



Mobile Mediator Control Function: An IEEE 802.21-based Mobility Management and Access Network Selection Model

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Abstract: Future users of mobile telephones and other handheld devices will benefit from a variety of wireless access networks including cellular networks, wireless LANs, and wireless MANs. Investments in new wireless infrastructures, new and changed use of radio spectrum, and built-in support for multiple radio access technologies in devices are driving forces behind this trend. The vision of Always Best Connected will finally be reached and users will connect seamlessly to various services delivered over the Internet regardless of media.

This paper proposes a combined network and application layer access network decision model for multimedia applications in heterogeneous networking environments. It builds on previous work of a network layer based metric used in combination with multihomed Mobile IP and introduces a mechanism for applications to interact with the mobility management system in the mobile node. This way, applications executing in the mobile node can decide either to take access network decisions on their own or to let the network layer handle mobility management tasks automatically based on default decision criterion decided by the end-user. An extended architecture based on previous work and the upcoming IEEE 802.21 standard for media-independent handover services is presented. The control plane, named “Mobile Mediator Control Function”, offers a set of events and commands through an additional service access point. Results from a scenario with a Voice over IP application running in the proposed environment simulated in OPNET Modeler are presented.

Keywords: Cross-layer design, IEEE 802.21, Application layer metrics, Mobile IP, Mobility management, Access network selection, Multimedia applications, Network layer metrics, Voice over IP, User policies

1. Introduction

Multi-Radio Access Technology (RAT) capabilities is rapidly becoming an important feature of upcoming standards like IMT-Advanced (a.k.a. 4G) and beyond systems. Today, high-end handsets typically have support for both cellular systems and WLAN systems. Also, there is finally a move from circuit switched to packet switched transport and a shift towards All IP networks. Voice over IP (VoIP) applications may today use the packet data services in the cellular networks and the circuit switched components will eventually be phased out.

Higher data rates and lower latencies are the most important technical factors behind this trend. Applications with easy-to-use graphical interfaces, low flat rates, and massive marketing efforts from the operators are other important factors.

There are a number of interesting research problems related to such networking environments, most notably efficient and scalable ways of performing access network selection and mobility management handling including location management and connection migration tasks. Also, various types of interesting optimization problems around mobility control and routing exist.

Mobility management in multi-RAT environments is typically handled both within the access networks themselves and on the overall heterogeneous level through tight or loose coupling. In the first case all radio access networks are connected to the same IP subnet, while in the latter case interworking is achieved through network layer [1, 2], transport layer [3] or application layer [4, 5] mobility management in order to maintain connections after vertical handoffs.

Cross-layer designed solutions for mobility management are currently being standardized by the IEEE under the initiative of Media-independent handover services (IEEE 802.21) [6] where the services are grouped into event, command and information services. The media-independent handover function (MIHF) is placed between the network and datalink layers, basically forming a layer 2.5 entity, see figure 1 below.

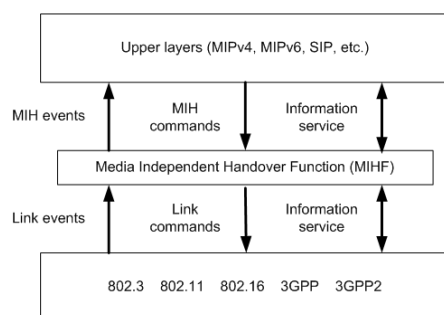


Figure 1: Basic Organization of Media Independent Hand-over Services

Also, remote MIH events and commands may be received from and sent to other MIH stacks respectively. This way, IEEE 802.21 enables co-operative hand-over decision making supporting both terminal-based and network-based mobility management schemes.

This paper proposes a mechanism for cross-layer designed decision making across the application and network layers introducing an extended information exchange model. The most notable benefit of using the proposed architecture is that it is fully backward compatible since the standard Socket API remains unchanged. Legacy applications may run as if they were executed in a fixed environment, while the proposed solution also enables mobility-aware applications to handle mobility in application-specific ways.

This paper is organized as follows: Chapter 2 indicates previous work related to this paper, while chapter 3 describes the proposed extensions to the architecture. Chapter 4 presents results from simulations and chapter 5 indicates related work. Finally, the conclusions of this paper and some indications on future work are summarized in chapter 6.

2. Previous Work

In previous work, a network layer mobility management scheme using Mobile IP [1, 2] was proposed [4]. Mobile IP basically separates the two functions of IP addresses both being used for routing purposes and end-point (host) identification. It uses two IP addresses for the mobile node (MN), namely a home address (HoA) being stable over time and a care-of address (CoA) giving the location of the MN. A home agent (HA) located on the home network is responsible for forwarding packets to the MN when it connects to foreign networks. The MN is informing the HA of its current point of attachment to the Internet, by sending binding update (BU) messages periodically. The HA replies to BU messages by sending binding acknowledgements (BAck) messages back to the MN.

Incoming traffic, i.e. packets originating from other hosts referred to corresponding nodes (CN), travel via the HA and are then tunneled through an IP tunnel using IP in IP encapsulation to the MN. Finally the MN takes care of decapsulation and delivery of packets to upper layers. Outgoing traffic, i.e. packets originating from applications in the MN, are handled vice versa.

Different types of route optimization techniques exist in the Mobile IP standards for IPv6. When used, all traffic does not have to pass through the HA. The possibility to register more than one CoA to the HA for a given HoA, often referred to as M-MIP (multi-homed MIP), is described in [5a]. This is a suitable way of implementing soft handover functionality.

The basic idea in previous work was to let the MN issue binding update BU messages periodically in parallel over all available interfaces and to study delay and delay jitter of the BACk messages sent in return from the HA. The relative network load (RNL) metric, based on those delay and jitter measurements in the available access networks, was introduced [5] to enable comparisons between access networks and to predict the performance of those networks. Also, the previously proposed architecture enabled the end-user to express his/her needs through policies where weights are set for monetary cost, battery consumption, and network performance (i.e. the RNL value) [6]. The solution is thereby a concrete implementation of the Always Best Connection vision [7] and has both been implemented in real-world prototypes [8] and simulated in Glomosim and OPNET Modeler.

The basic architecture is found in figure 2 below.

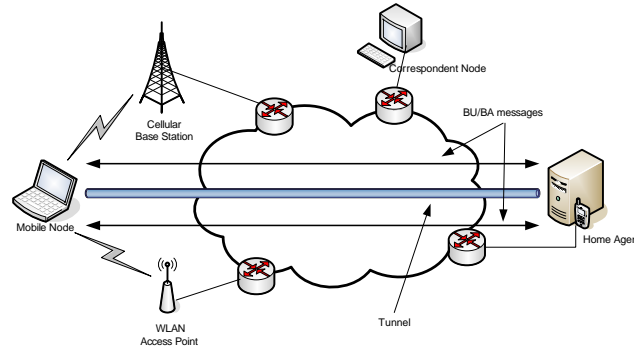


Figure 2: Overall Architecture

The formulae for calculating RNL_n and policy values U_n for access network n are found below:

$$RNL_n = \bar{z}_n + c J_n \quad (1)$$

$$\bar{z}_n = \frac{1}{h} RTT_n + \frac{h-1}{h} \bar{z}_{n-1} \quad (2)$$

$$RTT_n = R_n - S_n \quad (3)$$

$$D_n = R_n - R_{n-1} - (S_n - S_{n-1}) = (R_n - S_n) - (R_{n-1} - S_{n-1}) = RTT_n - RTT_{n-1} \quad (4)$$

$$J_n = \frac{1}{h} |D_n| + \frac{h-1}{h} J_{n-1} \quad (5)$$

$$U_j = w_p \ln P_j + w_c \ln C_j + w_b \ln L_j \quad (6)$$

$$L_n = RNL_n \quad (7)$$

where S_i and R_i are defined as

S_i = the time of sending BU message i
 R_i = the time of arrival of BU message i

$c, h, w_p, w_c,$ and w_b are positive, real constants and

$$w_p + w_c + w_b = 1.$$

h determines the history window for the weighted average calculations. For example, when $h = 5$, the most recent value will contribute to the calculated \bar{z}_n and J_n values with 20%.

c determines the weight of the RTT in comparison to the RTT jitter value. For example, when $c = 5$, the RTT jitter value is contributing five times more to the RNL metric value than the RTT value does.

The variables $\bar{z}, D,$ and J are initialized with the following values:

$$\bar{z}_0 = RTT_0$$

$$D_0 = 0$$

$$J_0 = D_1$$

Furthermore, P_j represents power consumption while C_j is the monetary cost for access network j respectively.

The actual network selection decision is made so that the network with the least value of U is chosen. However, handovers from access networks with large coverage areas (like UMTS and CDMA2000) to access networks with smaller coverage areas (like WLAN and WiMAX) are delayed until the condition

$$U_{\text{new}} < U_{\text{old}} - a$$

is true where a is a hysteresis avoidance constant used in order to avoid ping-pong effects.

The architecture was also extended to take care of varying needs among a set of applications simultaneously executing in the same MN connected to two or more access networks. The background was that an access network selection decision for one application may not be the ultimate decision for another application. Generally speaking, realtime and non-realtime applications as well as interactive and non-interactive applications may have different requirements on network characteristics.

In previous work differentiation in access network selection decisions for a set of simultaneously executing applications was proposed to be handled through port-based handling [9]. The BU message structure was changed, so that the MN could indicate to the HA to direct traffic destined for certain combinations of ports and transport protocols via a specified access network. Furthermore, the architecture was extended to include a service level model and an Internet mobility monitor [10] where different layers exchange events and information via service access points.

This paper refines the model even further and proposes details in the message exchange mechanisms between the application and network layers introducing an IEEE-based extension for network-layer mobility management. It also presents results from simulations focusing on the performance of the combined decision making model when used in a scenario with VoIP application.

3. Proposed Extensions of the Architecture – Introducing the Mobile Mediator Control Function (MMCF)

A. Model Assumptions and Basic Problem

The model introduced in this paper is based on the principle of “everything over IP, IP over everything” implying m applications running over IP (using either TCP or UDP as transport protocols), in turn connected to the global Internet via n access networks, see figure 3 below.

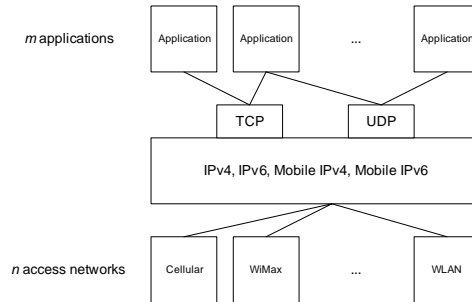


Figure 3: Overall model of the mobile node

Let $M = \{1, 2, \dots, m\}$ be the set of applications, $N = \{1, 2, \dots, n\}$ the set of access networks, and $s(i, j, t)$ denote the policy value (from Eq. 6) for application i for each $i \in M$ and access network j for each $j \in N$ at a specific time t . In the general case, the basic problem is thus to find the access network $j \in N$ that minimizes the value of $s(i, j, t)$ for each $i \in M$ at time t .

In order to support this type of environment also giving the opportunity to applications to either handle mobility management automatically or by themselves, the architecture is extended with an information exchange model for upper layers.

B. Proposed Extensions

Following the principles of IEEE 802.21, an additional service access point is introduced to implement the control plane for the combined network and transport layer. Also, messages are split into events, being transferred from the network layer to the application layer, and commands, being sent the other way around. The control plane of the combined transport and network layers is named the “Mobile Mediator Control Function” and shares functional entities for mobility management, access network selection, network monitoring, and policy engine with the user plane, see figure 4.

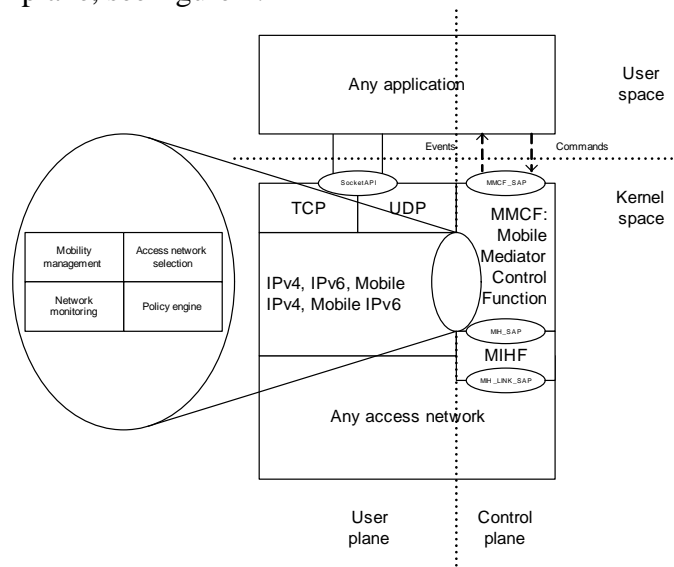


Figure 4: User Plane and Control Plane of the Proposed Architecture

The proposed supported messages that are exchanged over the Mobile Mediator Control Function Service Access Point (MMCF_SAP) are found in table 1 and table 2 below. Events beginning with MIH are direct mappings from IEEE 802.21 while the others, beginning with MMCF, are part of the proposal in this paper.

The MMCF Policy Value Alarm event is sent whenever the policy value is above the threshold. The MMCF Policy Values Report events are sent periodically indicating the policy values for all available access networks. Since different applications may have set different weights for the policy value calculation, those values may vary from application to application for a certain access network.

The MMCF Configure command is used by applications executing in the MN to configure weights for the policy value calculations and report intervals. The MMCF Configure Thresholds command is used to configure threshold levels. Finally, the MMCF Configure Handover Mode command allows the application either to handle handovers manually or ask the network layer to handle handovers automatically according to the calculated policy values for that specific application. Applications are identified by port numbers and transport protocol.

Table 1: MIH Events and MMCF Events

Event	Description
MIH Event Register	Register for MIH event notifications
MIH Event DeRegister	Deregister for MIH event notifications
MIH Link Up	L2 connection has been established
MIH Link Down	L2 connectivity is lost
MIH Link Going Down	L2 connectivity is predicted to go down
MIH Link Event Rollback	Predicted event has not occurred and hence event indication must be rolled back
MIH Link Parameters Report	Link parameters have crossed specified threshold
MIH Link SDU Transmit Status	Indicate transmission status of all PDU segments
MIH Link Handover Imminent	L2 handover is imminent
MIH Link Handover Complete	L2 handover has been completed
MMCF Policy Value Alarm	The policy value for chosen access network is above threshold
MMCF Policy Values Report	Policy values for all available access networks

Table 2: MIH Commands and MMCF Commands

Command	Description
MIH Get Status	Get the status of link
MIH Switch	Switch session between specified links
MIH Configure	Configure link parameters and parameter thresholds
MIH Configure Thresholds	Configure thresholds for Link events
MIH Scan	Scan the network
MIH Handover Initiate	Initiate handover
MIH Handover Prepare	Prepare for handover and query available resources
MIH Handover Commit	Mobile node has committed to handover
MIH Handover Complete	Handover has been completed
MIH Network Address Information	Obtain network address on new link
MMCF Configure	Configure weights for the policy value calculations and report intervals
MMCF Configure Thresholds	Configure thresholds for policy values
MMCF Configure Handover Mode	Configure the network layer to execute handovers automatically or manually

C. Description of Core Functionality

The core functionality needed to implement the network layer including its control plane, i.e. the “Mobile Mediator Control Function”, includes handling of incoming payload packets from the HA, incoming BACk messages from the HA, and outgoing payload traffic. Also, functionality for issuing BA messages over each access network has to be implemented as timed events. Furthermore, decisions on access network selection need to be timely handled, as well as distribution of reports to applications interested.

Finally, handling of the proposed MMCF Configure, MMCF Configure Threshold, and MMCF Configure Handover Mode events need to be implemented, as well as the existing MIH Link Up event, MIH Link Down event, and MIH Link Going Down event.

A list of events and their corresponding functionalities is displayed in table 3.

Table 3: Core Functionality of the Network Layer User Plane and Control Plane (“Mobile Mediator Control Function”)

Event	Core functionality	Event	Core functionality
Tunneled packet arrived from HA	Decapsulate packet, deliver to upper layers	Application sent MMCF Configure	Update data structure carrying weights and report interval for a specific application
BAck message arrived from HA	Calculate policy values for each application; issue a MMCF Policy Value Report if above indicated threshold value	Application sent MMCF Configure Threshold	Update threshold value for a specific application
Application layer packet arrived	Encapsulate packet, send to HA over selected access network (either application specific or default access network)	Application sent MMCF Configure Handover Mode	Update the flag for handling handovers automatically or manually
Issue BU message over a specific access network timer expired	Issue a new BU message for a specific access network carrying updated information on decisions for applications and default traffic	MIH Link Up event	Add specified access network to data structure containing available networks if listed in preconfigured list of networks of interest
Take new access network decision timer expired	For a specific application or default traffic, compare the latest policy values and select the access network with smallest value (if not handover mode for an application is set to manual); issue an MMCF Policy Value Alarm event if policy value is below its threshold	MIH Link Down event	Remove specified access network from data structure containing available access network; invoke procedure for take new access network decision immediately
Report policy values to application timer expired	Issue an MMCF Policy Values event	MIH Link Going Down event	Recompute policy values for each application for the access network that is indicated to go down; issue an MMCF Policy Value Alarm event if policy value is below its threshold

4. Results of Simulations

In order to evaluate the proposed architecture a scenario was defined containing a Voice over IP (VoIP) application (using the G.711 codec) running in an MN traveling 10 km at 10 m/s in an area entirely covered by a WiMAX network and partly by a WLAN type of network, see figure 5a.

The policy value for the VoIP application was studied along with the Mean Opinion Score (MOS) and the signal-to-noise ratio giving an opportunity to test the hybrid decision model allowed by the architecture proposed in Section IV of this paper. All in all, three cases were studied in parallel where handover mode was set to automatic in the first case and to manual in the second and third case. OPNET Modeler 14.5 PL0 [13] was used as simulation tool in all three cases. The constants c and h were set to $c = h = 5$, and the weight w_b was set to $w_b = 1$.



Figure 5a: Evaluation Scenario in OPNET Modeller

In the first case, see figure 5b, automatic hand-over mode was selected. Handover decisions from WiMAX to WLAN and back again to WiMAX were taken by the network

layer based on policy values. Handover to WLAN was decided when its policy value was three (3) units smaller than its WiMAX counterpart.

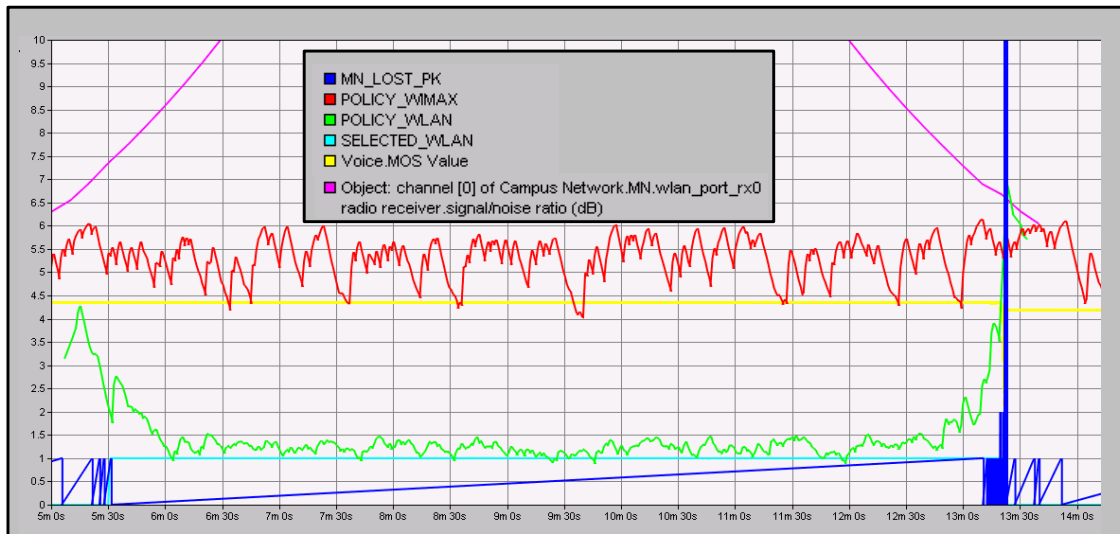


Figure 5b: First Case with Automatic Hand-over Mode Using Network-Layer Decision Making Selected

In the second case, see figure 5c, manual handover mode was chosen letting the application take handover decision itself. This is achieved through issuing an MMCF Configure Handover Mode command. Handover to WLAN was decided by the same criteria as in the first case (based on policy values), while handover back to WiMAX was decided when the MOS value decreased below 4.0 and executed by issuing an MIH Switch command.

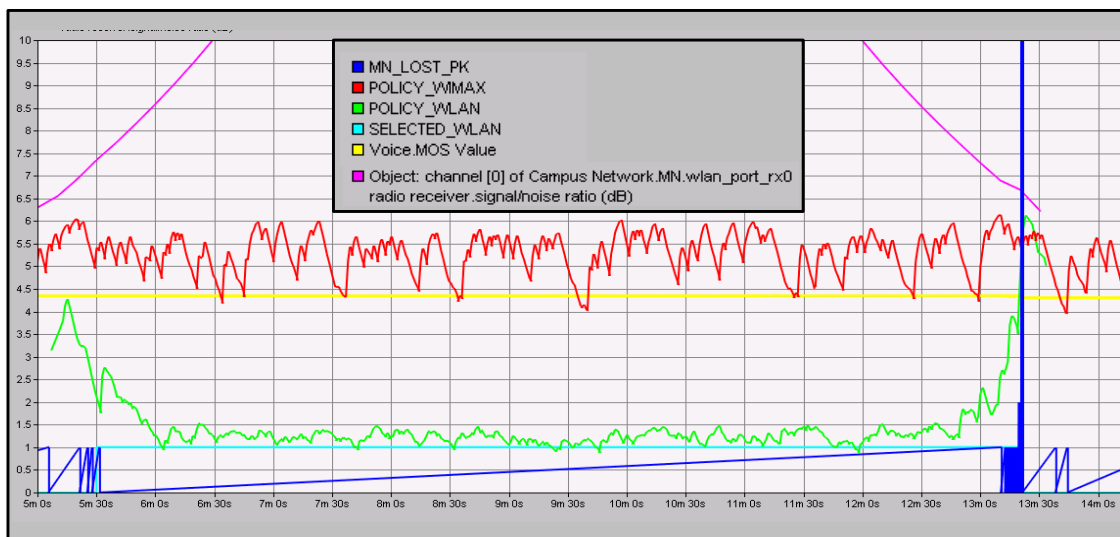


Figure 5c: Second Case with Manual Hand-over Mode Selected

In the third case, see figure 5d, manual handover mode was also chosen through issuing an MMCF Configure Handover Mode command. In this case, however, WLAN was decided to be used whenever the signal-to-noise ratio was over 8.0 dBm. This is achieved through issuing MIH Configure and MIH Configure Thresholds commands. As a result, MIH Link Parameters Report events are sent all the way from the datalink layer through the network layer up to the application layer whenever the current value has passed the threshold value. Finally, the application executes the handover decision by issuing an MIH Switch command taken care of MMCF.

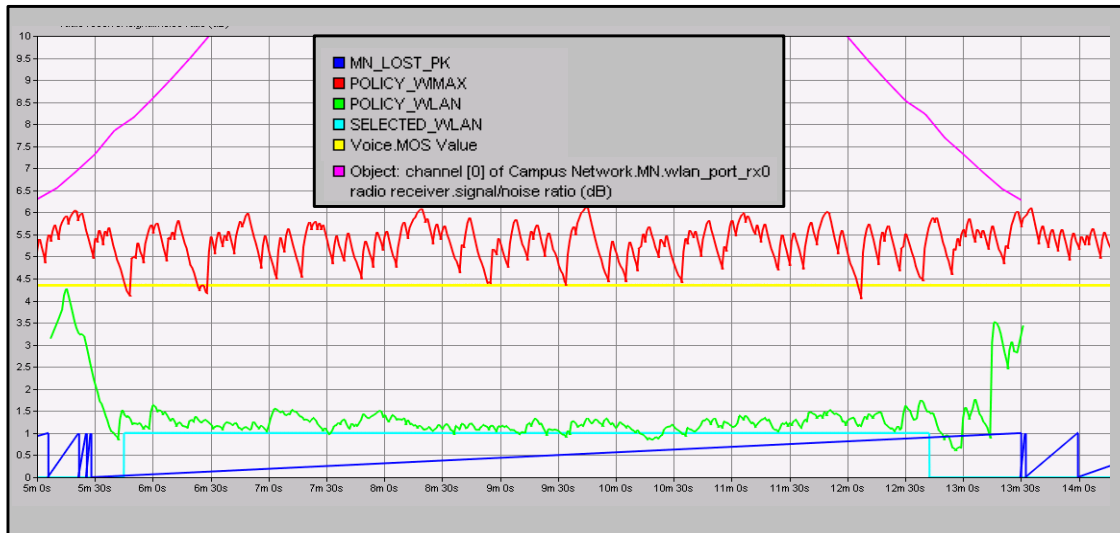


Figure 5d: Third case: Manual hand-over mode. Handover to WLAN is made if signal-to-noise ratio is 8 dBm or higher

MN_LOST_PK denotes number of lost packets, *POLICY_WIMAX* and *POLICY_WLAN* are the policy values for WiMAX and WLAN respectively, *SELECTED_WLAN* is 1 when WLAN is selected and 0 when WiMAX is selected, *Voice.MOS Value* is the calculated MOS value in the VoIP application, while *signal/noise ratio* (dBm) is the SNR value for WLAN at the physical layer (graph is cut at 10 units; actual SNR values go further up to 45 dBm)

The third case is the most signaling intensive. Figure 6 depicts all messages exchanged in the control plane of the system for that case at start up and handover.

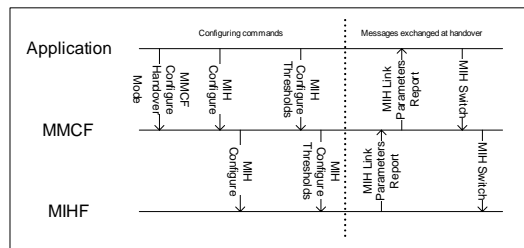


Figure 6: Signalling Scheme for Third Case

The results show clearly the benefits of the hybrid decision model when used in combination with a realtime multimedia application like VoIP. The best result wrt. packet losses is achieved in the third case where there is a threshold value set regarding the signal-to-noise ratio on the datalink layer. The application layer is timely notified about the degradation and issues an MIH Switch command immediately. The second best result in the selected scenario is achieved when the application monitors the quality itself through MOS value computations. The handover decision from WLAN to WiMAX is taken a bit late, but the quality degradation is less compared to the first case when letting network layer metric take care of the decision making itself.

5. Related Work

Research in the area of cross-layer designed mobility management is currently a hot topic and a number of initiatives are ongoing.

Lampropoulos et al. [14] describe how the IEEE 802.21 standard enables seamless, inter-technology handovers. Five principles for seamless inter-RAT handovers and their support from IEEE 802.21 are discussed: source RAT should take the handover decision taking inter-RAT measurements plus other handover information into account; admission control and reservation of resources at the new RAT should be made in advance; security and QoS context should be sent to new RAT during the handover preparation; source RAT

should provide MN with specific configuration information about the target RAT; and a unified way to exchange and interpret measurement reports and QoS context should be provided. The authors claim the IEEE 802.21 standard should be extended to further facilitate seamless handover provision. The proposed extensions in this paper solve some of the important shortcomings pointed out in [14].

Ali-Yahiya et al. [15] propose an interworking mechanism for WLAN and WMAN based on IEEE 802.21 coping with the characteristics of those two technologies. A number of entities, including a handoff monitor, a network selector policy engine, an information base, and a QoS adaptation module, are proposed. Also, a mapping between 802.11e and 802.16e service flows is defined. Support for mobility-aware applications taking their own access network selection decisions is, however, not explicitly included in the proposal.

Li et al. [16] present a multi-interface model used in MNs including a handover management module consisting of a policy manager, a handover decision trigger, a point of attachment (PoA) candidate cache, and a network selector. Cross-layer triggers are sent to the MobileIPv4 standard module. Promising results showing significantly reduced handover delays are reported. Details on the network selection algorithm are not provided and there is a lack of support for mobility-aware applications taking own network selection decisions.

Seol et al. [17] propose an interesting vertical handover solution for WiMAX and 3GPP networks based on IEEE 802.21 taking a network-based mobility management approach using Proxy Mobile IP [18]. The most important benefit of this approach is that MNs not being Mobile IP-enabled are supported. On the other hand, large changes to network infrastructure are needed.

6. Conclusions and Future Work

This paper proposed a cross-layer mobility management architecture based on IEEE 802.21 and previous work in the area. Simulations show that performance enhancements in terms of reduced packet loss rates when doing vertical handovers are achieved. Using the proposed hybrid decision making process taking simultaneous input from the datalink, network and, possibly, the application layers (using SNR, RNL, and MOS values respectively) was proven to be beneficial for the overall performance and quality of experience to end-users when connecting to devices to a heterogeneous networking type of environment.

It was also noted that the network layer metric is of most interest when taking handover decisions among several available access networks giving hints on what access network to switch the connection to.

We intend to extend the study of the proposed model by implementing the real-world prototype to a Windows Mobile platform and to perform experiments in a multi-RAT environment composed of UMTS, CDMA2000, WiMAX and WLAN type of networks. We also intend to perform studies on large-scale networks optimizing total network performance.

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