The VERHO Mobility Management System for Heterogeneous Network Environments

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***Abstract*— In this paper we present our solution for intelligent network interface selection and (vertical) handover control for heterogeneous multi-access environments. The 4th generation mobile communication system is seen here as a combination of several access technologies optimized for different purposes. A combination of these access technologies can constitute, with intelligent control, a 4G access with capabilities to support various application and user requirements and preferences. A policy based vertical handover controller system, called VERHO, utilizes input from several cross-layer sources, the Mobile IPv6 protocol and network interface selection to achieve both proactive and intelligent vertical handovers between a variety of access interfaces. Real-time link status information, access point scanning support, user profiles, policies and Multiple Attribute Decision Making algorithms provide flexibility in interface selection and result in an Always-Best-Connected access for the user. We present the VERHO architecture, discussing and showing the possible benefits of the system for the future.**

***Index Terms* — Multihoming, Wireless, Heterogeneous, Interface Selection, 802.21, Media Independent Handover**

1 Introduction

In the last few years the number of mobile devices, as well as access technologies, have increased and this tendency is expected to continue. The number of cellular subscribers has increased exponentially since the beginning of the 1990's, and even more accelerated growth is expected with the advent of 3rd generations networks (3G). Also, the development of mobile devices is now leading us to a direction where we can have multiple access interfaces on a single device enabling a variety of network services. Even today, advanced cellular phones can support multiple access technologies in addition to traditional cellular ones, e.g. Wi-Fi, and Bluetooth.

The deployment of current wireless technologies is rapid and on-going. The properties of wireless technologies differ in several attributes. The access technologies can be divided into Wireless Wide Area Networks (WWAN), Wireless Local Area Networks (WLAN) and Wireless Personal Area Networks (WPAN), mainly according to their offered coverage area. In [1] the authors introduce the term *wireless overlay networks*, which reflects the fact that several access technologies will co-exist in the future and their coverage area will overlap. The term *overlay* refers to overlapping networks, where WWAN, WLAN and WPAN networks constitute the different layers of access technologies. Also, the access technologies will have different characteristics related to several technology-specific parameters, such as Quality-of-Service (e.g. delay, jitter), bandwidth, coverage area, cost, power consumption and security [2].

In considering several of the technology parameters and users and applications with different needs and requirements, it is generally thought that no access technology will or even can be superior to other technologies. Due to their partly conflicting characteristics, as well as physical restrictions, maintenance, deployment costs, etc. none of the access technologies meet all the demands of modern communication. On the contrary, access technologies of different characteristics are converging into one heterogeneous, but ubiquitous access network, where different access technologies with different parameters complement each other. We refer to these kinds of networks as 4th generation networks (4G).

1.1. Fourth generation communication system

A fourth generation communication system can be thought of as a combination of network technologies with different characteristics. References [3] and [4] discuss related visions and research challenges. The key features of 4G networks are

- High usability – access anywhere, anytime and with any technology
- Support for multimedia services at low cost - access and communication speed
- Personalization – Always-Best-Connected concept
- Integrated services – Quality of Service 4G networks will be entirely packet based.

For this reason, the core networks (CN) of cellular systems are evolving into packet switched networks based on the Internet Protocol (IP). IP is generally thought of being the integration layer for all the access technologies and applications [4]. The term All-IP (i.e. Native IP) refers to the integrating nature of the Internet Protocol [5]. Also, with the success of Voice over IP (VoIP) technologies, voice communication is evolving towards IP connectivity, and Session Initiation Protocol (SIP) is seen as the most likely enabling technology. Every kind of content has to be accessible with good quality (or diverse set of qualities) and at a reasonable cost anywhere, anytime and with any technology, without compromising service security.

The vision discussed above creates many research challenges. Here we focus mainly on the above 3rd layer challenges, link technology specific technology challenges (such as adaptive coding/modulation, multiple antenna technologies) being out of scope. For example, [3] divides the research challenges into mobile station, system and service categories.

Terminals need to be capable of discovering different wireless systems by scanning. Traditional technology specific (Layer 2) scanning techniques might not be enough for selecting the best usable link at each point in time. The decision of the best link is dependent on many parameters, but taking into account multiple different parameters can render the decision making complex. Thus the question arises: What is the sufficient level of complexity to come up with optimal decisions? The aim is towards Always-Best-Connected (ABC) access [6]. Reference [7] discusses different enabling technologies, such as different protocol stack enhancements, mobility support and End-to-End QoS support, to provide ABC.

From the system point of view, efficient mobility and location management of mobile devices is important. Mobile IPv6 [8] is quite successful in trying to solve this problem, but the handover processes cause an increase in system load, high handover latency and packet losses, and require some improvements. Also, heterogeneous networks induce some additional problems related to interface selection and simultaneous access. Moving networks (NEMO) create some additional research challenges to mobility management protocols. To provide End-to-End Quality-of- Service (QoS) requires access technology independent QoS procedures. Basically IP or higher layer QoS architectures (e.g. differentiated or integrated services) or possibly mapping procedures with different QoS mechanisms [7] are needed. Security and privacy solutions need to be flexible due to various technologies and devices (varied capabilities, processing powers, security needs, etc) in use. Technology dependent solutions might not be the most suitable ones, but some upper layer solutions could be feasible. Single sign-on to the network is needed. At system level, also fault tolerance must be solved (e.g. hierarchical system or overlapping network) to provide users sufficient QoS [3].

In the future a consumer is no more dependent on any single provider, thus he/she might be a customer to several of them, possibly using their services simultaneously. For these new business architectures, accounting procedures and accounting data maintenance is needed. For the operator, new ways of gathering the surplus is needed because of the increasing usage of unlicensed networks. New challenges include also an open access model, where a municipal network is seen as a part of the general infrastructure and is built without a profit making operator [21]. Service based approaches seem to be the current view. Traditional billing systems (technology and transaction dependent) might go out of fashion altogether. In this paper we concentrate on technical issues related to mobility management with interface selection in heterogeneous environments. Even though we do not depend on Mobile IPv6, we consider it to be the most likely choice for forming the foundation for IP mobility management.

There exist several related projects, both within and outside the standardization bodies, which study the field of IP mobility management to fulfill the needs of users and applications in upcoming heterogeneous wireless environments.

1.2. Related research

Internet Engineering Task Force (IETF) standardized the Mobile IPv6 (MIPv6) protocol in its Mobility for IPv6 (mip6) charter, in June 2004. Since then, several other charters have been working on enhancing the MIPv6 functionality, with performance, reliability, multihoming, etc. in mind. For example

- MIPv6 signaling and Handoff Optimization (mipshop),
- Mobility EXTensions (MEXT) [18] working group for IPv6. Among others, it includes multihoming and firewall issues, mobile node (MN) bootstrapping with Authentication, Authorization & Accounting (AAA) and IPv4-IPv6 dual stack solutions,
- Proxy Mobile IPv6 (PMIP) [19] for network based mobility management,
- Shim6 [20] is a network layer approach for providing the split of locator/identifier of the IP address, so that multihoming can be provided for IPv6 with transport-layer survivability

The Institute of Electrical and Electronics Engineers (IEEE) 802 working groups have traditionally focused on different access technologies, but in IEEE 802.21 [9] the researchers have worked on Media Independent Handover (MIH) services focusing not only on one specific access technology but on handovers and interoperability between different access technologies, including both 802 and non-802. It is introduced in more detail in Section 3.

In [10, 11, 12] the authors of these papers present policy-based interface selection procedures and architectures to support multiple access interfaces. They aim to provide mechanisms to make dynamic interface selection decisions.

1.3. Problem statement

Mobile IPv6 [8] handles the IP mobility management in an application transparent way. The applications are unaware of the links in use and about possible handovers taking place. The application flows (and possible transport layer connections) do not break even though the MN is moving between IP subnets. But the procedures related to the handovers result in a period of time when the MN cannot send nor receive data. This handover (or handoff) delay time causes packet loss and possibly packet retransmissions (in case of reliable transport protocols). The objective is to minimize the delay to offer the applications seamless connections in addition to non-breaking ones.

In case where the MN has multiple active interfaces (and links), one has to choose which interface to use. Pure MIPv6 implementations usually have some static priority for each interface, and the interface with the biggest priority is chosen for use. However, static priority based interface selection may not be sufficient for users with different preferences nor for applications with different demands in heterogeneous environments [13].

The objective is to find ways to provide Always-Best-Connected access for different users with a minimum user intervention.

1.4. Paper outline

In Section 1 we presented previous and on-going research work related to the challenges of 4G systems. Section 2 presents the VERHO system architecture. Section 3 amends the VERHO system with the IEEE 802.21 standard, and Section 4 introduces two prototype applications that can benefit from VERHO's knowledge of the link and handover information. Section 5 discusses the VERHO architecture and its benefits in a heterogeneous environment. Section 6 concludes the paper and presents some ideas for future work.

2 VERHO CONTROLLED MOBILITY

2.1. Overview

The VERHO system is designed to manage available interfaces, links and access points in a multi-interfaced mobile IP-networked device. Basically, the system gathers information about available interfaces (link types, access points, etc.), decides dynamically during run-time about how the interfaces could be utilized best and performs IP handovers using Mobile IPv6.

The system has a cross-layer design, since the goal is to provide link information to interested layers. Figure 1 shows which layers VERHO interacts with.

- Link Information Provider (LIP) extracts link information from network interfaces (Link Layer),
- Link Access Controller (LAC) gets information from LIP and controls MIPv6 handovers (Network Layer),
- Applications can utilize information provided by LIP and LAC (Application Layer),
- Users can set their profiles through a Graphical User Interface (GUI) and see some statistics from the underlying system.

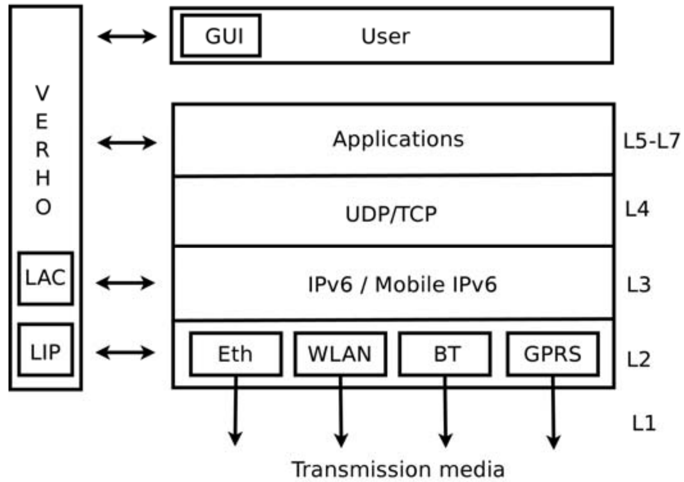

Figure. 1. VERHO cross-layer interaction

2.2. System architecture

The system consists of several modules, each with a dedicated purpose. The following chapters revisit all of them. Figure 2 shows a high level overview of the architecture. The components communicate with each other over Desktop Bus (D-BUS). D-BUS is a messaging bus mainly for local inter-process communication (IPC) and remote procedure call (RPC) on a single host.

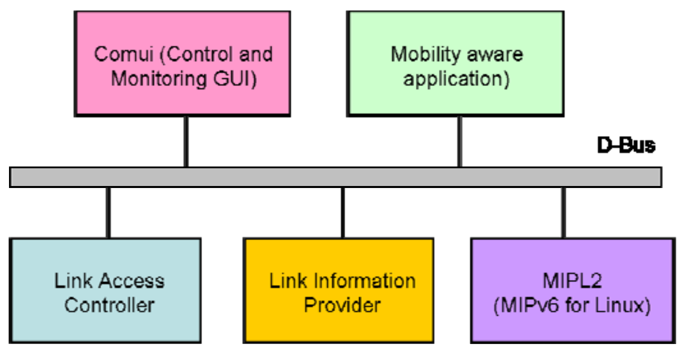

Figure. 2. VERHO D-Bus architecture

The core VERHO system consists of the Link Information Provider (LIP) and the Link Access Controller (LAC). The task of LIP is to keep an up-to-date information database about the available links and provide some control functions (e.g. connecting to Access Points). LAC gathers link information from LIP and makes decisions regarding the usage of available links; moreover, it controls Mobile IPv6 when IP layer handovers are needed to be accomplished.

The system has a GUI for controlling and monitoring purposes and it uses D-BUS to get link information from LIP and to control the system via LAC. Just like the GUI, other applications can utilize the features of LIP and LAC. For example, all of the developed mobility aware demonstration applications use LIP and LAC over D-BUS.

From a more technical point of view, the whole system is implemented in a Linux environment. Mobile IPv6 for Linux v2 (MIPL2) is used as the MIPv6 implementation with some D-BUS interface additions. The whole system is developed in user space. The GUI and the demonstration applications are written using GIMP Toolkit, G-Streamer, and Java Media Framework.

2.3. *Link Information Provider*

The task of LIP is to extract information about the available network interfaces and links [15]. This information is then made available over D-BUS for consumption. LIP consists of two main parts, the Link Module (LM) and the Access Point Module (APM). Figure 3 shows a high level architecture overview of LIP.

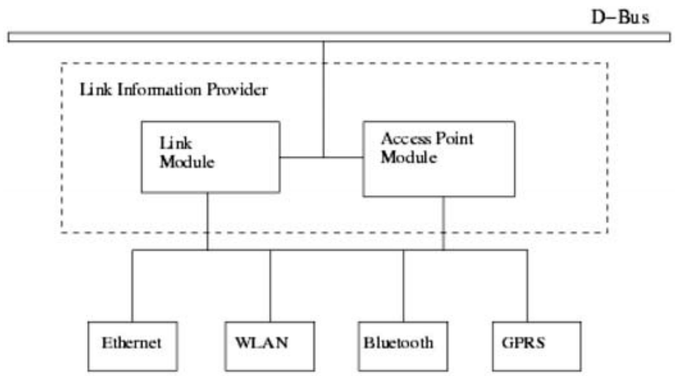

Figure. 3. High level LIP architecture

2.3.1. *The Link Module*

LM extracts information from interfaces. It supports IEEE 802.11 WLAN, Bluetooth, General Packet Radio Service (GPRS) / Universal Mobile Telecommunication System (UMTS) and wired IEEE 802.3 Ethernet interfaces. Each technology is managed by a separate technology-specific submodule and these submodules export a common interface. In this way it is easy to extend the system with new access technologies.

Link information is provided by two means. Whenever an event takes place in a monitored interface that the LM is capable of listening to or when a new interface appears, a signal is sent over D-BUS carrying the new link information. Also, consumers can ask LIP (using RMI over D-BUS) for information about a specific interface or about all the interfaces.

The information provided by each access technology is quite heterogeneous. Even if the same information can be extracted from two different technologies, conversion to a common dimension may be necessary. For this reason LM, in addition to providing raw link information, provides unified link information for link parameters whenever that makes sense. Table I shows some of the link parameters that are unified by LM. The Parameter Name column shows the name of the parameter after unification.

Signal Strength is somewhat special among the information provided by LM. Its value is the source for the Link Going Down and Link Coming Up indications.

Signal Strength dimension value is a dynamically calculated unified value. For WLAN it originates from Signal to Noise Ratio (SNR), for Bluetooth from Link Quality and for GPRS from Signal Quality. Its range is from 1 to 5 and is calculated by dividing the technology specific value (e.g. SNR in the case of WLAN) into five ranges using hysteresis. For more specific information on the classification of the signal quality, refer to [15].

TABLE I
UNIFIED LINK PARAMETERS

Parameter name	Dimension
Signal Strength	Integer value between 1 and 5
Tx Power level	Converted to dBm
Bitrate	Converted to kbps

Besides providing information, LM helps consumers by indicating the actual cause of the signaling of link information. Some of these indications can be seen in Table II.

2.3.2. *The AP Module*

The AP Module (APM) provides information and controlling facilities for Access Point management. It supports 802.11 WLAN, Bluetooth and GPRS/UMTS access technologies. Just like LM, APM supports these access technologies via specific submodules in order to make the

TABLE II
LIP LINK INFO INDICATIONS

Indication	**Description**
Common	
NewIface	A new interface or interface change
DelIface	Interface disappeared (i.e. removed from the computer)
NewLink	Link established on interface
DelLink	Link deleted on interface
IfUp	Interface administratively enabled
IfDown	Interface administratively disabled
LinkComingUp	The link on the interface is becoming available
LinkGoingDown	The link on the interface is becoming unavailable
ChgIfName	Interface name changed
ChgTPL	Tx power level changed
ChgSigStr	Signal strength changed
ChgBitrate	Bitrate changed
ChgRMAC	Remote MAC changed (i.e. AP change)
WLAN	
ChgWLANName	WLAN name of interface changed
ChgSNR	SNR changed
ChgEnc	Encryption got enabled or disabled
ChgESSID	ESSID changed
Bluetooth	
ChgDevID	Device ID changed
ChgLQ	Link Quality changed
GPRS	
ChgSQ	Signal quality changed
ChgBER	Bit error rate changed
ChgPC	Power consumption changed

system easily extensible. Also, the technologies to access the link layer are the same as with LIP. AP information is also heterogeneous and varies between access technologies. Table III shows various information provided by APM.

APM manages an AP list for each supported access technology. AP information is sent to consumers in the same two ways as for LM. On events affecting APs, signals are sent to D-BUS about the change. Such changes can be

- New AP appeared
- AP disappeared
- AP state changed

TABLE III
AP INFORMATION

Access technology	AP Information
WLAN	ESSID, MAC addr, channel, bitrate, noise, signal quality
Bluetooth	AP name, MAC addr, Link quality, TX Power level
GPRS	AP name, IP protocol

2.4. Link Access Controller

The logic of the VERHO system resides in the Link Access Controller (LAC). LAC consumes LIP (LM and APM) information and controls MIPv6 handovers. The modifications to the MIPL implementation have been kept at a minimum level to support easy code portability to other implementations and protocols.

LAC manages a single list of all the interfaces. Each interface is assigned a flag and a preference value. The flag can indicate

- The interface state: Enabled or disabled.
- Preference Value calculation: Automatic or Manual.
- Interface state management: Automatic or Manual.

If the interface state is Disabled, the interface is not allowed to be used by MIPv6, i.e., no Care of Address (CoA) on the interface can be registered with the Home Agent (HA) or Corresponding Nodes (CN). By default, LAC manages the interface state automatically, that is, it enables and disables according to specific events (information received from LIP). The interface state can also be managed manually, in which case it is the responsibility of an outside party (e.g. an external application).

Preference values for interfaces are calculated by LAC dynamically and they change due to changing link information. Just like interface state management, preference value calculation can also be managed manually by some outside party, e.g. an operator, for load balancing purposes.

At any point in time, the interface in an Enabled state and with the highest preference value is chosen to be used. In case where there are several available connections with similar properties, a hysteresis or extra interface specific priorities might help in avoiding ping-ponging.

2.4.1. Preference Value Calculation

Preference values are calculated using the Simple Additive Weighting Multiple Attribute Decision Making (MADM) method. This method fits very well for the purpose of choosing among interfaces by taking into account multiple interface characteristics.

LAC uses the unified link information provided by LIP (shown in Table 1) to make its decisions. Each link characteristic is assigned a weight, which describes the importance of the given characteristic. A weight vector consists of a weight for each characteristic and defines a Profile. An outside party can supply or change profiles on-the-fly. Profiles can represent, for example, user demands, in which case the outside party is the user. The controlling interface (see Subsection 2.5) is used to define and activate user profiles.

The weighted average is calculated by Formula 1.

$$pv_i = \frac{\sum_{j=1}^{p} w_j * r_{i,j}}{\sum_{j=1}^{p} w_j} \quad (1)$$

pv_i is the preference value of interface i, w_j is the weight of characteristic j, $r_{i,j}$ is the value of characteristic j for interface i. In [16] different multiple attribute decision making algorithms with simulations are analyzed in more detail . MADM methods provided good flexibility due to the possibility of several affecting parameters. We also proposed an algorithm combining MADM algorithms aiming at the shortest distance from the optimal solution.

2.5. Controlling and monitoring GUI

Comui is the controlling and monitoring interface for the VERHO system. It is a graphical interface developed with the GTK+ toolkit and is available for the Linux based Maemo platform. Comui allows users to monitor and control the system and choose how much they want to participate in the link selection decisions. In addition to regular Linux PC, the VERHO prototype is developed for Nokia N770 Internet Tablet running the Linux based Maemo operating system. The screenshots are from the Maemo version.

A screenshot from the main screen can be seen in Figure 4. The user can see a list of different available network devices in the Type column (mobile phone, cable link and WLAN). The E/D column indicates whether the device is enabled or not, and the Rank column shows the calculated ranking value for each network device. Currently WLAN has the highest ranking (Active profile is Prefer Bandwidth) and thus it is the active device.

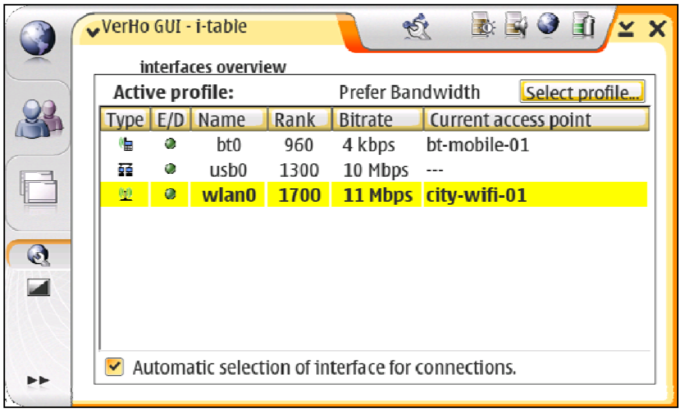

Figure 4. VERHO GUI main screen

The profile management screen is presented in Figure 5. The user can define different profiles according to his/her needs and preferences. For example, in the situation depicted in Figure 5, the user prefers bandwidth and thus the profile has a high weight and parameters on bitrate, some weight on the signal strength to have a good quality connection and no weight on power consumption.

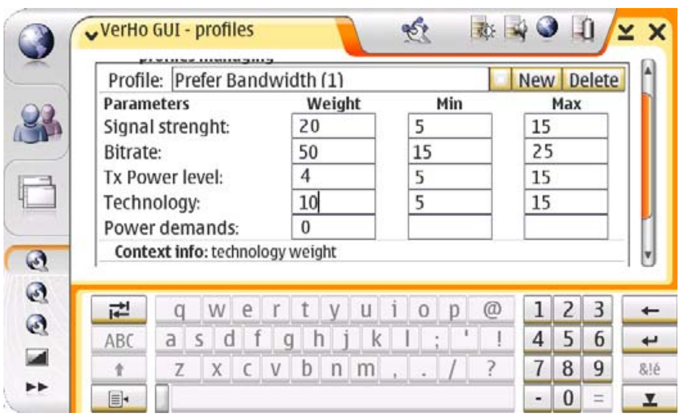

Figure 5. VERHO profile definition screen

Figure 6 shows the desktop applet, where the user can choose the best profile according to current needs. The applet shows also the currently used network interface. The operational principle is similar to mobile phones or laptops, where the user can define sound and battery profiles, e.g. “no sounds” or “beeping” on mobile phones and “maximum performance” or “stretch battery” on laptops.

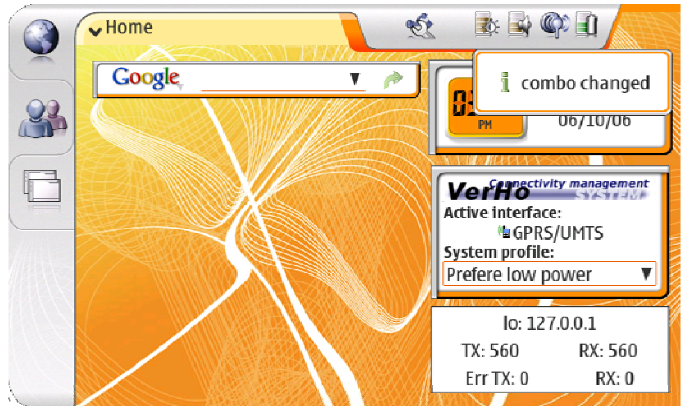

Figure 6. VERHO desktop applet with profile changer

3 IEEE 802.21 AND INTEGRATION WITH VERHO

3.1. *IEEE 802.21 Media Independent Handover overview*

The IEEE 802.21 standard introduces a MIH Function, which is located between L2 and upper layers, i.e. IP or MIP. It defines generic SAPs and primitives for both upper and lower layers. The MIH function consists of three services:

The Media Independent Event Service (MIES) signals the state changes of lower layers, the Media Independent Command Service (MICS) provides control for higher layers, and Media Independent Information Service (MIIS) serves information about the current and neighboring access networks. The functionality is introduced in Figure 7.

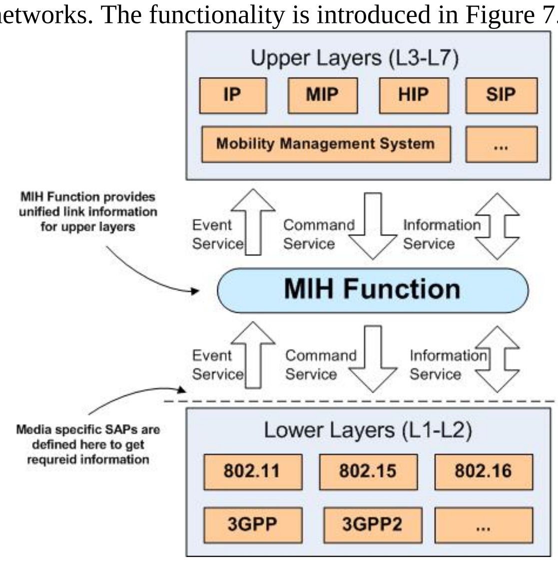

Figure 7. The MIH Function is located Between Layer 2 and Layer 3, defining a so called Layer 2.5.

MIH Function works as a generic link layer instance for upper and lower layers. It makes it possible to transmit unified information from lower layers to upper layers, regardless of the access technology used. To be able to acquire all required information, access technologies must be amended by technology specific Service Access Points (SAP). They are to be defined in IEEE standardization bodies such as 802.11u (SAPs for Wi-Fi) [22] and 802.16g (SAPs for WiMAX) [23] and in 3GPP/2 .

For the mobility management system, MIH Function works as an information unifier which collects information from networks, but does not decide anything. Thus handover policies are out of the scope of the standard, and it requires a mobility management system to work with.

3.2. Integration with the VERHO mobility management system

After following the development of 802.21 for a while, there was a decision to study how an integration of MIH Function and the VERHO system could be implemented. The functionality of MIH Function is pretty much similar to the LIP module, even though there are several advantages MIH Function has.

The biggest challenges regarding link information collecting can be identified to three categories. 1) The amount of information the LIP module collects is limited to a number of parameters supported in each access technology. Also, the provided information is not unified, so the name of parameters and parameter values must be converted to a common scale. Also, all the parameters are not supported in every technology. 2) Currently, scanning is the only way the LIP module can collect the information. Every time that information needs to be collected, the specific access interface must be activated and power intense activities performed. 3) Finally, probably the biggest challenge with LIP is the lack of standardization. It is our own proprietary implementation.

MIH Function can more or less solve the above mentioned challenges and limitations: 1) Standard amendments, i.e. SAPs, for each technology are used to provide unified link layer information. Information is stored in Information Elements (IE) which provide all information that is essential to make intelligent handover decisions. IEs specified in the standard support a wide range of parameters, and there is space reserved for future extensions and vendor specific implementations. 2) The exchange of IEs is based on request and response messages which make the information gathering effective. The mobile node can acquire information from all interesting networks via the active network interface, so there is no need to activate and burden other radios. In terms of power consumption this is extremely important. 3) Obviously the biggest benefit IEEE 802.21 can provide for the VERHO system is a standardized implementation. With a wide support of IEEE 802.21, the VERHO system can focus on decision making and managing the user mobility.

MIH Function is not, however, limited only to network information collecting, but it also provides Command Service for controlling network interfaces. As with information collecting, the benefit is a unified interface between the mobility management system and different network interfaces so that operating system dependent implementations are not needed. Command Service also introduces the possibility of network originated handovers that can be an important feature if there is a need to implement the network controlled or originated mobility management.

The hierarchy and structure of MIH Function and VERHO is introduced in Figure 8. MIH Function works now as so called Layer 2.5 between network and link layers. VERHO commands network interfaces and gathers network information over MIH Function. By utilizing the collected information, VERHO makes the mobility management decisions on the IP level.

The communication between different MIH Functions (e.g. MIH Function of MN and AP or AP to AP) relies on MIH Protocol which is defined in the standard.

The VERHO system is connected to MIH Function with SAPs which are defined in the standard. In addition to lower layers, VERHO is connected to Application Layer (L7) and the user – as was also done in the LIP implementation shown in Figure 1. The integration of VERHO with MIH Function does not change this part of the architecture, because a user and application interaction with the mobility management system is still needed.

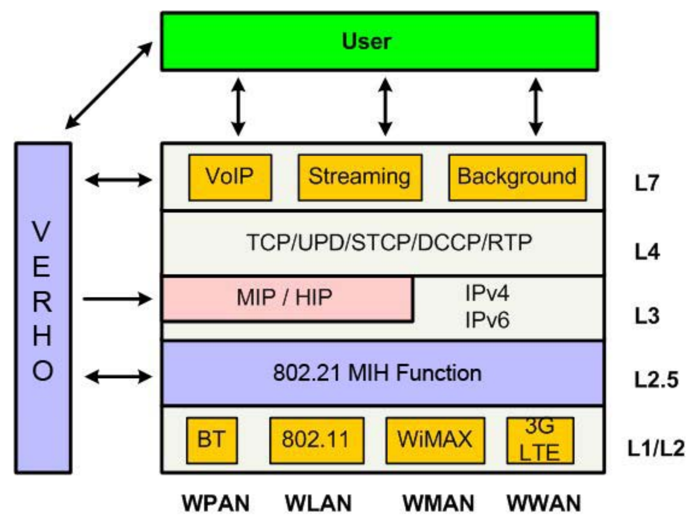

Figure 8. Integration of VERHO and IEEE 802.21 MIH Function

4 PROTOTYPE APPLICATIONS

The VERHO system can be used to develop mobility aware applications. A mobility aware application can use the provided information for example to adapt to the current link characteristics (e.g. a media player). Information provided by VERHO includes

- Link information from LIP (LM),
- Access point information from LIP (APM),
- Handover indications from LAC.

In the following sections we look at some of the prototype mobility aware applications developed within the VERHO project.

4.1. Multimedia streamer

Multimedia Streamer (MS) consists of a client and a server. It supports streaming of images, audio and video. Both the client and the server are written in Java. The client integrates image, audio and video playing functionalities. The server supports audio and video streaming. For the camera stream, a dedicated webcam acts as the server.

Streaming of multimedia content is done by using Real-time Transport Protocol (RTP) and RTP Control Protocol (RTCP), and Real Time Streaming Protocol (RTSP) is used for controlling the playing process (e.g. requesting the proper stream quality during adaptation).

4.1.1. Adaptation

The player runs on the MN and it is made mobility aware by listening to LIP and LAC information. Information about the active interface is available to the player. The player, based on the capabilities of the active interface, requests proper stream quality from the server. Whenever the player receives information from LIP and LAC, it checks whether the current stream quality is still valid with regards to the active interface. If it is not valid, the player requests the proper quality from the server.

4.1.2. Camera streamer

The camera used for the camera streamer is Axis 2100 and it supports only IPv4 networks. Due to the fact that the VERHO system operates only in IPv6, we needed to develop an IPv6-IPv4 proxy. The proxy is written in Java and its sole purpose is to relay the camera stream between IPv6 and IPv4 realms.

The camera uses HTTP to transfer images and it can transmit motion JPEG and still images in various image qualities. The different image types and qualities are accessible by using CGI requests via HTML GET destined for the web server running on the camera itself. The camera itself served as the streaming server and no separate server code was needed. During adaptation the client requests proper image quality from the camera using CGI and HTML GET method.

4.1.3. Audio streamer

The audio streamer server contains several audio files that can be requested by the client. Each audio file can be delivered with various qualities. During adaptation, the client requests a given quality and the server starts streaming the same audio file in the requested quality from the position where the last stream was stopped.

4.1.4. Video streamer

Unlike the audio streamer, the video streamer server supports pre-defined classes of qualities. A video content is prepared for all the supported classes as a separate video file. When the client requests a specific quality the server maps this request to a class and starts streaming the selected video file. During adaptation, the newly selected video file starts streaming from the position where the previous video stream left off.

4.2. IP-TV

The IP-TV is similar to the Media Streamer. Figure 9 shows the topology of the client/server model of the IP-TV. We have divided the operations into content, network, access and end-devices. Content providers provide only content with good quality to the customers. Network operators provide the adaptation services as well as digital rights management, etc. Access operators provide accesses to different technologies for the consumers. The VERHO device is just one of the devices consuming the IP-TV services tailored for the device's physical restrictions as well as for its software and access requirements and end users' preferences.

The TV stream is received from a terrestrial digital TV broadcast network. This stream is then made available on an IP network via multicast (one multicast channel per TV channel). In the network a node acts as an Adaptation Proxy (APr). The APr, on joining the multicast IP-TV stream, can provide different MPEG4 quality classes of the TV stream. In addition to adaptation, APr performs the conversion from IPv4 to IPv6 and from multicast to unicast for the clients. Mobile clients request the stream from the APr by indicating their quality requirements, which are provided by VERHO.

When a mobile client needs a different quality (e.g. due to moving to a different access technology), it informs the APr about its new requirements. The APr, upon receiving the request, maps the request of the client to a supported quality class and starts streaming the adapted content to the client.

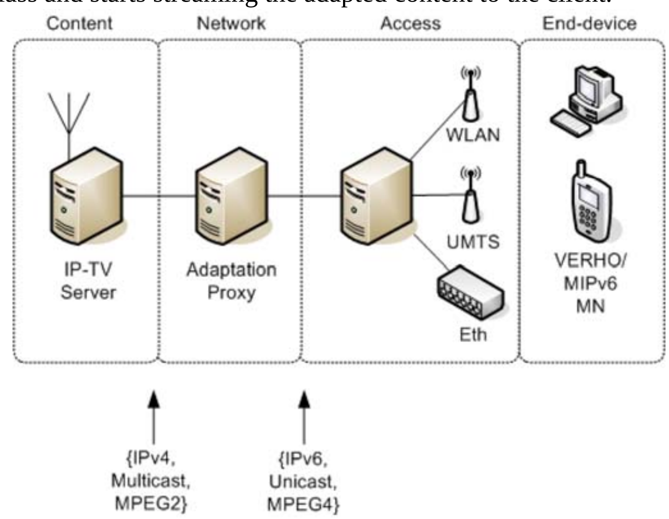

Figure 9. The IP-TV network

5 DISCUSSION

We did not discuss the design principles and benefits of the presented architecture of VERHO in Section 2 and 3. Now we consider some of these and refer to some earlier work. Also mobility management related challenges will be discussed here.

The use of link layer has been researched to some extent in the context of speeding up horizontal handover processes. For example, [17] defines triggers and hints to assist in fast triggering of handovers and proactiveness. In [15] there is a discussion on the use of link layer information in the context of heterogeneous networks with multi-interfaced terminals. Link layer triggers, hints based on signal strength and parameter unification are considered and their benefits presented. Link layer hints, such as Link-Going-Down, can be utilized to achieve a proactive behavior in the system. Moreover, pure link layer parameters can also be utilized as parameters in the multiple attribute interface and link selection. We can achieve seamless handovers by doing the handovers proactively, partly or entirely, while still connected to the old access router or by utilizing two links simultaneously resulting in soft handovers. The proactive handover preparation allows flexible handover delays. Currently, the handover delay correlates directly with the signalization delays of MIPv6.

Horizontal handovers have been affected traditionally by using signal strength and some hysteresis values. However, this is not suitable for multiple interface management. In [16] there are simulations of various Multiple Attribute Decision Making (MADM) based interface selection algorithms. The benefit of MADM methods is their flexibility due to several affecting parameters. But the intelligence of most of the MADM algorithms lies in the weight assignments. Weights determine how the algorithm utilizes the input parameters in the preference value calculation. This brings a lot of flexibility for users with different preferences for link characteristics. Currently, the weights are specified by user defined profiles, but they can be extended to other sources as well. For example, operators' viewpoint could be provided by introducing their profiles and policies to the interface selection. The weights have always a priority order, so there can never occur a situation where the network interface could not be selected. Also, the lack of some parameters does not prevent decision making, but will just hamper it. The weights can be modified to override the usual behavior, e.g. disable GPRS/UMTS while being abroad. The reader can refer to Figure 5 to see better how the weights are adjusted in the VERHO prototype.

VERHO, with the knowledge of multiple link status and handover timing and targets, can assist other applications as well. VERHO can provide, for example, realtime unified bandwidth information to applications (lets say ranging from 0-10), which can adjust their stream qualities appropriately. Adaptive mobility and link aware applications are seen as one of the research challenges of the 4G networks [4]. For example, LAC can be the source of information for MPEG-21 based adaptive multimedia terminals. The access network technology might also affect some internal states of an application. For example, an application could be designed to avoid fetching new emails when connected to an expensive network, or to sleep when the current network is insecure, etc.

From the perspective of the VERHO system, IEEE 802.21 is a highly welcome standard. It offers much the same functionality as VERHO, but also a significant number of new functionalities. The best performance is achieved by replacing LIP with the 802.21 advanced information framework and utilizing 802.21 Command Service for network interface management. In terms of power consumption, such design provides more feasible and permanent solutions than our technology dependent scanning mechanisms in LIP. It is extremely power consuming to try to scan network information frequently with all interfaces. However, without being aware of the surrounding networks, also the potential benefits of heterogeneous networking might not be achieved. IEEE 802.21 mechanisms to acquire information about surrounding networks via an active interface are an effective way to implement information collecting. IEEE 802.21 can provide handover candidate information, e.g. neighbor base stations, and it can be even supported with geographical location information. This helps in avoiding ping-ponging between networks as the handovers can be planned better.

The benefits of IEEE 802.21 will be strongly dependent on the scale of the implementation of the standard. If, for example, IEEE would implement 802.21 in 802-technologies, but 3GPP would not use it, the benefits would remain small. The issue is not technical but rather political. The convergence of networks and the development towards Internet based services is leading to a situation where clear boundaries between 3GPP, IETF and IEEE working groups are going to disappear. 3GPP based networks have been considered strictly operator controlled, while the IEEE technologies are merely used for implementation of non-operator controlled networks. This can be seen also in the architecture of technologies from both organizations. Now these two organizations with totally different backgrounds should start to work together to reach the next step in the convergence. Especially for 3GPP the motives might be questionable, because they co-operate with the GSM Association which is ruled by operators. A current business model for the operators is to have the users' traffic in their network while placing charge for it. IEEE 802.21 might lead this development to an opposite direction, depending partially on who will implement the decision making policies. The alluring opportunity for 3GPP in 802.21 might be in traffic sharing with other technologies. For example, the user's traffic could be routed always via a WLAN access point when such is available. Easing the load of cellular networks is necessary, because the current cost structure is too high to support quickly growing amounts of mobile data. However, there are other potential solutions to handle this issue, e.g. femtocell, which would also support the operators' business model better than by directing users to non-operator controlled networks.

An interesting topic in policy development and power management will be multihoming. Increasing the bitrate by improving coding or modulation has brought the performance of new wireless technologies such as WiMAX and LTE near to the limits of the Shannon's law. Combining the capacity of several network interfaces can increase the performance of the terminal. Multihoming can increase the system performance also in terms of reliability when the traffic of critical applications is routed via reliable networks and is secured to use another interface if the current one malfunctions. The obvious con with multihoming is more complex policy creation. The power consumption will increase, but so will the performance. One should point out that VERHO consumes very little power and resources itself; most of the power consumption originates from the network interfaces and terminal applications. In addition to power consumption, also signaling traffic will increase significantly with multihoming. There is plenty of development work going on in MEXT working group, and promising solutions can be tested thanks to the modular design of VERHO.

Designing the GUI for VERHO poses challenges. The current version allows detailed adjustments of profiles, but for many users the desktop applet alone can be confusing. How does the user know whether he should prefer bandwidth or network reliability? Power consumption and bitrate may be parameters that can be visualized clearly enough by the users, but some other parameters such as network reliability or latency are probably better suited for interaction between applications and QoS mappings. In the GUI design we had usability tests for test subjects, and the results were used to improve the GUI. The tested persons, were, however technology oriented students, so the results cannot be generalized. On the other hand, in this phase we did not want to go further in testing, and results were satisfying for a prototype. The GUI could be improved by providing statistical data information based on a usage history. It might help the users in understanding better the behavior of the device and also in adjusting better the settings to support their preferences.

6 Conclusions

In this paper we have presented the VERHO system, which utilizes information from different sources to calculate the best link to be used in a multihomed or mobile node. We have presented the VERHO architecture and discussed the possible benefits of the system in question. Link layer modules have a real-time status and quality information about the current interfaces. Access point management (scanning, connection, disconnection) enables automatic network and access point selection. User requirements are taken into account by using profiles, which map the interface selection algorithm executed by the Link Access Controller into a set of weights. LAC comes with the ABC selection and utilizes the Mobile IPv6 protocol to trigger the actual handovers.

Since VERHO has real-time knowledge of link status and handover timing, mobility aware applications can utilize the information provided by VERHO for different purposes, such as setting up a proper streaming quality to support the change in access technologies while moving. We presented two prototype multimedia streaming applications, which have been implemented to verify the concept.

The current system functions as a prototype for future generation mobile terminals with an All-IP access and ABC connections. As future work, the current interface management can be extended to support multihoming and simultaneous access based on application preferences, i.e. multihoming management. This, however, require that the work of the IETF MEXT working group will be finished, so that MIPv6 will support multihoming.

We are also looking forward to see how the IEEE 802.21 standard will be perceived among IEEE and 3GPP groups. For VERHO it would be a perfect amendment to network information collecting, but without wide implementation it will not provide real benefits.

The focus of the VERHO system is to provide an optimal connectivity for a single user. However, in the future the research could be extended to a simulator environment with a goal to optimize connectivity for multiple users, including some network load balancing functions.

As a future work, also the development of prototype application for Linux based devices should be continued and new features introduced. Especially, user centric design and power consumption are interesting topics to study.

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