A mobility framework to improve heterogeneous wireless network services

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Abstract: We propose and investigate the Internet Protocol version 6 (IPv6) enabled mobility framework to improve the user mobility experience in heterogenous wireless networks. The framework considers the traditional IP network infrastructure, IPv6 based mobility support, multihoming, traffic flow transparent handovers and flat/dynamic mobility policy enforcement to guarantee the Quality of Service (QoS) and Quality of Experience (QoE) with ubiquitous connectivity. Using Network Mobility (NEMO) we can provide a flexible network integration mechanism across WiFi, WiMax and UMTS systems vertically. The flexible approach overcomes the limitation of different networks access denial when nodes move using two operations: Policy enforced handover management and Dynamic handover implementation. The paper describes the design rationale behind the solution, introduces an experimental testbed and simulation models, validates mobility related services performance, and discusses our research findings.

Keywords: QOS; quality of service; QOE; quality of experience; mobility; handover; heterogenous; IPv6; policy enforcement; flexible network.

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1 Introduction

The fourth generation heterogeneous mobile communication network refers to a complex hierarchical system including different radio access technologies such as Long Term Evolution (LTE), Orthogonal Frequency Division Multiplexing (OFDM) access, Code Division Multiple Access (CDMA) based 3G networks, Time Division Multiple Access (TDMA) networks based 2G networks, IEEE 802.16 WiMAX, IEEE 802.11 WiFi compatible systems and other IEEE 802 networks.

The current heterogeneous systems are complex and there is high communication demand during mobility. Therefore node and network mobility becomes one of the most important features with significant impact on how communication systems evolve. A new level of mobility support is required by both service providers and end users to facilitate the emerging ambient and ubiquitous communications. Provided with such support, the end-user would rarely experience a forced service termination when roaming where certain types of networks may not available. The end-users can be also transparent from any mobility service changes while the service providers handle the background mobility signalling transfer.

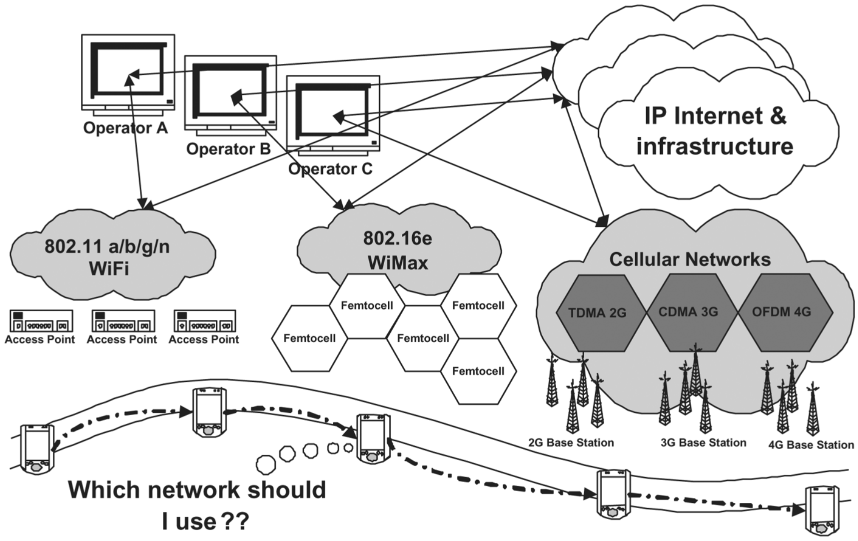
Among various solutions, Mobile IP is seen as a practical approach to provide the mobility support. The implementation is independent of radio access network types and transparent among applications. It is reasonable to incorporate the node and network mobility support in the context of next generation IP based transporting architecture (the mobilenode/mobile network referring to a node or node with an IP subnet, respectively, capable of changing their IP topological locations according to Lach et al. (2003). Figure 1 illustrates the heterogenous wireless networking environment in the current situation where major wireless radio access/network types are presented. In this scenario the networks are not integrated; they remain autonomous independently-managed entities. An end-user may have to frequently make network selection decisions or experience service termination when moving without the presence of seamless heterogeneous network (inter-network and intra-network) mobility management protocols. To introduce robustness, flexibility and adaptivity to this heterogenous wireless networking environment, we propose to use Internet Protocol version 6 (IPv6) for gluing the networks and hence providing the generic inter-network and intra-network communication platform. Motivated by service quality improvement, the mobility framework consider three important enablers which are:

- IPv6 Multihoming scenarios in the 802.11 WiFi compatible access and IPv6 transparent traffic vertical handovers
- Dynamic network selection protocols using policy based flow distribution
- Socio-Economic drivers that the current heterogenous wireless networks need to consider: The 'tussle' (Clark et al., 2005) management for end user and infrastructure providers.

The emergence of new converging mobile services challenging their existing business model. A double network and service heterogeneous environment has emerged from the inter-operability of different technological standards and alignment between different players, challenging the traditional assumptions of network providers (Blumenthal and Clark, 2001). These new services and their following generations require high bandwidth capacity and lead to conflicting interests between the different stakeholders involved, in particular but not limited to infrastructure and service providers (Clark et al., 2005). The heterogeneous environment may lead to inefficiencies e.g., the deployment of parallel architectures or even system failure. In particular, key challenges are the service qualify problems, justification for further infrastructure investments and regulatory challenges. We treat the first two enablers as the technical problems and the 'tussle' management enabler an application issue. Application drives can be translated into Multiple Attribute Decision Making (MADM) or Dynamic Decision Making (DDM) parameters, then input to the flexible mobility framework to make a better mobility decision and optimise the system performance.

The paper starts with a short description on the state of the art IP based wireless networks mobility and handover management review in Section 2. Section 3 details our proposed mobility framework using adaptive policy enforcement, cross platform handover scenarios with system characteristics, the multi-homed networking experiment testbed and computer simulation environment. We verified the mobility related Quality of Experience (QoE) in Section 4 and finally detail our research conclusion and outlook in Section 5.

Figure 1 An illustration for current heterogenous wireless networking environment



2 Related work and issues

A number of Internet Protocol version 4 (IPv4) mobility protocols have been proposed, designed and implemented that complement the base Mobile IP protocol. The development of these protocols has generated considerable interest in industry and academia to improve mobility handling capability. The cellular IP protocol supports paging and a number of handover techniques. A similar approach is the Handover-aware Wireless access Internet Infrastructure (HAWAII) (Vicente and Ernesto, 2006), which is a separate routing protocol to handle mobility. Designed to address the weaknesses in mobility, the two protocols belongs to traditional Mobile IP extensions based mobility management protocols. All these proposals require routers on remote networks to serve as Foreign Agents (FAs) that provides complicated detunnelling points for datagrams meant for registered end users.

Taking a new approach based on mobile IPv6 protocols with feathers direct routing, the network mobility (NEMO) basic support protocol (Devarapalli et al., 2005) enables complete networks(nodes) to roam among different access networks or subnets without disrupting network nodes ongoing sessions and without requiring any specific mobility capability in the hosts. However, it has limitations on layer 2 and layer 3 performances, due to the increased path length, service differentiation and networking environment, and the packet overhead that this solution introduces. Such limitations trigger the need for routing optimisation, policies enforcement, and network/service selection protocol for medium access layer and transporting layer.

Depending on different network performance interests such as QoS, QoE or mobility efficiency. Each protocol has differing strengths and shortcomings, and it might be difficult to find an absolute winner for a specific network. For example, in a system architecture envisaged by Garcia et al. (2009), only network selection problem among 802.11a, 802.11g and WiMax is addressed for specific IP Television (IPTV) application. On the other hand, most proposals for all IP hybrid network did not address inter-system (vertical mobilities) and system integration issues. Currently the NEMO proposal allows **Multiple Care-of Address** implementation. It is facilitated through **Flow Bindings** (Ropitault and Montavont, 2008) and is being standardised. Multi-interfaced Mobile Router (MR) is designed to fully benefit from all of its network interfaces. Due to flow bindings, the MR operators can define routing policies to redirect efficiently each flow among all network interfaces currently in use according to their service requirements such as cost, bandwidth, security or QoS. We have therefore extended our previous WiFi only multihoming testbed, Wang et al. (2008a) to focus on the transparent and instant heterogenous wireless network mobility. The service providers are then provided a chance to realise dynamic flow management across different platforms, alleviating the tussle difficulty.

3 The flexible mobility framework

We first design a representative networking environment including three current wireless communication systems, which are WiFi, WiMax and 3G based Universal Mobile Telecommunication System (UMTS) cellular system. To facilitate flow bindings in this environment, two types of policies are issued at the network selection points to manage and handle mobility issues. An output policy can also define a binding of a specific interface for a given mobile router such as a binding ID or a specific application flow in IPv6 based multihoming case. The two polices are:

- *Flat policy*: The network selection point enforce plain handover procedure for intra-system mobility management

- *Dynamic policy*: The network selection point enforce vertical handover procedure for inter-system mobility management.

Table 1 presents essential characteristics of the mobility scenarios (Note: Trans. stands for Transparent mobility and we does not differentiate the mobility characteristics between two different access networks). It explains required operation procedures at different layers for traffic handover between network accesses (interfaces), e.g. From WiFi to WiFi or From WiMax to UMTS. At physical layer, notice that the mobile IPv6 traffic handovers among WiFi access points or subnets, the WiMax Femtocell serving base stations roaming or the cellular UMTS traffic handovers do not involve physical layer linkage changes thus existing radio resource management protocols are kept and the flat policy is enforced. Such a handover occurs when an end user (flow) enters into another entity that belongs to the same network therefore we also call it **horizontal handover** or **intra network handover**.

Between WiFi access and WiMax access, WiFi access and UMTS access, and UMTS access and WiMax access, a **vertical handover** (**inter network handover**) happens when a flow leaves the serving network and communicates with another entity that belongs to a different network access. The end user or flow does not necessarily change the connection method to an MR. The MR can act as the mobility agent negotiating with backbone IP networks to continue a communication session. For example, as shown in Table 1, for physical layer and medium access layer, during the connection change time from one access to another access, the traffic transfer can be arranged at MRs so the end users are transparent from mobility handling procedures. Dynamic policies are enforced here for vertical handovers to maximise the heterogenous wireless network usage with a guaranteed QoE. For example, the handover from WiFi access to WiMax access is triggered by an "WiFi access lost-of-connection" event. A dynamic policy which has specifications for different layers is then enforced to transfer the traffic layer by layer from one interface to the other interface, before an end-user or a flow connection lost.

Without dedicated equipment such as RAKE receiver in UMTS CDMA systems, the IEEE 802.11 WiFi compatible systems can only support node mobility at reasonable speeds. Measurements (Ott and Kutscher, 2008) have shown that outdoor internet access for moving vehicles may be feasible. IEEE 802.11 transmission rates of 1, 2, 5.5, 11, 22, 48 and 54 Mbit/s have been observed, depending on the distance to the access point and the signal quality. Consequently, a significant higher maximum throughput of some 15 Mbit/s at 80 km/h on a highway has been observed. But from the results it can be seen that the effective net data rate is about 6.4 Mbit/s with LAN access link. Expensive UMTS network supports high speed mobilities but is lower in data rates. The current WiMax incarnation, Mobile WiMax, is based upon IEEE 802.16e-2005 and 802.16d, the downlink rate is up to 10 Mbps in a 10 Mhz channel at medium moving speed of 75 km/h (Shen, 2008).

Each communication system exhibits different QoS and QoE performance result therefore selecting or shifting to the most appropriate one for a particular service request is critical to provide QoS and QoE to the end user. A balanced distribution of load between the available network modes is also critical to avoid one network mode becoming excessively loaded and leading the system to an unstable state. It is more reasonable to switch services from expensive cellular and WiMax to the cost-effective NEMO enabled 802.11 WiFi. After a dynamic policy is enforced, the inter

Table 1 The flexible mobility management framework for the heterogenous wireless network

	WiFi *WiFi*	*WiMax* *WiMax*	*UMTS* *UMTS*	*WiFi* *WiMax*	*WiFi* *UMTS*	*UMTS* *WiMax*
Physical layer	IEEE 802.11a/b/g	IEEE 802.16e/d	UMTS 2100MHz	Trans.(MR)	Trans.(MR)	Trans.(MR)
Policy enforce	Flat policy	Flat policy	Flat policy	Dynamic policy	Dynamic policy	Dynamic policy
Mobility type	horizontal	horizontal	horizontal	vertical	vertical	vertical
MAC layer	Contention CSMA/CA	Connection-oriented MAC	W-CDMA	Trans. (MR or EU)	Trans. (MR or EU)	Trans. (MR or EU)
Routing layer	IP routing, Ad hoc	IP routing	Packet switch, IP routing	IP routing	IP routing	IP routing
Mobility speed	Low, medium	Low, medium, high	Low, medium, high	Low, medium	Low, medium	Low, medium, high
Data rate	Low, medium, high	Low, medium	Low, medium	Low, medium	Low, medium	Low, medium

network handover triggers a switching process between different radio access networks. A functional unit named the **Status Check Point** is activated to avoid unnecessary cross platform handovers, a functional unit named **Negotiation Unit** keeps monitoring the channel availability status and updates the association level between different traffic flow to grant or reject handovers, and a functional unit named **Network Selector** aims to divert a flow back to intra network handover using flat policy. Once the **Network Selector** confirms that the intra network handover is not available, if the flow is currently communicating in WiFi mode, the selector searches available WiMax and cellular base stations in neighbouring cells. If the flow is in cellular mode, it looks for either direct communication through WiFi access points or searches for a fixed WiMax base station to instigate WiMax access. If the flow is in WiMax mode, it searches for WiFi communication or a cellular access transfer. The **Network Selector** uses several short network search expire times for both intra-network search and inter-network search to make sure the traffic flow is not isolated during the network selection process. The inter-network handover steps are described as:

1 For *N* flows, $0 < i < N$, sort $Flow_i$ in descending order based on weighted calculations involving service class, QoS requirement and service urgency

2 Order the Flows waiting for handovers in a queue from higher weighted applications to lower weighted applications; For *K* triggers, $0 < j < K$, calculate $Trigger_j$ of each flow to determine whether a handover is required and the handover time

3 Try to divert the flow session to **Intra Network Handover** before **Inter Network Handover**. Check the media access constraint, then the flow makes a handover decision. Fail all handover requests that did not pass the checks, for $N = N - 1$, go back to Step 1.

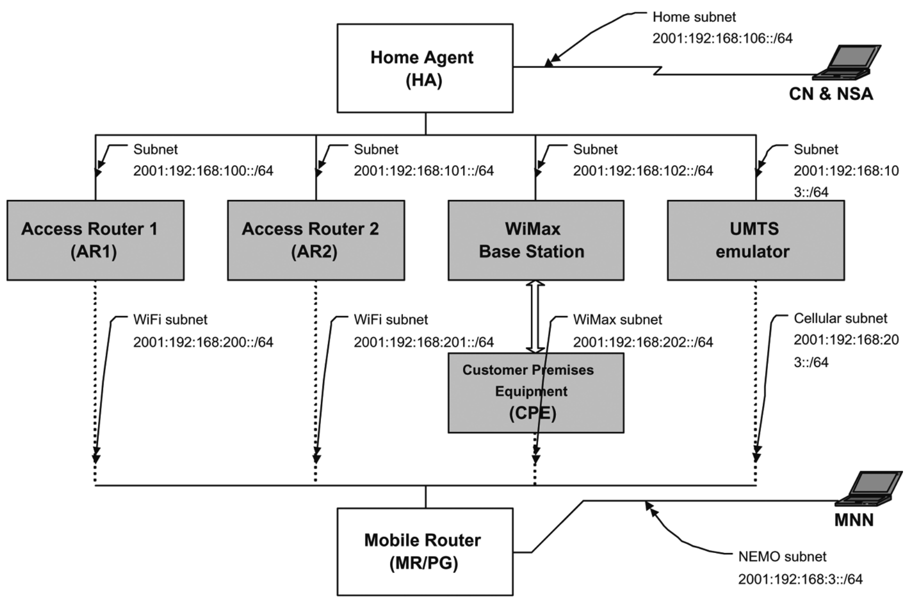
More information on the system mode selection, user differentiation and negotiation, multiple handover triggers, congestion control and system cooperative mobility can be found in Shen (2008).

3.1 Mobility framework testbed

We have constructed a heterogenous wireless network mobility testbed and believe the testbed can provide first hand real-time data for flow binding experiments for the complex environment, as shown in Figure 2. A set of customised Linux boxes and routers were configured to act as the Network Selection Algorithm (NSA) enabler, Status Check Unit, Negotiation Unit, the Corresponding Node (CN), the Home Agent (HA) and the Personal Gateway (PG)/Mobile Route (MR) equipped with two WiFi interfaces, one Airspan WiMax interface with Customer Promises Equipment (802,16d, Airspan MicroMAXd model, Time Division Duplex (TDD) 5.8 GHz) and a cellular interface emulator. The Mobile Network Node (MNN) (mobile node) is a Windows XP PC in the mobile network whose multi-access and mobility proxy is the MR. The NSA was simplified as a network policy generator in the experiments. To test video, data transfer and voice service including traditional voice and VoIP, the Correspondent Nodes (CN) is a video streaming server, a FTP server, and a voice service server for the mobile node. For example, IPv6 enabled VLC media applications can be used for video streaming and FTP, representing typical realtime and non-real-time applications, respectively.

The MR acts on behalf of the end user nodes within its mobile network. Firstly, the MR indicates to its HA

Figure 2 The novel heterogenous wireless network mobility testbed



that it is acting as a MR as opposed to a mobile host. Secondly, the MR informs the HA of the mobile network prefixes. These prefixes are then used by the HA to intercept packets addressed to the mobile nodes and tunnel them to the MR at its care-of address, which in turn decapsulates the packets and forwards them to the mobile node. Packets in the reverse direction are also tunnelled via the HA in order to overcome Ingress filtering restrictions. In this case the HA decapsulates the packets and forwards them to the CNs. The handover execution is built upon the NEMO implementation (NEPL) with integrated Multiple Care of Addresses (MCoA) support in multiple subnetworks as shown in Figure 2. Once a trigger is received and parsed, the enclosed policies are enforced with the IPv6 routing table at the HA and the MR. The subsequent packets meeting a policy are marked with the corresponding flow binding ID such as 100 or 200. A routing table per binding ID is generated, e.g., routing tables # 100 and # 200. These tables are looked up for forwarding the marked packets to the corresponding interfaces. IPv6 stateless host auto-configuration was achieved through the RADVD module. The multihomed MR automatically configures a CoA for each of its interfaces and registers the CoAs with the HA via the MCoA support.

The testbed evaluates both horizontal and vertical handover mobility, and also tests IPv6 multi-homing scenarios. As shown in Table 1, the vertical handovers in the testbed happen between cellular access and WiMax access, between cellular UMTS and WiFi, and between WiMax and WiFi. For example in a typical experiment for the testbed, as shown in Figure 3, a mobile node associated with a three radio interfaced MR starts moving in a trajectory from point 0 to point 3. The CN of this mobile node can be any node in the heterogenous system using any radio access in the system. At point 0, the mobile node is connected to the CN through standard a WiFi interface. At point 1, the mobile node is associated with another WiFi router with different subnet IPv6 address. This means during the transfer the traffic has migrated from one subnet to another subnet and such a mobility scenario can not be implemented in IPv4 networks. However, the handover between point 0 and 1 is still horizontal as only 802.11 WiFi network access did not change. At point 2, the mobile node is associated with a WiMax base station using standard WiMax interface. The handover between point 1 and 2 is vertical since the access has been changed from 802.11 access to 802.16 access. At point 3, the mobile node communicates with the CN directly through cellular UMTS interface. The handover between point 2 and 3 is also vertical as the access has been changed form 802.16 to UMTS based cellular access. As we explained in Section 3, the handover process can be transparent to end user therefore the end user may not notice any service quality changes all the way through albeit in the background, the serving network access types has been changed two times. The testbed's layer 3 handover is completely handled at IPv6 backbone networks.

3.2 *Mobility framework simulation models*

The mobility framework has been also validated through OMNET++ (Varga, 1999), simulation, which is a discrete event simulation environment with Graphic User Interface (GUI) support. We mainly consider packet level and session level modelling, but not at bit level. Multimedia traffics including voice, video and WEB data are modelled. The voice traffic is modelled by means of an exponentially distributed call duration random variable with mean, τ_H, equal to 3 min. With respect to QoS, the video trace is directly incorporated into the simulator. A WEB traffic input model named ON/OFF model by Staehle et al. (1999) has been used. It has several activity levels with ON periods and OFF periods. The Voice over IP (VoIP) traffic is also treated as an ON and OFF sessions with mean duration equal to 6 min.

A Time Division Duplex (TDD) link is used for UMTS to support a higher link-rate of 20 Mbits/s. The signalling mini slot duration is 10% of the time-slot duration. Given the mini slot time of 0.143 ms, a transmission bit rate of 20 Mbit/s, and 80 bits of

Figure 3 A horizontal and vertical handovers scenario presentation for the testbed

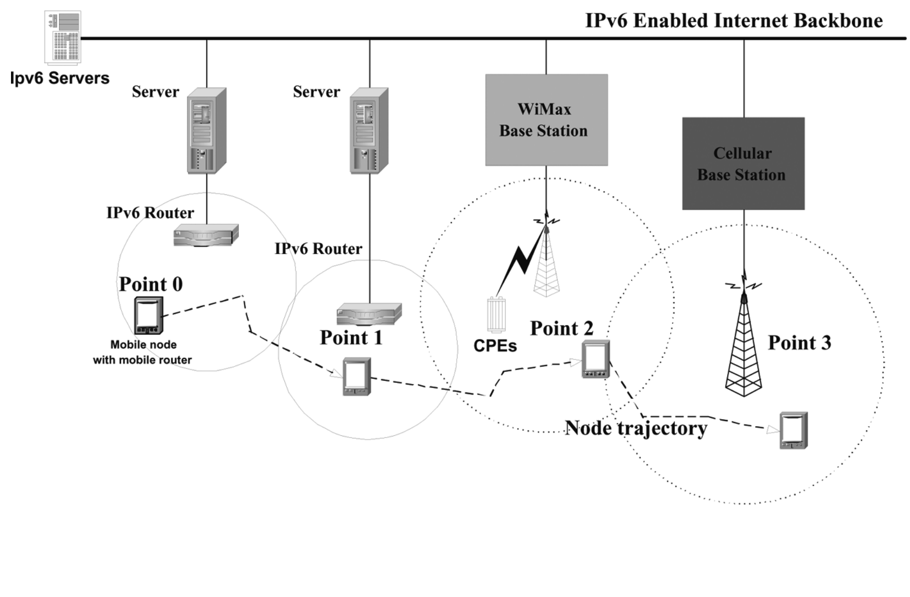
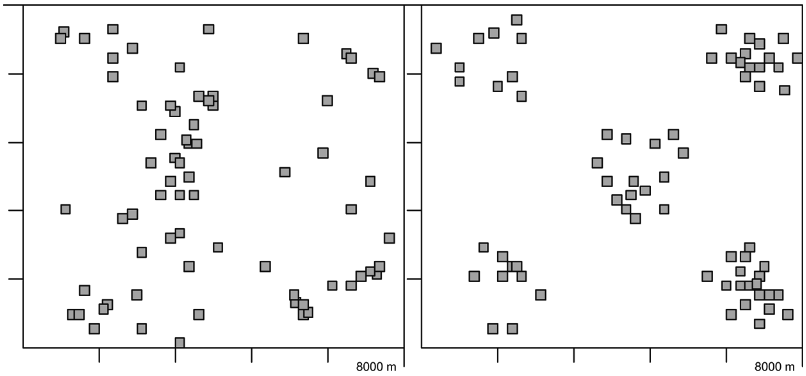


Figure 4 Mobile node movement behaviour using APMM algorithm, left figure presents nodes distribution at simulation start and right figure presents nodes distribution at simulation finish



signalling information, there is a guard interval of 0.139 ms for receiver turn-around time. The WiFi deploys CSMA/CA with exponential backoff. Slot time is set to 20 μs. The sender is responsible for: receiving frame from upper layer; going to Backoff (BO) procedure; transmitting frame; waiting for ACK (Acknowledgement) and going back to BO procedure. The receiver node takes care of: Checking if received frame is ok; waiting for Short Inter Frame Space (SIFS) and transmitting ACK. In BO procedure, if the time is due to timeout, the sender either doubles Contention Window (CW) or waits until channel is idle plus an additional DCF Inter Frame Space (DIFS). CW is adjustable and simulation parameter is listed as:

- *SIFS*: 10 μs.
- *DIFS*: 50 μs and $DIFS = \mathrm{SIFS} + 2\,X$ slot time.
- *BO*: variable backoff (within one CW) and CW min: 31, CW max: 1023.

Three WiMax layer two sublayers are modelled: service-specific convergence sublayer (CS), the MAC common part sublayer, and the security sublayer. QoS functions are implemented in the MAC common part sublayer. Several service classes are defined to satisfy various QoS requirements. For example, a VoIP connection is often associated with Unsolicited Grant Service (UGS) to support Constant Bit Rate (CBR) or CBR-like flows with constant bandwidth allocation. According to the QoS associated, the BS schedules radio resources with various scheduling disciplines, such as round robin or First In and First Out (FIFO). The transport layer functions are assumed to be handled by IPv6 backbone networks.

An Attraction Points oriented Mobility Model (APMM) (Murray, 2007; Shen et al., 2007) based on the random waypoint model is modelled to reflect node moving behaviours in heterogeneous environment e.g., the end-users gather at a city centre during the day and go back to suburbs in the evening. The algorithm first selects N attractors that are distributed at points where nodes will originate from or progress towards. Prior to heading for attraction points, nodes are grouped together using Cell Type Transition Probability, each subscriber selects a destination area with probabilities. Figure 4 presents a typical node movement changes and how the user mobility pattern within a simulation set can be shaped, at the beginning, all nodes are scatted around in this metropolitan environment, after 200 simulated minutes the nodes have moved to one of five predefined attractor points which locate in the middle of northwest, northeast, southwest, southeast and centre. The probability is statistics related and changes, e.g., the northeast and southeast regions are defined have higher attractor probabilities than the rest of hot spots thus more nodes are gathered at the right side. The *Speed Control* mechanism of node movement micro control is also introduced. The speed may continuously increase or decrease. In each step, a new speed sample $v(t_{k+1})$ for a node is calculated according to:

$$v(t_{K+1}) = V(t_K) + a^*(t_{K+1} - t_K) \tag{1}$$

where $v(t_{K+1})$ is speed the next sampling time, $V(t_K)$ is the current speed, accelerating speed a^* is a non-linear variable associated with the distance between a node and its destination attractor point (a^* decreases usually when approaching the attractor point) and $\Delta t = (t_{K+1} - t_K)$ is the sampling period. Different nodes may start with various speed, therefore we introduce another two parameters which are v_{Upper} and v_{Lower} to regulate speed behaviour. Equation (1) applies to a node only if $v_{\mathrm{lower}} \leq v(t_{K+1}) \leq v_{\mathrm{Upper}}$, otherwise at the next sampling point, the speed remains unchanged.

4 Service quality evaluations

The mobility framework using mobile IPv6 has a minimal impact on existing heterogeneous network infrastructure. It is expected to guarantee multiple services with varied QoS requirements. The system capacity in a single cell is largely dependent on the level of inter and intra cell interference in cellular and WiMax mode, the same-entity interference in cellular and WiMax mode and multiple access interference in WiFi mode. Apparently, such capacity can be increased by using IPv6 enabled inter-network load balancing while the interferences can be largely avoided by diverting traffics. We in this section address the mobility directly related parameters: the service grade and the handover performance.

4.1 Network service grade

Used as a comparative benchmark, another heterogenous wireless network without dedicated mobility management is simulated. The handover procedures for its WiFi, UMTS or WiMax sub-network operates as follows: a mobile node establishes a communication session with a base station or an access point on a channel. When the node travels to another location noticing reduced signal strength, if there are channels free in the target cell, the node transfers its communication session to the new base station or access point, otherwise this attempt for handover is marked as a failure. To enhance this plain handover performance and introduce fair competition, some handover procedure parameters have been modified. At layer 2, the content based channel access for WiFi has been modified in favour of mobility. For the other two systems who use slotted channel allocation protocol, each one reserves a number of channels dedicatedly to serve handover requests. In the event when a node lodges a request but can not find any free channels, the reserved slots are then be activated. The number of reserved channels is not fixed and is adjusted according to the communication demand and input traffic volume. The channel reservation handover algorithm has been proved that it can produce similar system performance results when compared to more sophisticated algorithms e.g., traffic prediction based algorithms by Pollini (1996).

The heterogenous wireless network being tested implements the handover mobility framework. Both flat and dynamic mobility policies have been enforced. Each network has the same portion of traffic demand. The APMM mobility algorithm is used on mobile nodes. Cellular system base stations and WiMax Fmetocells are placed at calculated places (Shen and Pesch, 2009) while we assume a evenly distributed access points for WiFi access.

Figure 6 presents the total traffic load carried per cell against the network Grade of Service (GoS) for the two heterogenous wireless networks. To simplify, we name them as HWN mobility test and HWN original, separately. Each environment has the same amount of resource such as system bandwidth. Both traffic flows that are terminated normally and those that failed prematurely due to handover failures contribute to the total load carried. Normal traffic account for the effective load carried. The GoS is defined as:

$$\text{GoS} = \frac{\lambda_n B_n + \lambda_h P_h}{\lambda_n + \lambda_h} \qquad (2)$$

where λ_n is the mean new session arrival rate, λ_h is the mean handover session arrival rate, B_n is the blocking probability of a new session, and P_h is the probability of handover failure. The results have shown that in HWN mobility test system, the traffic load performance is significantly better than that of the original HWN system. At a GoS level of 0.3, which is a typical system performance entry goal, the total load carried by HWN mobility test is approximately 11.8 Erlangs, compared to 9.6 Erlangs by HWN original. The transparent traffic balancing and load shifting yields major gains in the effective load carried on. It is also observed in other experiments that the increasing GoS (>0.3) leads to a reduction in the effective carried load in HWN original since the handover overheads greatly increase, therefore the handover channel reservation upper limit should be defined to mitigate the problem or implement the proposed mobility management framework or other mobility management protocols.

Figure 5 The Grade of Service against traffic load carried comparison for two HWN systems

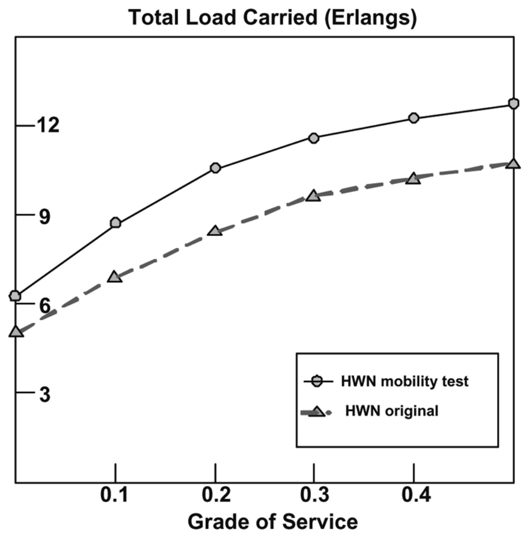
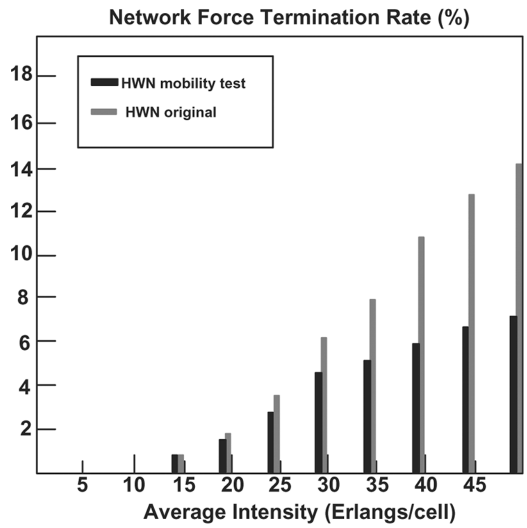


Figure 6 The forced termination performance comparison for two HWN systems



4.2 Network forced termination performance

Figure 6 presents the results of network forced termination performance for HWN mobility test and

HWN original system. The traffic input for this experiment is comparatively high which is up to 50 Erlangs per cell. The network forced termination is defined as: A session is forced to terminate due to handover failure or medium access failure (typically caused by traffic congestion). Apparently, the HWN mobility test system utilises existing heterogenous medium resources efficiently and ensures the required level of service effectively. Meanwhile, it again indicates that the mobility framework balances the traffic load among the three interfaces. The improvement becomes marginal after the system is heavily loaded (>25 Erlangs/cell). The result is interesting since a dynamic traffic balancing usually presents even or worse performance compared to a fixed traffic balancing plan under high traffic input. Two main reasons contribute to this phenomenon: for each type of traffics, the inter-network handovers is not frequent even under high traffic load and most services during the active course stays in the sub-network; the flat policy for intra-system handovers is enforced before dynamic policy for inter-system handovers to reduce the signalling overhead and operation cost. On the other hand, the HWN original system can not divert traffic to other networks that means there is a high probability instant traffic types will use up the available bandwidth. The 'hot spot' traffic flows suffer resource contention.

The research is also interested in examining whether each traffic profile is satisfied with the QoS in terms of handover blocking probabilities. Therefore an experiment is carried out to evaluate each traffic type's performance when the traffic load is being increased. From result we notice that the traditional voice traffic's performance is the most stable one under any traffic load, most nodes are guaranteed with QoS in terms of handover traffic blocking. Even under high traffic load between 25 Erlangs/cell to 50 erlangs/cell, the average handover blocking rates are less than 2%. The majority of traffic blocking attributes to the video and WEB data services including VoIP, in average over 5% under high traffic load (>25 Erlangs/cell). The result suggest a mobility handover protocol considering traffic characteristics and fast decision making to be implemented. We may also use Stream Control Transmission Protocol (SCTP) instead of Transport Control Protocol (TCP) at the transport layer to reduce packet loss probabilities and error rates.

5 Conclusions and research outlook

This paper discusses and examines an IPv6 empowered mobility framework for the mobility management of IEEE 802.11 WiFi compatible, IEEE 802.16 WiMax and cellular system co-exist heterogenous 4G communication environment. The IPv6 mobility support provides a unique mechanism to integrate heterogenous wireless networks with mobile router. The results have proved that the network traffic has been fairly distributed and shifted among different networks. The emerging communication applications such as VoIP, Digital Video Broadcasting (DVB) and Peer-to-Peer (P2P) surely can benefit from the mobility flexibility since:

- the user experience in terms of connectivity or forced termination rate is improved with an extended ubiquitous coverage
- the service providers can more easily and adaptively rent bandwidth from the infrastructure providers
- the end-uses are always stay connected while the network selection and transfer is transparent.

In the future work, we would like to investigate on market place oriented network selection algorithms and policy enforcement mechanisms driven by social-economy motives like 'tussle management'.

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