A JOINT IEEE802.21 AND CROSS LAYER MODEL

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Abstract— In the near future devices will be required to roam across heterogeneous networks with seamless ease. These devices have to contend with problems of heterogeneity inherent in the different link access technologies. Mobility management protocols that are traditionally not equipped to handoff between dissimilar networks will have to take decisions necessary for service continuity. Recent efforts by the IEEE802.21 group have culminated in a draft standard introducing Media Independent Handover Services. The standard provides a framework that abstracts link-specific characteristics from higher layered mobility protocols. This will enable various mobility protocols to handoff uniformly and seamlessly across heterogeneous networks. A Media Independent Handover Function (MIHF) is designed to translate different network interface messages to generic events that can accessed by the higher-layered mobility protocols. However the message load on the MIHF can reduce the response time of event notification and command delivery to and from the mobility protocols. A more time-sensitive solution is presented by introducing a Cross Layer Manager (XLM) into the protocol stack. The results show that better performance is achieved to reduce the number of unserviced events and commands. This shows a critical improvement that would make the XLM model feasible for Next-Generation mobility management.

Index Terms— Cross Layer Design, Mobility, Next-Generation Networks

I. INTRODUCTION

Global roaming, the key driver of Next-Generation Networks (NGN), consists of ubiquitous network coverage and seamless network roaming. To fulfill ubiquitous coverage, existing networks will have to provide access to a uniform set of services recognizable by the user in any locale. Since the majority of communication services are being incorporated into the Web, all deployed access networks will have a direct or indirect connection to the Internet; this is known as the IP-CAN (IP Connectivity Access Networks). For seamless roaming across the access networks, mobility management protocols have to ensure service continuity during handoffs.

The access networks are heterogeneous for 2 reasons. One is that capital investment in existing infrastructure will mean that network owners will not want to forgo their technology and invest in other expensive ventures. The other reason for heterogeneity is that different network requirements drive different network specifications. Practically, a single network cannot cater for all different user needs or provide all services. Issues such as cost, coverage, data rate and ease of deployment dictate differentiated technology specifications [1].

As a result, 4G devices are expected to have multiple interfaces for an Always Best Connected (ABC) mobility paradigm [2]. The ABC mobility scenario enables devices to connect to the best access network in terms of coverage, cost and bandwidth [3]. A multi-interface device can switch from different technologies; this is known as macro-mobility [4]. Macro-mobility often includes vertical handoff between differing technologies if there are distinct network administrators for each network type [4]. Vertical handoff [5], as opposed to horizontal handoff, switches the network context at a point higher than layer-2. Horizontal handoff takes place at the data link layer since micro-mobility handoff management is built into layer-2 protocols. The de facto point of switching in vertical handoff is seen to be at the network layer [6].

The IP protocol invariably dominates the network layer since future generation networks will be built on the packet-switching paradigm made popular by the Internet [7]. The primary IP mobility management protocol is Mobile-IP which is upgraded into MIPv6 when IPv4 migrates to IPv6. MIPv6 tackles mobility through address redirection. An IP address serves as both an identifier and a route guide. Hence a Point-of-Attachment (PoA) change is resolved through re-routing by assigning the roaming device a new IP address for its migrated subnet. Ultimately, even with multi-homed devices [8], MIPv6 is still inadequate to handle advanced mobility scenarios present in 4G networks [3].

In addition to MIPv6 there are other mobility management processes residing at higher layers in the protocol stack with SIP being a popular integrated protocol. These mobility processes are designed to handle either terminal, personal, session or service mobility and require a transparent platform for network context switches. Transparency is achieved by abstracting network links which is the goal of the IEEE802.21 working group.

This paper overviews the IEEE802.21 Media Independent Handover framework and its messaging system. Then a singular IEEE802.21 and a dual Cross Layer Manager and IEEE802.21 (XLM/MIHF) model are compared. Part II of the paper presents works relating to mobility management

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and cross layer design. Part III presents the IEEE802.21 framework and its constituent Media Independent Handover Function. Part IV shows how a Cross Layer Manager could work based on an IEEE802.21 model. Simulation of a singular IEEE802.21 and a joint XLM/MIHF model is carried in which results obtained are presented in Part V. Part VI shows the conclusions drawn from the evaluation. Future work is shown in Part VII, the last part of the paper..

II. RELATED WORK

Several mobility management techniques have been proposed for Next-Generation All-IP Heterogeneous Systems. These techniques, seen in [13-19], present integration architectures where devices in 4G networks can vertically handoff to WLAN networks. With the notable exceptions of the policy-based handoffs in [2] and the content-awareness in [16] most solutions reviewed do not inject user preferences into the handover decision. The shortcomings of these works are that the solutions are only specific to certain network configurations and integration architectures and cannot be scaled to encompass all NGN.

Cross layer design techniques are being introduced to allow the traditional TCP/IP stack to cope in wireless environments [4]. Even though the schemes seen in [20-22] do not address mobility management, they still portray how cross-layer design leverages the protocol stack in wireless access networks. Cross layer signaling such as in [20] can enhance the reactivity of the protocol stack by quickly extracting relevant information from non-adjacent layers. These design principles are used in this paper to find responsive solutions to mobility management in unpredictable environments.

Finally IEEE802.21 MIHS services are used for handover optimization in [10] in conjunction with SIP and in [23] through FHMIP. These two papers show that MIHS-assisted handovers are a significant improvement over traditional vertical handoffs.

III. IEEE802.21

Currently the IEEE802.21 group is in the process ratifying a draft standard for Media Independent Handovers [10]. IEEE802.21 defines a set of services called Media Independent Handover Services (MIHS) that provide mechanisms for heterogeneous network handover. The services are provided by a unified interface which is called the Media Independent Handover Function (MIHF).

The MIHF and the MIHS services it provides - Media Independent Event Services (MIES), Media Independent Command Services (MICS) and Media Independent Information Services (MIIS) - are described in subsequent subsections.

A. *Media Independent Handover Function*

The Media Independent Handover Function (MIHF) abstracts lower layers from higher layers and vice versa. This is accomplished by defining a global set of services, the Media Independent Handover Services (MIHS).

These services are accessed through Service Access Points (SAP). The Service Access Points are API that define a set of primitives that translate into services when accessed by layers. The 3 subsets of SAP are MIH_SAP, MIH_LINK_SAP and MIH_NMS_SAP. The MIH_SAP provides a unified API to layer-3 and layers above it. The MIH_LINK_SAP is uniquely defined by each connected network interface. The architecture of the MIHF and its SAP can be seen in Fig. 1.

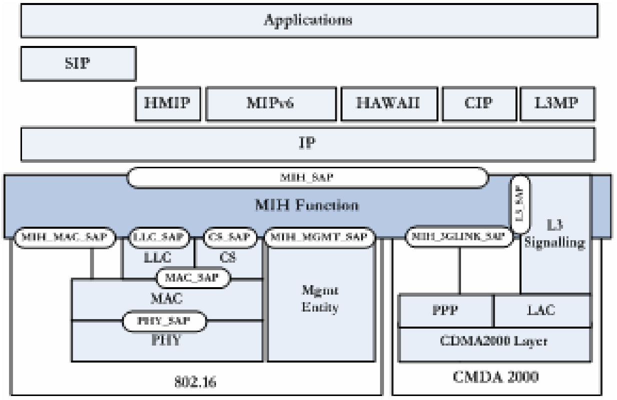

Figure 1. An IEEE802.21 based Protocol Stack.

B. *Media Independent Event Services*

The Media Independent Event Services (MIES) allows interested protocols to be notified when subscribed events occur.

Events notify higher layers of changes in the links status through which mobility decisions can be taken. Link events are translated into Media Independent Handover Events by the MIHF. Event types fall into the administrative, state change, link parameter, predictive, link synchronous and link transmissions categories.

C. *Media Independent Command Services*

The Media Independent Command Services (MICS) allows commands to be delivered to link layers by higher layer mobility protocols. The commands can either configure link behavior or poll the links for their status.

The MIH_SAP primitives translate mobility decision outcomes (commands) into Media Independent Handover (MIH) commands. For the pre-determined commands refer to the IEEE802.21 standard in [11].

D. *Media Independent Information Services*

The Media Independent Information Services (MIIS) allows handover-related information to be relayed across networks. MIIS messages relate to quality of service, cost information, channel parameters, network discovery, security, power management issues, service and application classes and network vendor’s information. The MIIS provides a report mechanism to handover decision engines in advanced mobility scenarios.

In the next subsection we describe how the functional blocks of the IEEE802.21 can be used in a typical mobility scenario.

E. *An IEEE802.21Mobility Scenario*

The Media Independent Handover Function (MIHF) is a shell framework and is not intelligent enough to resolve mobility decisions. It is up to the higher-layer mobility protocols to use the Media Independent Handover Services (MIHS) to resolve an advanced mobility scenario.

A high-layer mobility management protocol (MMP) enforces its decision-making policies for handover. The decision-making process can be reactive (such as MIP's Advertisement timeouts) or proactive (such as FMIP's link layer polling). In the latter case, the MMP can query network resources to get a better understanding of the network conditions. It can use the MIHS to poll the link layer status or to allow notification when networks become available. After obtaining network condition parameters the MMP can evaluate whether it should handoff or not. Such a scenario is presented in Fig. 2, where a mobile node actively scans for available networks.

Once it has been notified of an available network on a non-active link (L2) it can query its conditions. By setting thresholds for L2 conditions it can decide to handoff when L1's conditions degrade beyond L2's.

The query and handoff commands are launched by the MMP (this is not shown in the Fig. 2). These commands are translated by the MIH_SAP to MIHS primitives. Thus the MMP controls the operation of the mobile node's handover procedures with no logical processing by the MIHF.

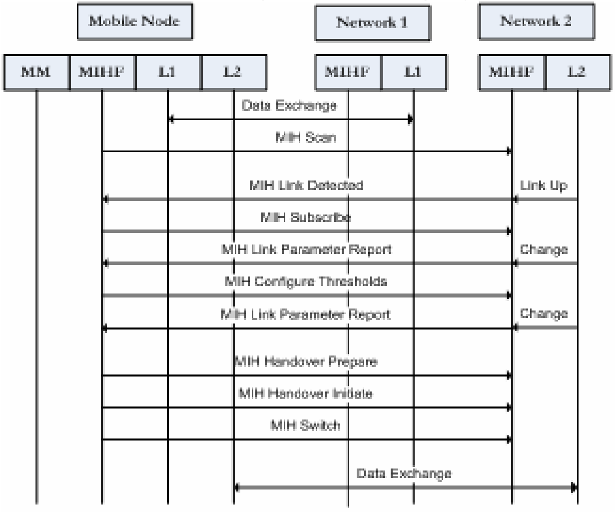

Figure 2. A 802.21-based Mobility Scenario.

Even with the IEEE802.21 standard current MMPs cannot deal with the advanced mobility scenarios found in NGN networks [3]. A cross layer mobility scheme has been proposed by the authors in [3] which would alleviate the problems facing current MMPs.

IV. A JOINT IEEE8021.21 AND CROSS LAYER MANAGER

Cross layer design is seen to be the most ideal paradigm to handle advanced mobility scenarios [3]. Cross layer design can increase movement detection [3], allow the protocol stack to cope in a wireless environment [4] and capture application, service and user requirements. The cross layer mobility management scheme used here was presented in our previous work [3].

The proposed cross layer scheme consists of a Cross Layer Manager (XLM) which houses 3 functional blocks, namely, the Link Information Manager (LIM), the Decision Engine (DE) and the Handoff Manager (HM). The LIM is used to capture application, service and user requirements into a state data structure through Service Access Points (SAP). The lower-layer SAPs that are attached to the link interfaces are defined by the standard to export generic MIHS to the XLM. The higher-layer SAPs are tailored for each attached layer by providing an API to the layer-specific mobility-relevant information. These customized SAPs are defined by augmenting interfaces to protocols that are can provide prudent mobility information. The User_SAP gathers network preferences and cost budgets from the user. The App_SAP gathers delay tolerances and jitter information for the current service session. The Trans_SAP allows the XLM to monitor traffic to gauge conformance to the application. The Net_SAP is used for address configuration through prefix-fetching. The DE contains the decision algorithms required for target network selection. These decision algorithms take the compiled context and content-awareness information from the LIM and run cost functions in [3] to target an optimal network for the current service session. The content-awareness information is taken from the higher-layers through the customized SAP and the context-awareness information is through the MIHF-exported SAPs. The decisions carried out by the DE are different from traditional mobility solutions since it evaluates both context and content-awareness information. Standard mobility solutions such as SIP only evaluate content-awareness and MIP only considers context-awareness. In addition these mobility solutions do not consider user requirements for handovers. However the XLM's DE resolves these problems and signals the HM which executes handoff procedures to the target network.

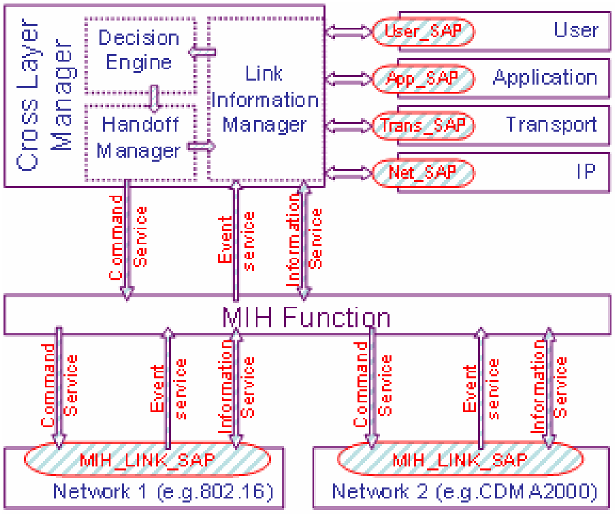

Figure 3. A Cross Layer Manager based on a Media Independent Handover Function.

This paper presents a joint XLM and IEEE802.21 mobility model. The XLM matches the application, session and user requirements with the most suitable target access network. It maintains a state table of the network conditions of each connected link through Media Independent Event Services (MIES). The XLM periodically or reactively solicits MIH Link Parameters Report through MIH Get Status commands for each link. The report is then compiled into each link's respective state table for comparison when executing handoff decisions. When the DE targets the best connected access network it wakes up the HM. The HM would then issue handoff procedure commands through the Media Independent Command Services (MICS). In addition, to ensure service continuity, SIP Re-Invite and MIP Binding Updates re-registration commands are issued for a handover session. A joint XLM and IEEE802.21 protocol stack is shown in Fig. 3 with 2 network cards, WiMAX and CDMA2000.

The XLM represents a unified mobility model which provides a single point in the entire protocol stack where a handover decision can take place. This is in contrast to multiple mobility protocols that could co-exist within the protocol stack. For example, L3MP, MIP and SIP could run in tandem to using MIHS to resolve handovers. If these protocols are uncoordinated and the MIHS service sets are not truncated (such as docking the MICS Handover Initiate command for SIP), handover disparities occur.

If multiple mobility protocols can issue a handover command using the MIHS, conflicts could arise from disparate decision-making processes. Currently terminal, session, service and personal mobility can be carried out by several management protocols. No co-ordination and integration models between the protocols exists [20]. The XLM focuses on terminal mobility, which is intrinsically related to the other mobility types [3]. The DE can integrate and co-ordinate the other mobility types by providing the session, service and personal mobility protocols a feed into the decision-making process. However because there is a single point where the handoff command can be issued conflicting commands can be eliminated. Conflicts cause various handover disruptions including the 'ping-pong' effect. The 'ping-pong' effect is where a device toggles between 2 or more networks over a short time frame.

In addition to conflicts, duplicate and redundant messages occur in the scenario where multiple mobility management protocols are un-coordinated. Disparate protocols can issue the same command which can cause redundancy. There is no need for multiple link parameter reports to exist within a single protocol stack. The XLM can maintain a singular data structure pertaining to the network conditions. Thus the XLM eliminates the redundancy of duplicate commands issued by multiple protocols.

This reduces the high message load on the MIHF introduced by multiple protocols referencing the MIH_SAP. The XLM can partially relieve the load on the MIHF by exporting some of the service primitives. This eliminates the need for SAP decoding by the MIHF from the XLM messages. Some of the functionality of the MIHF is shifted to the XLM. Whilst the MIHF handles the services provided to the lower layers, the XLM exposes service primitives to higher layers. This load sharing is envisioned to drastically reduce the load on the MIHF which results in a faster response time. This is because the XLM sits behind the SAP API and the messages generated by the DE and HM are not decoded; this reduces the overall message decoding time.

Results obtained from simulations presented in the next section aim to verify this hypothesis.

V. RESULTS

A simulation was done to compare the performances of a sole 802.21-based model against that of a joint Cross Layer Manager (XLM) and IEEE802.21 model. Two mobility runs, mobility1 and mobility2, were executed in the OMNET++ simulator, with each run corresponding to a model.

The sole IEEE802.21 model consists of 3 connected network interfaces WLAN, WiMAX and CMDA2000. In addition 3 mobility management protocols (SIP, MIP and L3MP) are running concurrently on top of the Media Independent Handover Function (MIHF). The joint XLM and IEEE802.21 model sees the mobility protocols' functionality shifted to the XLM. The link layer interfaces, however, remain the same.

The link interfaces exhibit pseudo-random behavior similar to a typical mobility scenario. The events are randomly generated according to a truncated uniform distribution. The mobility protocols issue commands depending on the events generated. The decoding delay time exhibited by the Service Access Points (SAP) mirrors a normal distribution with very small standard deviation.

The number of messages received and sent by each of the MIHF in the first run (mobility1) and the MIHF and XLM in the second run (mobility2) is recorded. These messages are a combination of lower layer events and higher layer commands. In mobility2 the total number of messages received or sent by the MIHF is less than in mobility1. The number of unserviced messages refers to the number of messages remaining in the decoding pipeline. In other words the unserviced messages are the commands and events that need to be correlated to their corresponding services by the SAP. The statistics from both simulation runs can be seen in Table 1.

TABLE I
STATISTICS FOR THE SIMULATED MOBILITY RUNS

Mobility1	Number of Generated Events = 43152
	Total Message Count in the MIHF = 103461
	Total Messages Sent by the MIHF = 25737
	Total Messages Received by the MIHF = 77724
	Number of Unserviced Messages = 34573
Mobility2	Number of Generated Events = 43152
	Total Message Count in the MIHF = 52411
	Total Messages Sent by the MIHF = 9097
	Total Messages Received by the MIHF = 43314
	Number of Unserviced Messages = 25005

The graphs in Fig. 4 and Fig. 5 show the number of message arrivals and departures for both mobility runs. Fig. 4 shows the number of messages received by the MIHF from MMPs and link-layer interfaces while Fig. 5 shows the number of messages dispatched by the MIHF. They steadily increase and over a long simulation time the graphs estimate to linear lines. The increase is due to the fact that the MsgCount is a variable that increments for every message arrival. Thus the instantaneous value of MsgCount is the total number of messages received until that time in the simulation. For a short simulation run the graphs do not estimate a linear line because of the randomness of message arrival times.

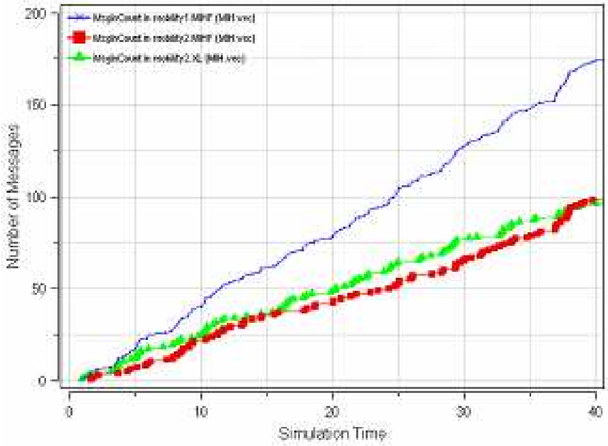

Figure 4. A Graph showing the Number of Messages (MsgInCount) Received at modules for 2 runs.

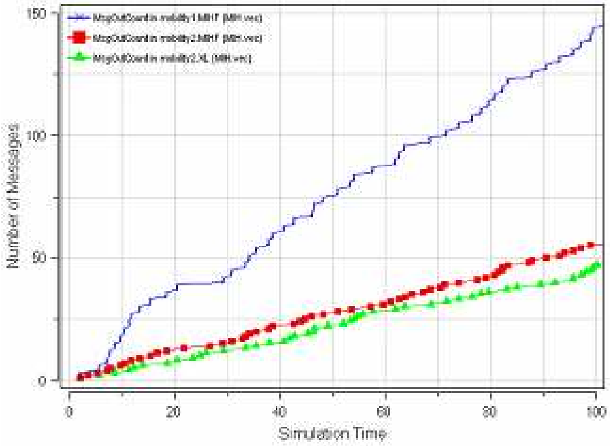

Figure 5. A Graph showing the Number of Messages (MsgOutCount) Sent at modules for 2 runs.

The notable differences in the two graphs are the slope of the two graphs; there are less outgoing messages from the MIHF and XLM/MIHF than their incoming counterparts.

From the two previous graphs one can note the higher message load in mobility1 than in mobility2. The time it takes to service a message from its time of receipt is recorded. This is the message response time. The message response time can either be the time taken to forward an MIH event from a link event or issue a link command from an MIH command. The graph in Fig. 6 shows the mean message response times in the two simulation runs, mobility1 and mobility2. There is a higher response time in mobility1 than in mobility2's load-sharing modules. The higher the message response time line is the slower the service response is in that run.

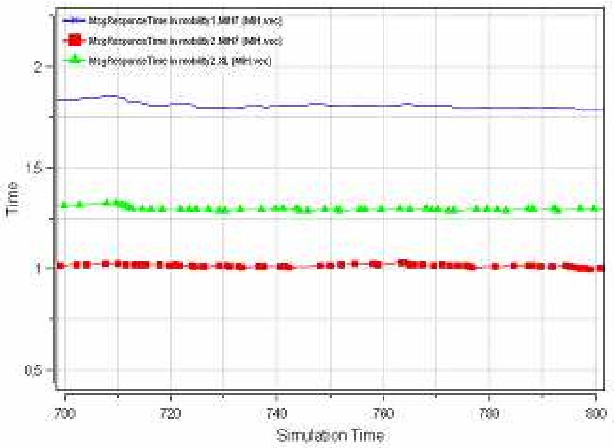

Figure 6. A Graph showing the Mean Message Response Time (MsgResponseTime) at modules for 2 runs.

The significance of the results is shown in the next section.

VI. CONCLUSIONS

In this work, we have shown that the joint XLM/MIHF model can reduce the load on the MIHF which results in an increased message response time. This is a critical performance enhancement because the operation of mobility protocols depends on the timely delivery of commands and events. This is especially paramount in wireless environments where rapidly changing conditions need to be quickly disseminated to higher-layer protocols. If a link event is not propagated quickly enough across the protocol stack service disruption could occur due to latent handovers. The XLM reduces the time taken to service and dispatch messages by exposing service primitives to the higher layers. This also eliminates the need for HM and DE message decoding further increasing the mean response time.

The XLM's aim is to provide a single point of handover which eliminates the problem of conflicting commands that occur when multiple mobility management protocols are running.

VII. FUTURE WORK

Future work includes obtaining results that would verify that the joint XLM/MIHF model reduces the number of duplicate, conflicting and redundant commands. By providing a single point where a handover decision can take place, handover disruptions can be eliminated. Work in progress also includes obtaining results showing how the 'ping-pong' effect can be eliminated.

REFERENCES

[1] H. Anthony Chan, "Overview of Wireless Data Networks Standards and Their Implementation Issues," Talk presented at the 12th ICT Cape Town, May 3-5 2005.

[2] H.J. Wang, R.H. Katz, J. Giese, "Policy-enabled handoffs across heterogeneous wireless networks",

Mobile Computing Systems and Applications, WMCSA 1999.

[3] G.K. Kalebaila, A.H. Chan, “Advanced Mobility Support in Next-Generation All-IP Wireless Networks: A Cross-Layer Approach - Part I”, Personal, Indoor and Mobile Radio Communications, 2006 IEEE 17th International Symposium.

[4] G. Carneiro, J. Ruela, M. Ricardo, “Cross-layer design in 4G wireless terminals”, IEEE Wireless Communications, vol. 11, issue 2, April 2004.

[5] J. McNair, Fang Zhu., “Vertical handoffs in fourth-generation multinetwork environments”, IEEE Wireless Communications, vol. 11, issue 3, June 2004.

[6] I.F. Akyildiz, S. Mohanty, Jiang Xie, “A ubiquitous mobile communication architecture for next-generation heterogeneous wireless systems”, IEEE Wireless Communications, vol. 43, issue 6, June 2005.

[7] E. Gustafsson, A. Jonsson, “Always Best Connected”, IEEE Wireless Communications, vol. 10, 2003.

[8] Christer Åhlund, Arkady B. Zaslavsky: Multihoming with Mobile IP. HSNMC 2003, pp. 235-243.

[9] Jared Stein, “Survey of IEEE802.21 Media Independent Handover Services”.

[10] A. Dutta et al, “Seamless Handover across Heterogeneous Networks – An IEEE802.21 Centric Approach”, WPMC 2005.

[11] IEEE P802.21/D00.05, “Draft IEEE Standard for Local and Metropolitan Area Networks: Media Independent Handover Services”, January 2006.

[12] J. McNair, Fang Zhu., “Vertical handoffs in fourth-generation multinetwork environments”, IEEE Wireless Communications, vol. 11, Issue 3, June 2004.

[13] I. S. Misra, S. Dey, and D. Saha, “4G All IP Integration Architecture for Next Generation Wireless Internet”, NCS 2005.

[14] Q. Wang and M. A. Abu-Rgheff, "A Multi-Layer Mobility Management Architecture Using Cross-Layer Signalling Interactions", Proc. IEE 5th European Personal Mobile Communications Conference (EPMCC'03), Glasgow, Scotland, UK, pp. 237-241, Apr 2003.

[15] Y. Xiao, K.K. Leung, Y. Pan, and X. Du, "Architecture, mobility management, and quality of service for integrated 3G and WLAN networks", ACM Wireless Communications & Mobile Computing, vol. 5, issue 7, pp. 805 - 823, November 2005.

[16] P. Bellavista, M. Cinque, D. Cotroneo, and L. Foschini, "Integrated support for handoff management and context awareness in heterogeneous wireless networks", ACM International Conference Proceeding Series, vol. 115, pp. 1 - 8, 2005.

[17] C. Politis, K.A. Chew, and R. Tafazolli, " Multilayer mobility management for all-IP networks: pure SIP vs. hybrid SIP/mobile IP", Vehicular Technology Conference, vol. 4, pp. 2500- 2504, April 2003.

[18] A. Wilson, "Optimising Wireless Access Network Selection to Maintain QoS in Heterogeneous Wireless Environments", WPMC 2005, Aalborg, Denmark.

[19] H.J. Wang, R.H. Katz, and J. Giese, "Policy-enabled handoffs across heterogeneous wireless networks", Mobile Computing Systems and Applications, Proceedings WMCSA 1999, pp. 51-60, February 1999.

[20] Q. Wang and M. A. Abu-Rgheff, "Towards a Complete Solution to Mobility Management for Next-Generation Wireless System", unpublished.

[21] S. Shakkottai, T.S. Rappaport, and P.C. Karlsson, "Cross-layer design for wireless networks", IEEE Communications Magazine, vol. 41, issue 10, pp. 74-80, October 2003.

[22] I.F. Akyildiz, Jiang Xie, and S. Mohanty, " A survey of mobility management in next-generation all-IP-based wireless systems", IEEE Wireless Communications, vol. 11, issue 4, pp. 16- 28, August 2004.

[23] Q.B. Mussabbir and W. Yao, “Optimized FMIPv6 handover using IEEE802.21 MIH services”, Proceedings of first ACM/IEEE international workshop on Mobility in the evolving internet architecture, San Francisco, California, pp. 43 - 48, 2006.

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