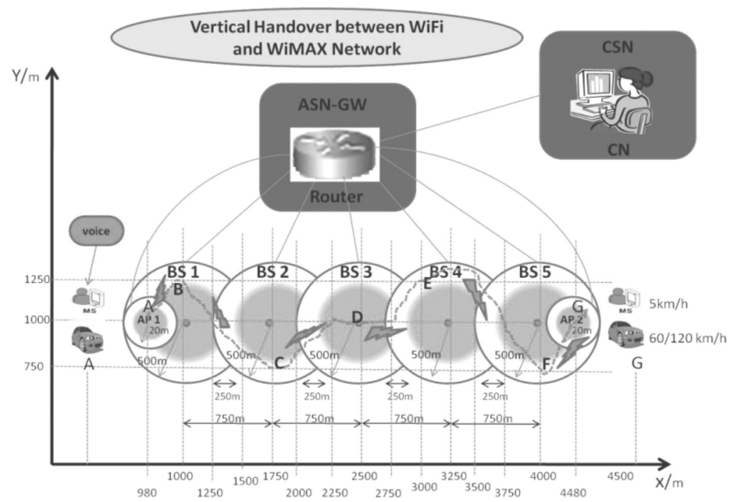

Figure 2. Heterogeneous Handover Scenario at Half-cell Overlap Coverage

2.2.3. The Handover Simulation Flow chart

The simulation and MIH handover flow charts are given in Figures 3 and 4, respectively, which illustrate the configuration and behaviour of the handover scripts in NS-2. The WiMAX *controller agent* messages are mapped between the BSs via the MAC ‘0’ channel for effective updating of the routing table and for sending *neighbour advertisement*, *Uplink Channel Descriptor (UCD)*, *Downlink Channel Descriptor (DCD)* and *synchronisation* messages between the BSs through the backbone link.

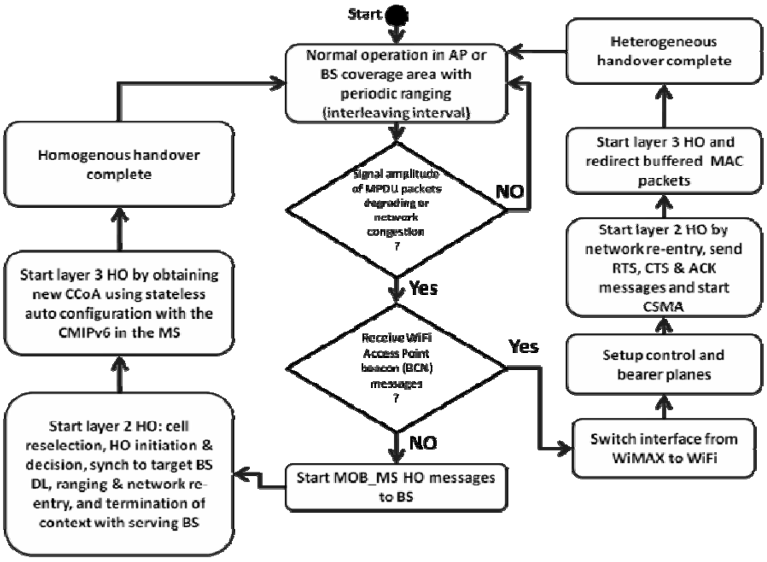

Figure 3. Handover Flow Chart for the API Script

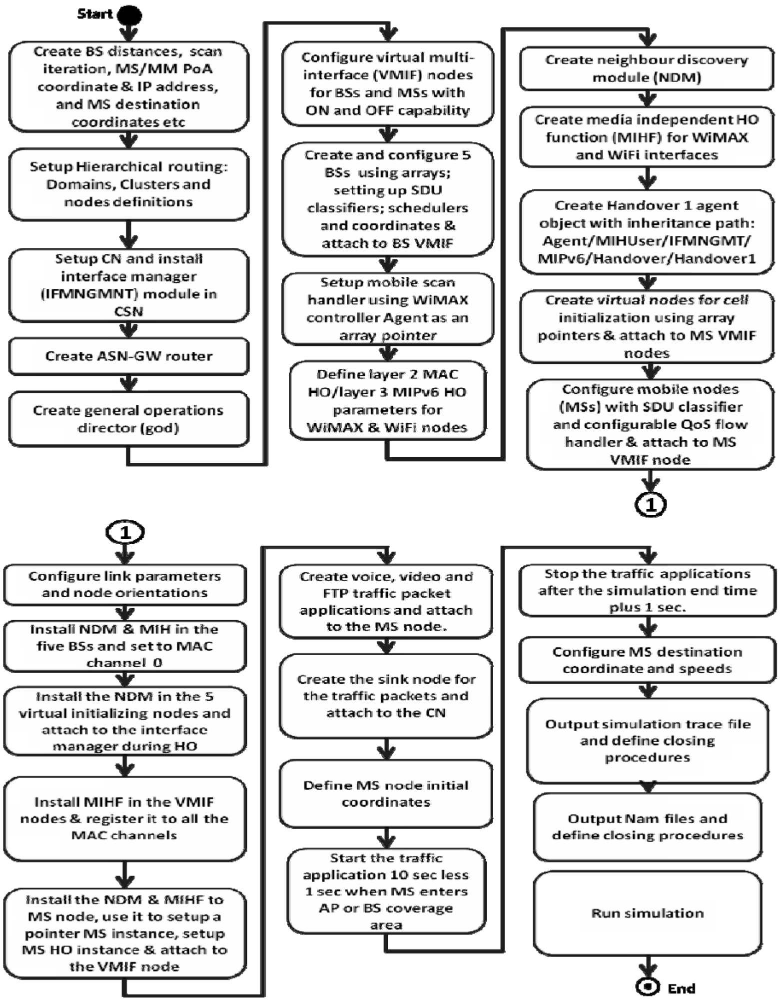

Figure 4. Simulation Flow Chart

2.3. Simulation Parameters and Network Configuration

The simulation parameters are shown in Table 1. The MIHF routing protocol *Noah* is used to handle node ID change and interworking between WiFi and WiMAX interfaces, and the WiMAX and mobility modules used in the NS-2 simulations are designed by NIST [10]. The NIST application program interface (API) handover script is modified in order to implement the handover scenarios.

Table 1. Simulation Parameters

Simulation parameter	**Values**
MAC/802_16 scan iterations	5
MAC/802_16 scan duration	50 s
MAC/802_16 interleaving interval	40 s
MAC/802_16 link going down factor	1.1
MAC/802_16 UCD interval	5 s
MAC/802_16 DCD interval	5 s
MAC/802_16 channel number	0
WiMAX Frequency bandwidth	5 MHz
WiMAX bit rate bandwidth	10 Mbps
WiFi frequency bandwidth	5 MHz
WiFi bit rate bandwidth	11 Mbps
Number of channels per base station	5 (0-4)
Modulation and code rate	OFDM 16 QAM 3/4
Vehicular speeds	60 km/h and 120 km/h
Pedestrian speed	5 km/h
Number of packets sent per second	50
Frequency band	3.5 GHz
Cyclic Prefix	0
Base station transmit power	15 W
Base station coverage area (High dense Urban)	500 m
Channel type	Wireless channel
Radio propagation model	Two ray ground
Wireless interface queue length	50
Antenna model	Omni directional antenna
Routing protocol	*Noah* (modified DSDV for inter technology routing)
Number of base stations	5
Number of access points	2
Number of subnet for horizontal handover	13
Number of subnet for vertical handover	15
Scheduling algorithm	Round robin

2.3.1. Homogeneous Handover MIP Addressing

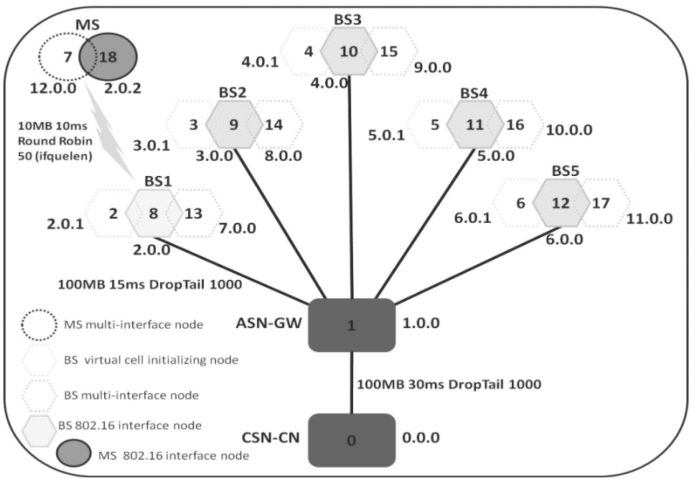

Figure 5. Horizontal Handover with Node ID and IP Addressing

At the start of the simulation, the MN 802.16 interface is assigned IP address 2.0.2 and node ID 18. This is the PoA parameter at the HN BS1. The virtual multi-interface node, shown in Figure 5, is assigned IP address 12.0.0 and node ID 7. This models CMIPv6 IP address assignment on the MS. The remaining IP addresses and node ID assignments on the other interfaces are shown in Figure 5. Virtual initialising cells and multi-interfaces make the MN MIH capable. The BSs, multi-interface nodes, ASN-GW and CSN-CN, are assigned to different subnets to give a total of thirteen subnets (0 to 12). Each subnet has different clusters and each cluster has different nodes.

From the simulation, it can be observed that as the MS traverses the BSs, the PoA IP address changes to the new CCoA in each subnet. This causes handover in Layer 3 (i.e. the IP address of node 18 keeps changing until it becomes 6.0.2 in the last subnet or FN of BS5). This is as a result of stateless auto-configuration by the CMIPv6 in the MN when a new network prefix is detected by the BSs with the support of route advertisement broadcasts. The multi-interface node on the MS (node 7) maintains IP address 12.0.0 throughout the journey with the cluster and the node ID remaining unchanged.

2.3.2. Heterogeneous Handover MIP Addressing

The IP addresses and node ID assignments network for the MMT used in heterogeneous network simulation are illustrated in Figure 6. The MMT PoA IP address and node ID (for the virtual multi-interface node) are 14.0.0 and 7, respectively; for the WiMAX interface, the subnet assigned is IP address 2.0.2 and node ID 18; and for the WiFi interface, the subnet assigned is IP address 2.0.3 and node ID 21.

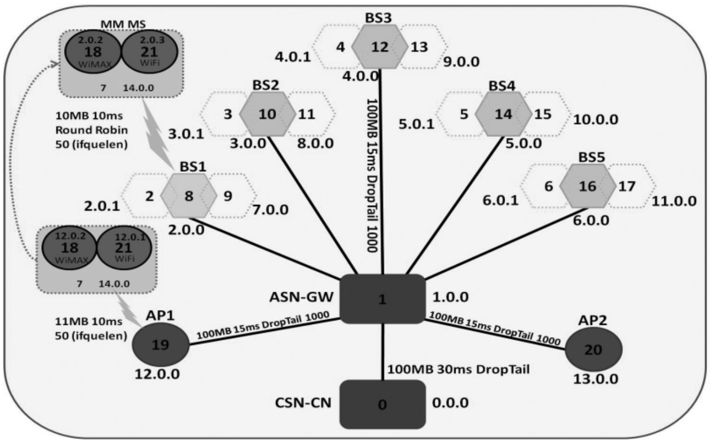

Figure 6. Heterogeneous Handover with Node ID and IP Addressing

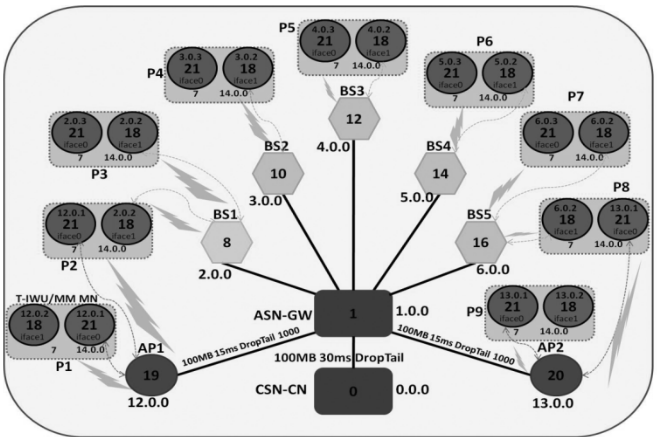

Figure 7. CoA IP Addresses Change in Heterogeneous Handover

The MMT operates four agents: MIHF, CMIPv6, Handover (HA) and Interface Manager Flow (IFACEMGR). The CoA IP address changes of the MMT during the heterogeneous handover process is shown in Figure 7. The ND modules are installed in the two interfaces of the MMT, *viz*.: interface 0 (iface0 – WiFi interface) and interface 1 (iface1 – WiMAX interface).

Starting from AP1 coverage area (Figure 7), subnet 12.0.0, the ND module periodically sends beacon signals and Route Advertisement (RA) broadcasts constantly in its coverage area. The MMT is set in “P1” (Figure 7). On entering this coverage area, the MN connects to a channel, following time and frequency synchronisation. The ND module in the WiFi interface receives RA from subnet 12.0.0 of AP1 with information (e.g. router life-time, network prefix life-time, network prefix (in this case 12.0.0) and BS RA interval). If the CMIPv6 agent in the MMT is enabled, this information is used to carry out stateless auto-configuration and assigns a CoA IP address of 12.0.1 on the WiFi interface. This is then followed by a binding update, where the MN sends the autoconfigured IP address over this interface to the network. In the event when the MN enters AP1 coverage area without receiving an RA broadcast, the CMIPv6 agent will request the ND module in iface0 to send a Route Solicitation (RS) broadcast. The ND module in subnet 12.0.0 receives RS from the WiFi interface, processes it and sends an RA broadcast containing BS router network information, which is used to obtain a CoA.

At “P2” (Figure 7), the MMT moves from AP1 to BS1. On leaving the AP1 coverage area, the network prefix 12.0.0 on the ND module of the MN will expire. At the same time, the MIHF agent in subnet 12.0.0 of the AP1 and subnet 2.0.0 of the BS1 adds MAC channels for MPDU communication; the MMT subnet 14.0.0 adds IFACEMGR agent. In addition, the MIHF agent adds MAC channels to the WiFi interface IP address (12.0.1) and WiMAX interface IP address (2.0.2) to communicate with the MAC channels created in the AP1 and BS1. At periodic times, subnet 14.0.0 of the MMT will receive the status of the local MIH using the *MIH-Get_Status function* message in iface0 and iface1 with link identification (ID) information (i.e. link type), MAC MN number and MAC PoA number. In the MMT subnet 14.0.0, the MIHF and HA agents receive a *link detected* trigger, while the IFACEMGR agent receives MIH events. If the new interface is optimal, a connection is launched over the link, making the MIHF and HA agents to receive a *link up* trigger and IFACEMGR agent to receive MIH events. This changes the link ID parameters. Afterwards, during the *link up* trigger and during handover in subnet 14.0.0 of MMT, the HA agent receives the new prefix 2.0.0 from the BS1 such that the old address is 12.0.1 (on the WiFi interface) and the new address is 2.0.2 (on the WiMAX interface).

At some point in subnet 14.0.0 of the MMT, the MIHF agent sends a capability discovery request, which is received in subnet 2.0.0 of BS1. It then sends a capability discovery response to subnet 14.0.0 of MMT. If the new WiMAX interface offers a better option, it starts checking for flows in order to redirect packets. The MMT studies SFID 0 using iface0 and SFID 1 using iface1. If iface1 is better than iface0, the flow is redirected to it. Subsequently, the CMIPv6 agent in the MMT sends redirected messages using iface1. The MIPv6 agent in CN IP address of 0.0.0 receives redirected MPDU packets from iface1. The CMIPv6 agent in the MMT receives *ACK* for redirected packets from CN IP address 0.0.0. The exchange of capability discovery between subnet 2.0.0 of BS1 and subnet 14.0.0 of MMT will continue.

From “P4” to “P7” (Figure 7), the IP address of the MMT interface changes its CoA based on the domain prefix broadcasts received from the BSs (BS2 to BS5) as the MN traverses these BS’s coverage areas. At “P8” (Figure 7), iface1 is in the coverage area of BS5 but iface0, on receiving a beacon signal and network prefix broadcast from AP2, wakes up the interface and assumes a CoA IP address of 13.0.1. The flows are monitored to obtain the optimum interface. In AP2 coverage area, the flow is fully redirected to iface0. The MIHF agent continues to send link scan signals to the coverage area and receives a scan response while continuing to study flows until MIHF and HA agents in iface1 receive the *link going down* trigger with the IFACEMGR event [35-37]**.**

3. Results and Analysis

The simulation of the MAC layer has been carried out for the homogenous and heterogeneous handover scenarios. These simulations have measured the MAC PDU of voice packets that are sent by the MS at the various speeds previously identified. In this section, three handover performance criteria are analysed, *viz*.: handover delay, jitter and throughput.

3.1. Homogeneous Handover Scenario
3.1.1. Pedestrian Speed
Figure 8 shows the throughput performance of homogeneous handover at pedestrian speed. It can be seen that a uniform throughput (50packets/s) occurs during the interleaving interval with both the transmit and receive voice MAC PDU packets having the same throughput for the journey from a HN to FNs. The throughput falls to about 45packets/s during the first handover (400s of simulation time) and to about 46packets/s during the second (950 s of simulation time), third (1500s of simulation time) and fourth (2050s of simulation time) handovers. From observations during the simulation, this occurs due to lower packet loss during synchronisation and resumed channel scanning.

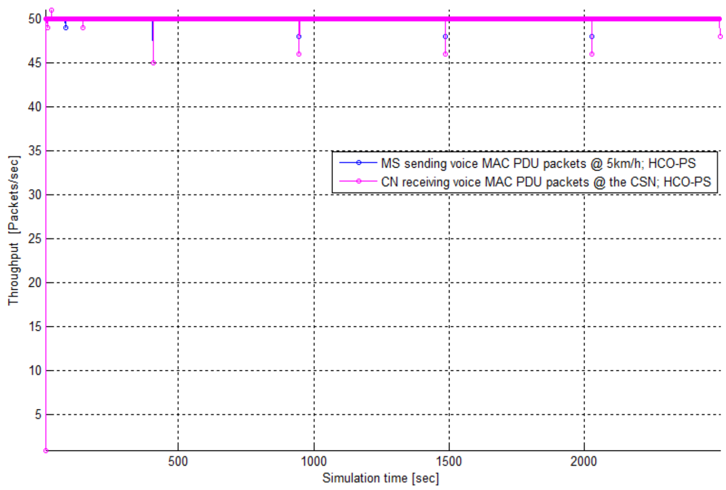

Figure 8. Throughput for Pedestrian Speed at Half-cell Overlap Coverage

There was a small incidence of packet loss in transmit and receive throughput in the first interleaving interval (less than 250s of simulation time) in the coverage area of BS1 due to errors introduced by the radio propagation environment.

3.1.2. Low Vehicular Speed

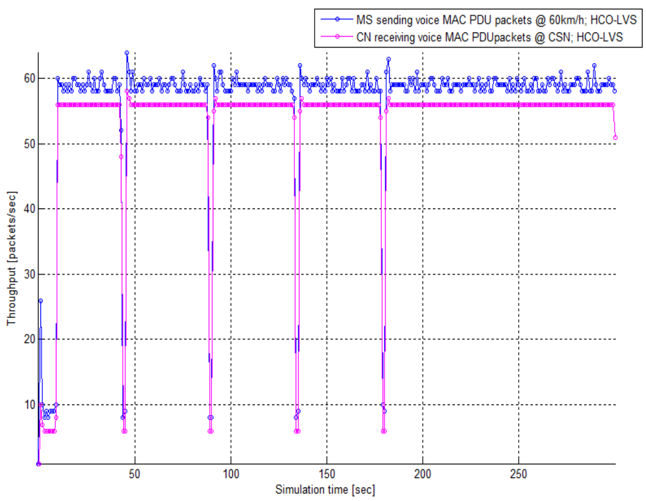

Figure 9. Throughput for Low Vehicular Speed at Half-cell Overlap Coverage

From Figure 9, it can be seen that the transmit voice MAC PDU has non-uniform throughput, in the region of 60 packets/s, while uniform throughput is performed by the receiver voice MAC PDU. The non-uniform throughput occurs due to the impairments introduced by the radio propagation environment (e.g. delay and Doppler spread caused by the relative motion of the MN and the BSs), which affects the OFDM symbols of the voice MAC PDU packets.

During a handover, the packet loss rate is about 50 packets/s or the equivalent of 8000 bytes/s. These packet losses occur during time and frequency synchronisation in the target BS at network re-entry. At the beginning of transmission, it is observed that the initial packet loss rate is approximately 5 packets/s due to delayed network entry during the start of the simulation at the HN. After the final handover, the throughputs are increased gradually and then remain stable. The rapid increase of throughput occurs because of an increase in voice MAC PDUs due to packet redirection on the wireless interface buffer of the BSs. Whereas, a fairly stable throughput occurs due to the wired link between the BSs and the CN, which is not affected by radio propagation effects.

The end-to-end delay during the interleaving interval varies between 30 and 45ms, rising to 47.5ms during handover. The end-to-end jitter varies between 0 to 15ms, and, again, runs to 47.5ms during handover. Example simulation outputs can be seen in Figures 10 and 11.

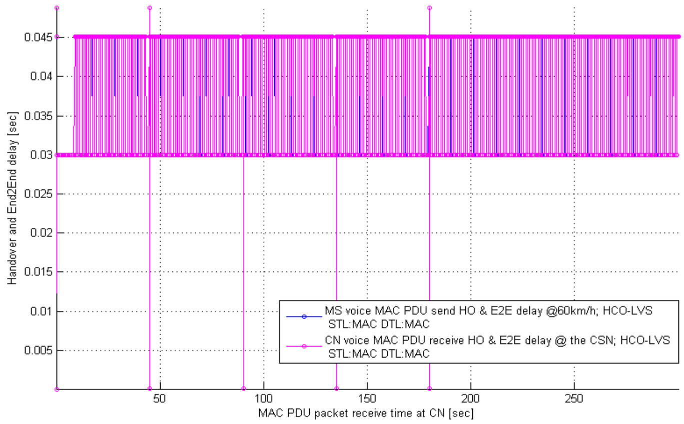

Figure 10. Handover Delay for Low Vehicular Speed

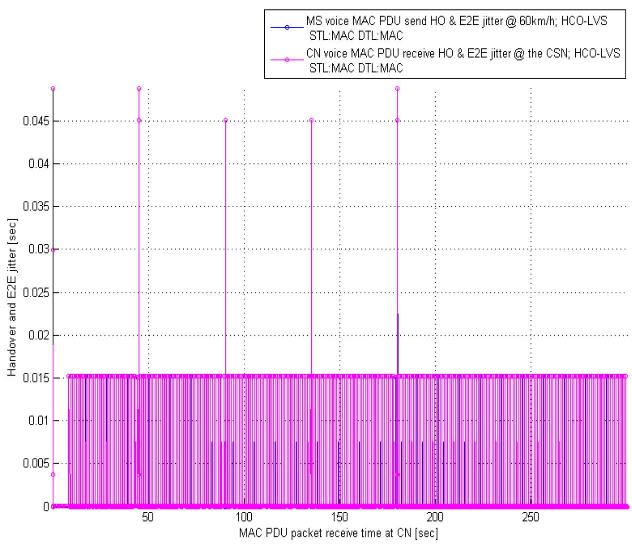

Figure 11. Handover Jitter for Low Vehicular Speed

3.1.3. High Vehicular Speed

The simulation results show that the throughput follows the same pattern as low vehicular speed except that the interleaving interval is shorter in the coverage area of BS1 to BS4 due to the MN travelling at a higher vehicular speed. This result can be seen in Figure 12. The MN spends more time in BS5 having traversed BS1 to BS4 at a faster simulation time.

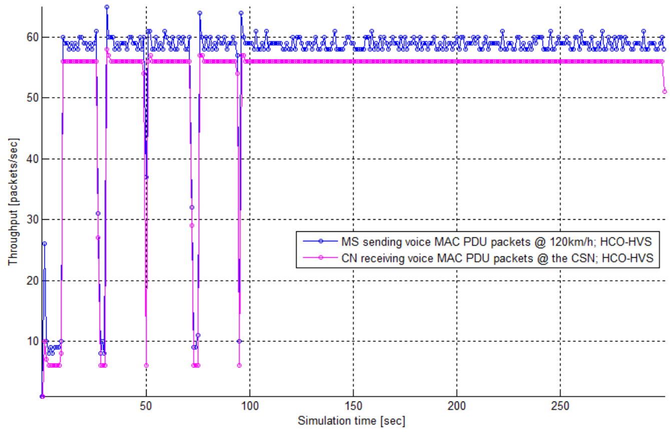

Figure 12. Throughput for High Vehicular Speed at Half-cell Overlap Coverage

The end-to-end delay and jitter characteristics are the same as those for low vehicular speed.

3.2. Heterogeneous Handover Scenario

The throughput performance of heterogeneous handover is illustrated in Figure 13, which shows an instantaneous packet loss occuring during the switch mode. This is due to an additional packet flow, and the redirection of MAC PDUs between WiFi and WiMAX interfaces and also at the interface buffer of the BS. During handover and MMT switching from the WiFi interface to the WiMAX interface on leaving AP1 to BS1, the packet loss rate is 1 packet/s. At the CN, which receives lower voice MAC PDU, the packet loss rate is 4 packets/s.

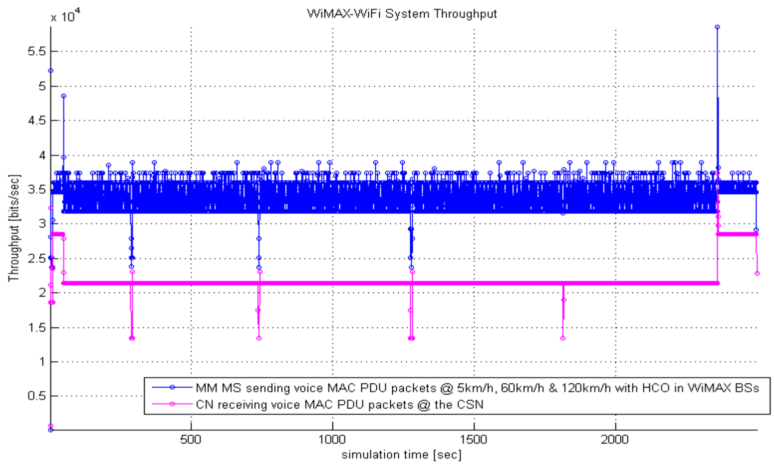

Figure 13. WiFi-WiMAX Handover Throughput

On leaving BS5 and entering AP2, the MMT experiences an improvement in packet loss rate by 1 packet/s due to entering the WiFi network. At the CN, the packet loss rate is also improved by about 4 packets/s.

From AP1 to BS1 and from BS5 to AP2, the handover delays are 48 and 45ms, respectively. The corresponding values for jitter are 15ms and 45ms, respectively. The difference in performance is due to delay variation in receiving beacon signals from AP2 as a result of the delayed waking up of the 802.11 interface. From the simulations, it is observed that there was no packet loss during handover and during switch mode from WiFi to WiMAX interface and vice-versa. This is due to the proximity of the interfaces in the MMT and faster switch mode between these interfaces. Table 2 shows comparison of WiMAX forum standard with the Simulation for Voice Traffic.

Table 2. Comparison of WiMAX Forum Standard with the Simulation

Application	WiMAX Forum Standard		Simulation			
			Horizontal handover		Vertical handover	
	Delay	Jitter	Delay	Jitter	Delay	Jitter
VoIP and Video Conference	< 150 ms	< 50 ms	46 ms	47 ms	46.5 ms	30 ms

4. Conclusion

Mobile WiMAX technology can be used to extend the benefits of WiFi networks to deliver the next-generation of broadband Internet services. The main requirement for achieving seamless integration of mobile WiMAX and WiFi access networks is to minimise handover interruption and preserve the QoS as an MS moves between mobile WiMAX and WiFi access technologies. Maintaining tolerable handover performance in terms of: delay, jitter and throughput during handover between networks at pedestrian and vehicular speeds are essential criteria for network operators if they are to provide reliable IP services, including VoIP. The results presented in this paper suggest that it is possible to implement a heterogeneous network comprising of mobile WiMAX and WiFi access networks that are within the performance criteria defined by the WiMAX Forum.

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