OPTIMIZED FUSION OF HETEROGENEOUS WIRELESS NETWORKS BASED ON MEDIA-INDEPENDENT HANDOVER OPERATIONS

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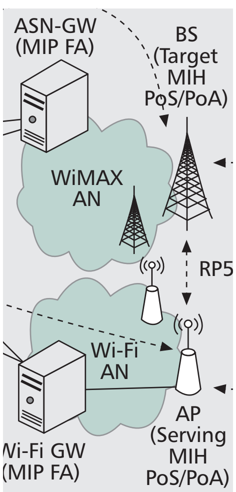

The authors describe enhanced handover functionality for integrated WiFi/WiMAX networks, based on the recently established IEEE 802.21 standard that serves to glue together heterogeneous wireless access technologies.

ABSTRACT

In recent years a plethora of wireless technologies has become available. Users may efficiently utilize heterogeneous network infrastructures while moving among different access networks in order to attain better services, everywhere and at any time, following the always best connected concept. In this article enhanced handover functionality is described for integrated Wi-Fi/WiMAX networks, based on the recently established IEEE 802.21 standard that serves to glue together heterogeneous wireless access technologies. Moreover, alternative implementation choices are introduced with an emphasis on the mapping of primitives between the IEEE 802.21 standard and the various underlying access network technologies. As a result, optimized media-independent handover operations are provided alongside highlighted possible improvements to the related standards.

INTRODUCTION

The proliferation of wireless network technologies has offered consumers the ability to connect to the Internet in many alternative ways. Ubiquitous network access is emerging as the number one target of the industry for the future. It is expected to give a boost to the telecommunication market, improve operators' revenues, and provide the new fourth-generation (4G)-driven networking paradigm for service provisioning over heterogeneous access technologies.

A major concern in such settings is the cooperation between the diverse networks or, differently stated, how the plethora of available wired and wireless access means such as Wi-Fi, WiMAX, third-generation (3G)/Universal Mobile Telecommunications System (UMTS)/Long Term Evolution (LTE), Digital Video Broadcast-Handheld (DVB-H), and Ethernet can interoperate in order to always offer the best services, everywhere and at any time according to the *always-best connected* paradigm.

User satisfaction is greatly affected by factors such as connectivity and terminal mobility. The experience of handover between various access networks, security, and unified authentication are only but a few of the key issues that should be addressed, with handover operation seen as the key factor for achieving seamless and ubiquitous communication.

To this end, handover mechanisms are the subject of numerous efforts made in the context of standardization bodies and other scientific research institutes and organizations [1]. A very recent, systematic, and promising approach that deals with this problem is the initiative under the IEEE label of Media-Independent Handover (MIH) Services, which promises to enhance handover experience when users roam between *any* access technology, covering both IEEE 802 and non-IEEE 802 networks.

Specifically, IEEE MIH Services Working Group (IEEE 802.21 WG) [2] introduced a new Layer 2.5 (L2.5) protocol that combines network functionality from all different access technologies into a common set of commands, events, and information services. The translation of this set is further used to efficiently manage the lower layers (i.e., use specific link layer primitives for each device interface).

This article starts by describing the context in which the recently established IEEE 802.21 standard comes to offer solutions, and then provides an in-depth analysis of the MIH services. The popular choice of integrated Wi-Fi/WiMAX networks serves as an example configuration setting to the work herein, where certain architectural alternatives are further elaborated. The analysis is further enhanced with discussion of the IEEE 802.21 signaling and its mapping to link-layer primitives, alongside proposed improvements. To conclude, the main outcome of this study is summarized, and remaining open issues are outlined.

RECENT TRENDS IN IEEE 802.21

The interest in the fusion of different access technologies using the IEEE 802.21 protocol has triggered much research effort from both indus-

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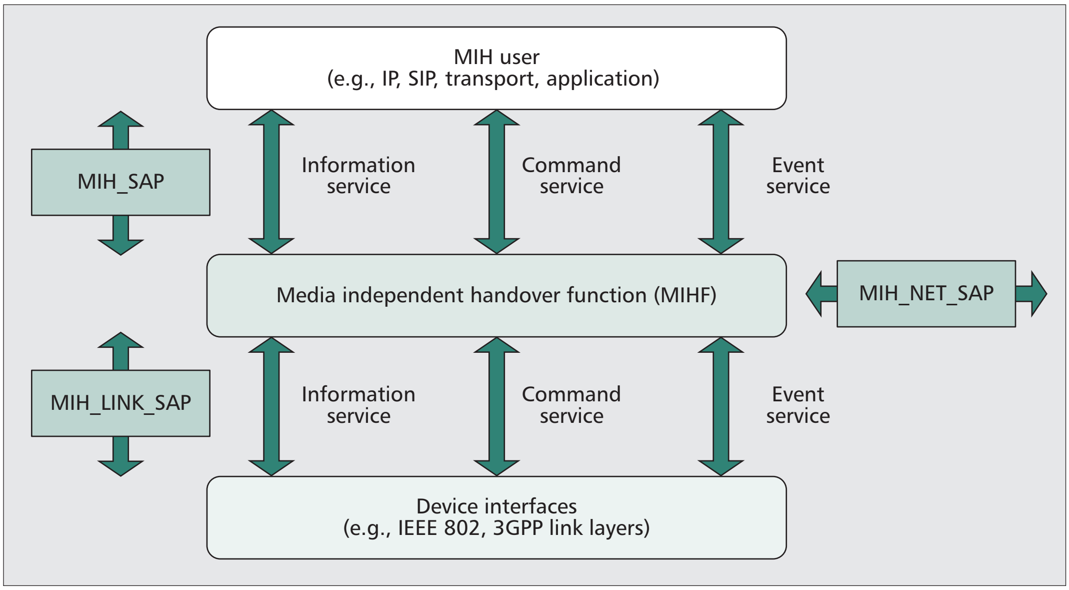

Figure 1. *IEEE 802.21 architecture.*

The key concept of the IEEE 802.21 standard is to provide a mechanism for performing vertical handover independently of the underlying access network technologies. At the heart of this mechanism resides the Media Independent Handover Function.

try and academia. Related efforts by major telecommunications vendors mainly focus on basic MIH functionality for specific handover scenarios, such as the Wi-Fi to WiMAX handover demonstrated by Intel [3] or the joint testbed used by InterDigital and BT [4] to demonstrate both the viability and performance of the IEEE 802.21 MIH protocol in an emulated IMS framework. The aim of such efforts is to provide a proof of concept for the IEEE 802.21 functionality and highlight its benefits for the end user in terms of service provision.

With respect to standardization bodies, the Third Generation Partnership Project (3GPP) and WiMAX Forum are also addressing interoperability issues, another indication of the high level of interest in this topic. Until this moment, both groups have focused on and promoted their own solutions in order to address intertechnology mobility issues and hence compromise on any possibility for seamless interaction with forthcoming access technologies. Recently, though, these standardization bodies have taken notice of the potential of the IEEE 802.21 standard and started evaluating its impact within their respective architectures.

Furthermore, several research and development initiatives have investigated key aspects for the incorporation of the IEEE 802.21 services in the 4G framework in order to provide extended functionalities. For example, in [5] seamless handovers in a heterogeneous network are performed by extending IEEE 802.21 operations for layer 3 mobility and quality of service (QoS) signaling between the mobile node (MN) and the network. Similarly, in [6–8] the mobility management for WiMAX technology is enhanced with the aid of MIH signaling.

Other research efforts have examined critical aspects of the handover procedure. When, for example, security is considered, the handover procedure is shortened in time, and service disruption could become unnoticeable if security associations and configurations are performed at higher layers before the MN moves to the new network [9]. Another significant aspect is the handover decision and sophisticated management of the underlying link layer interfaces. Similar to the previous case, the standard MIH functionality does not support these operations, but they can be added using an extra module embedded in the MN for efficiency and flexibility [10].

From an architectural point of view, the location of MIH functionality has also been examined for an integrated WiMAX/3GPP network case [11, 12]. Security and scalability is improved when MIH-enabled nodes are chosen carefully, while nodes that execute critical operations (e.g., the handover decision mentioned earlier) are placed deeper in the core network, thus minimizing any MIH signaling between network entities. Finally, the accurate mapping of MIH messages to link layer primitives has been identified as a key factor toward efficient use of network interfaces [12].

To this end, in the following sections the issues related to MIH entities' location are investigated, and new mapping of MIH messages to link layer primitives is proposed, extending the current capabilities of IEEE 802.21 and related standards.

Overview of IEEE 802.21 and Wi-Fi/WiMAX Network Capabilities

In this section a short overview of the IEEE 802.21 standard is provided, and interoperability capabilities of the Wi-Fi and WiMAX technologies with other networks are described.

IEEE 802.21

The key concept of the IEEE 802.21 standard is to provide a mechanism for performing vertical handover independent of the underlying access network technologies. At the *heart* of this mechanism resides the MIH Function (MIHF), a logical entity placed between the device interfaces (technology specific link layers) and the MIH

Regarding interworking with IEEE 802.21, the IEEE 802.11u draft standard defines a new MAC State ConverGence Function that provides additional services to the ones offered by the IEEE 802.11 standard.

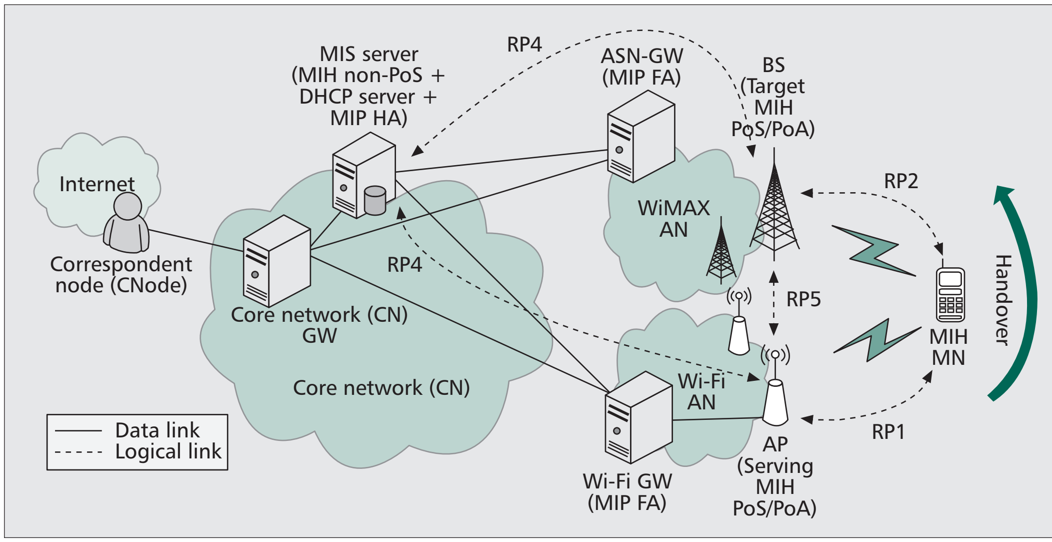

Figure 2. *Wi-Fi/WiMAX architecture for the PoA/PoS approach.*

user that represents the upper layers (layer 3 and above). Such an entity, as depicted in Fig. 1, can be located at both the mobile and network nodes, and supports three types of services: media independent event service (MIES), media independent command service (MICS), and media independent information service (MIIS).

The MIES concerns the detection of events (link layer triggers) from the device interfaces and their report to the MIH user(s), while the MICS is responsible for the execution of commands from the MIH user(s) on the available link layer technologies. The last service (i.e., the MIIS), enables information retrieval from network databases for sophisticated handover decisions. All aforementioned services use standard service access points (SAPs) for message exchange. More specifically, the `MIH_SAP` is used for communication between the MIH user and the MIHF, and the `MIH_LINK_SAP` handles MIH signaling exchange between the MIHF and the technology-specific link layers. Communication between peer MIH entities (often used by the MIIS) takes place over the `MIH_NET_SAP`.

In order to exchange MIH signaling between peers, specific roles have been assigned to network nodes according to the IEEE 802.21 framework. Initially and before the handover, the MIHF entity in the MN is directly connected to a peer MIHF entity in a network node (point of service [PoS]). The PoS can be located either at the network point of attachment (PoA) with which the MN has an active layer 2 connection (serving PoA) or deeper in the network. When handover occurs, available PoAs are evaluated (candidate PoAs), and the final one is selected (target PoA). Furthermore, different PoSs may be chosen to offer MIH services to the MN.

IEEE 802.11 (Wi-Fi)

The IEEE 802.11 (a.k.a Wi-Fi) [13] technology provides wireless connectivity to MNs within a local area network (LAN). The IEEE 802.11 standard defines only layer 2 protocols offering data, control, and management functions, while interworking with external networks (and IEEE 802.21 in particular) is specified by the IEEE 802.11u draft standard [14].

More specifically, in IEEE 802.11, data functionality is provided by the physical medium-dependent (PMD), physical layer convergence protocol (PLCP), and medium sccess control (MAC) sublayers. The PMD is responsible for coding/modulation, and the PLCP offers a common interface for higher layers to control the device. Asynchronous data, security, and packet ordering services are provided by the MAC sublayer that interfaces with higher-layer protocols through the link layer control (LLC) sublayer. Besides data plane, control, and management procedures (e.g., scanning, synchronization, authentication, association, measurement reports, and QoS support) are realized through the MAC sublayer management entity (MLME) and the physical sublayer management entity (PLME). These management entities are used by the station management entity (SME) in order to apply a centralized management policy for the MN.

Regarding interworking with IEEE 802.21, the IEEE 802.11u draft standard defines a new MAC state convergence function (MSCGF) that provides services additional to the ones offered by the IEEE 802.11 standard. It is an extra level of intelligence for the wireless device and allows higher layers to efficiently extract link layer information as well as manage the wireless device appropriately.

IEEE 802.16 (WiMAX)

The IEEE 802.16 (a.k.a. WiMAX) [15] standard defines a broadband wireless access technology for metropolitan area networks (MANs), specifying the MAC and physical (PHY) layers of the protocol stack. Herein, we emphasize the mechanisms and interfaces provided by the WiMAX protocol stack for integrating the IEEE 802.21 protocol primitives.

In WiMAX the MAC layer is split into three distinct sublayers: the service specific convergence sublayer (CS), MAC common part sublay-

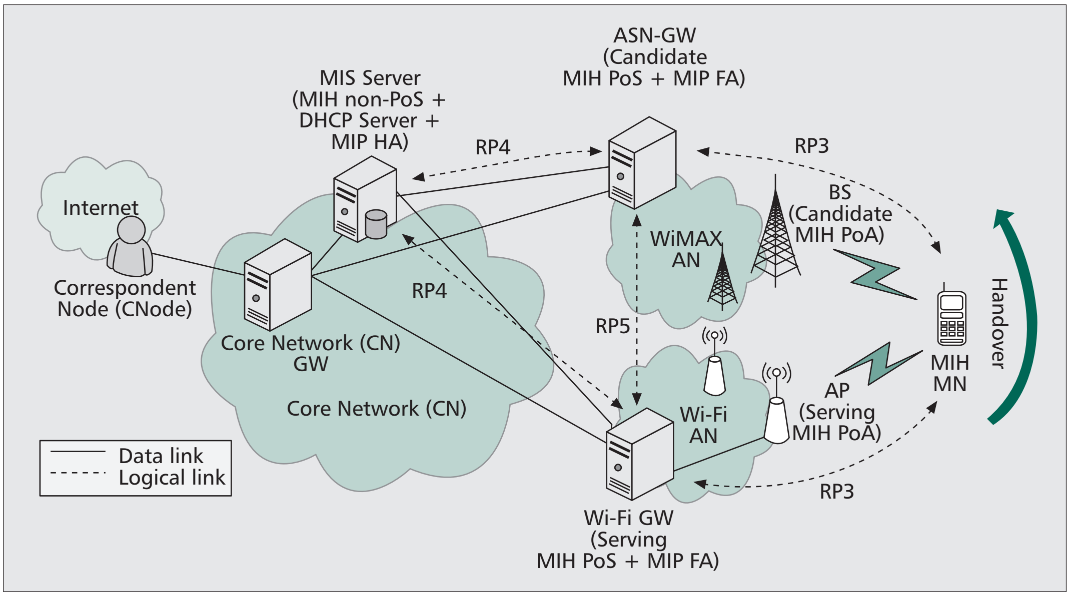

Figure 3. *Wi-Fi/WiMAX architecture for the non-PoA/PoS approach.*

According to the IEEE 802.21 standard, two main alternatives emerge as possible architectural choices for future implementations. These are PoA/PoS and the non-PoA/PoS approaches. Their main difference concerns the location of PoS functionality.

er (CPS), and security sublayer (SS).The CS is the first sublayer of the MAC layer, classifying the packets received from upper layers to the appropriate WiMAX connection and delivering them to the MAC CPS. The MAC CPS is responsible for the core MAC functions, such as system access and connection establishment, as well as QoS and mobility management (MM). QoS is achieved by associating each packet traversing the air interface with a specific service flow (latency, jitter, throughput, and scheduling service).

The IEEE 802.16g-2007 [16] standard has been defined to efficiently integrate the IEEE 802.16 system with the higher-layer control and management functionalities. In particular, 802.16g specifies the network control and management system (NCMS) abstraction, which represents the higher-layer entities (e.g., QoS and/or MM functions) that interoperate with the IEEE 802.16 system. Furthermore, the control SAP (C-SAP) and management SAP (M-SAP) establish communication between the WiMAX system and NCMS entity(ies) for control and management purposes, respectively. The M-SAP is used for less time-sensitive management plane primitives, such as system configuration and monitoring statistics, whereas the C-SAP is used for more time sensitive control plane primitives, including MM and MIHF services. Further details about the integration of WiMAX and 802.21 MIH primitives are given later.

Proposed Wi-Fi/WiMAX Architectures

According to IEEE 802.21, two main alternatives emerge as possible architectural choices for future implementations. These are the PoA/PoS and non-PoA/PoS approaches. Their main difference concerns the location of PoS functionality, which in the first case is placed in a PoA, while a non-PoA component is chosen in the second case. Both approaches are described in this section.

More specifically, the PoA/PoS approach concerns the incorporation of IEEE 802.21 PoS functionality in a network node such as the Wi-Fi access point (AP) or WiMAX base station (BS). Such an approach for an integrated Wi-Fi/WiMAX network is depicted in Fig. 2. In this figure Wi-Fi and WiMAX access networks (ANs) are connected to a core network ([CN] — a.k.a. connectivity service network [CSN] in the WiMAX context) in order to offer IP connectivity between a correspondent node (CNode) in the Internet and an MIH-enabled MN (MIH MN). Access for the MIH MN is provided over Wi-Fi through the AP and the Wi-Fi gateway (Wi-Fi GW). The AP in this topology is reachable from the MN through the RP1 interface. Similarly, for the WiMAX AN, the BS that acts as a combined PoA/PoS offers the MIH MN access to the WiMAX infrastructure (i.e., WiMAX-specific CN elements such as the access service network gateway [ASN-GW]). According to the IEEE 802.21 communication model, the interface between the BS and the MIH MN is denoted as the RP2 interface, while the RP5 interface is considered between the BS and the AP.

In the CN the MIIS server maintains the database that provides information services to the MIH network nodes in the ANs and MIH MN, while the CN GW acts as the *frontier* of the integrated Wi-Fi/WiMAX network with the Internet. Besides MIH functionality, the MIIS server also supports Dynamic Host Configuration Protocol (DHCP) server and MIP home agent (HA) functionality. Therefore, the MIIS server is able to interact with MIP foreign agents (FAs) located in the ANs for MM purposes. It should also be noted that the MIIS server is logically connected to the PoS entities in the ANs through RP4 interfaces.

Alternatively, in the non-PoA/PoS approach (Fig. 3), any PoS functionality in the ANs is moved closer to the CN, with the ASN-GW and

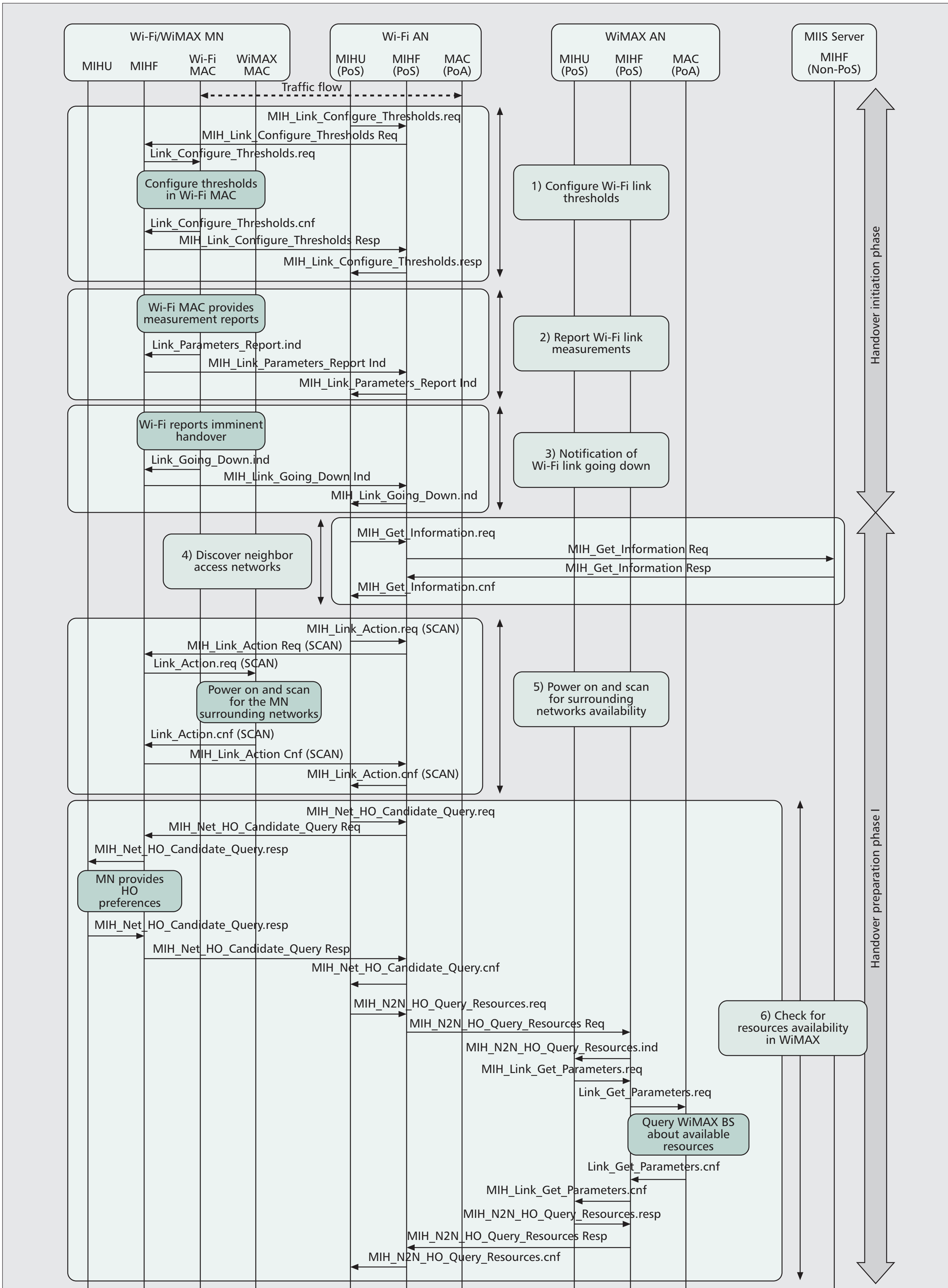

Figure 4. *Handover initiation and preparation I phases.*

Wi-Fi GW supporting MIH operations. Since PoSs are implemented in network nodes that are not PoAs, the RP3 interfaces are used for inter-MIH protocol communication with the MIH MN, with the aid of a layer 3 MIH transport mechanism.

Basic IEEE 802.21 Signaling and Primitive Mapping

The previous sections summarize the basic functionalities of the IEEE 802.21 standard, as well as possible locations for the MIH entities within the Wi-Fi and WiMAX access networks. In this section we start by proposing a generic seamless handover procedure between Wi-Fi and WiMAX, optimized with IEEE 802.21 mechanisms. Thereafter, we describe a detailed mapping between IEEE 802.21 primitives and the link layer primitives for both Wi-Fi and WiMAX access technologies.

IEEE 802.21 Signaling Description

This subsection aims to describe a generic seamless handover procedure between Wi-Fi and WiMAX radio access technologies optimized by the IEEE 802.21 framework. The presented handover scenario involves a multimode terminal, with Wi-Fi and WiMAX interfaces, as well as the IEEE 802.21 entities. The PoA/PoS architecture, depicted in Fig. 2, has been selected for distributing the MIH entities within the network elements. A mobile-initiated network-controlled handover procedure is described in this section, where the network is responsible for controlling all the handover mechanisms and decisions. Message sequence charts are used to demonstrate the most important phases of the handover process: initiation, preparation, execution, and completion.

Handover Initiation Phase: Link Unavailability — Initially, the MN is connected to the Wi-Fi AP and exchanges traffic with the CNode on the Internet. An MIH user (MIHU) installed on the Wi-Fi AP, hereafter denominated by Wi-Fi MIHU, using the `MIH_Link_Configure_Thresholds` command, remotely configures the thresholds for which the Wi-Fi link layer on the MN will report measurements to the MIH layers (Fig. 4, step 1). As a result, by emitting `MIH_Link_Parameters_Report` events, the Wi-Fi link layer on the MN will periodically notify the registered MIHUs with measurement reports about the link layer. In addition to these periodical notifications, the Wi-Fi link layer emits `MIH_Link_Parameters_Report` events toward the registered MIHUs if the configured thresholds are exceeded and are no longer satisfied by the wireless link (Fig. 4, step 2). Furthermore, a `MIH_Link_Going_Down` event is sent by the Wi-Fi link layer if the air link conditions start degrading, and it is predictable that within a certain period of time the connection will be lost and a handover be imminent (Fig. 4, step 3). After collecting this information, the Wi-Fi MIHU has information about the Wi-Fi link layer conditions in real time and, if necessary, can trigger the handover preparation phase before the Wi-Fi link goes down.

Handover Preparation Phase I: Network Discovery, Scan, and Resources Check — Immediately after receiving the `MIH_Link_Going_Down` event on the network side, the Wi-Fi MIHU initiates the handover preparation phase by triggering the candidate access networks discovery process, as illustrated in Fig. 4. Information about the candidate access technologies is retrieved by querying the MIIS server using `MIH_Get_Information` messages (Fig. 4, step 4). As an example, this query can be based on the current PoA location, and its result returns the candidate networks (PoAs) nearby, along with their main characteristics. The last information is quite useful because it can help the MN later scan specific radio networks rather than every available network. In this specific case, the MIIS server indicates that a WiMAX access network is available. Consequently, the WiMAX interface of the MN is powered on in order to start a scanning procedure to check if the WiMAX BS is reachable (Fig. 4, step 5). When the scanning phase is completed, the MN notifies the Wi-Fi MIHU that the WiMAX network is accessible. Thereafter the Wi-Fi MIHU checks for the availability of the MN to handover and retrieves MN preferences regarding the candidate ANs by exchanging `MIH_Net_HO_Candidate_Query` messages with the MN. Next, the Wi-Fi MIHU retrieves resource information from the WiMAX access network via the backbone using `MIH_N2N_HO_Query_Resources` messages. The MIH user installed on the WiMAX BS, hereafter called WiMAX MIHU, in turn, uses the `MIH_Link_Get_Parameters` command to check for available resources (Fig. 4, step 6).

Handover Preparation Phase II: Handover Decision, Power Up, and Resources Activation — Based on the resource availability check, scanning results, and other network information retrieved earlier from the MIIS server, the WiMAX access network is selected for handover by the Wi-Fi MIHU. The handover decision also enables a `MIH_Link_Action` (`LINK_POWER_UP`) command exchange between the Wi-Fi MIHU and the MN in order to establish link layer connectivity with the WiMAX PoA (Fig. 5, step 1). Finally, to conclude the preparation phase of the handover, resources in the WiMAX link must be activated. The reservation request is transported up to the WiMAX MIHU through the `MIH_N2N_HO_Commit` messages (Fig. 5, step 2). Thereafter, the WiMAX MIHU triggers the `MIH_Link_ Actions` (`QOS_RESERVATION`) command to communicate and enforce the reservation decision on the WiMAX system. These MIH commands are executed either locally at the target PoS or remotely at the MN, depending on the radio access technology. In the figure only the local method is illustrated. It is important to mention that the resource reservation procedure could be performed in parallel with the handover preparation during the link layer connection establishment procedure.

Handover Execution and Completion — After resources activation has completed, the MN starts the handover execution phase, also illustrated in Fig.

> The presented handover scenario involves a multimode terminal, with WiFi and WiMAX interfaces, as well as the IEEE 802.21 entities. The PoA/PoS architecture, has been selected for distributing the MIH entities within the network elements.

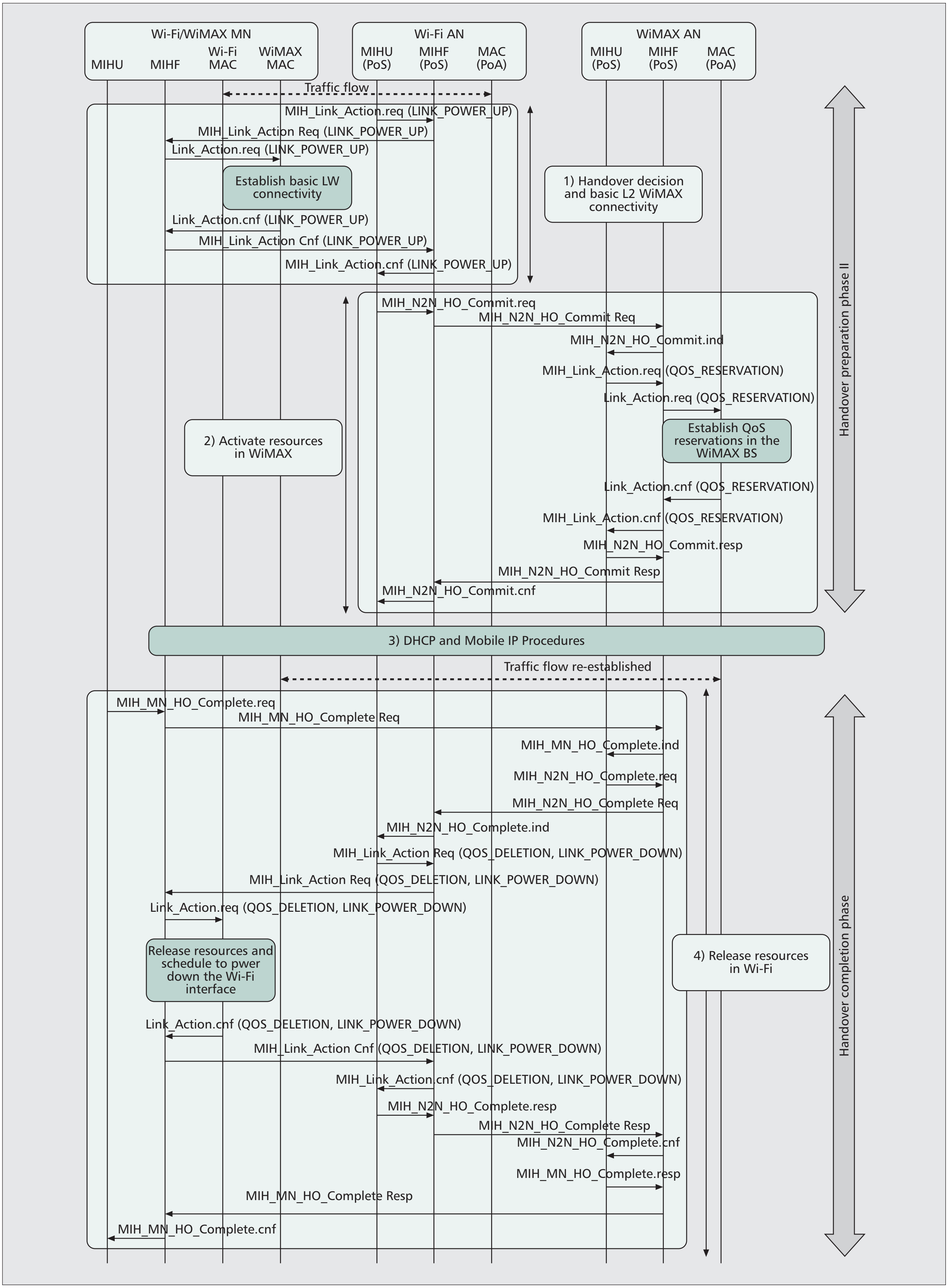

Figure 5. *Handover preparation II, execution, and completion phases.*

HO	Step	Primitives		
		IEEE 802.21	IEEE 802.11u or IEEE 802.16g	
HO initiation phase	1. Configure WiFi thresholds (Fig. 4, Step 1)	`Link_Configure_Thresholds.req/cnf`	`MSGCF-Set-ESS-Link-Parameters`	Network configuration (802.11u)
	2. Report WiFi measurements (Fig. 4, Step 2)	`Link_Parameters_Report.ind`	`MSGCF-ESS-Link-Threshold-report`	Network events (802.11u)
	3. WiFi Link going down notification (Fig. 4, Step 3)	`Link_Going_Down.ind`	`MSGCF-ESS-Link-Going-Down`	Status reporting (802.11u)
Handover Preparation Phase	4. WiMAX power on and scan (Fig. 4, Step 5)	`Link_Action.req/cnf` (`SCAN`)	`M-SSM-REQ/RSP` (`POWER_ON`)	Subscriber station management (SSM) service (802.16g)
			`C-HO-REQ/RSP` (`HO_SCAN`)	MM service (802.16g)
	5. Check for resources availability in WiMAX (Fig. 4, Step 6)	`Link_Get_Parameters.req/cnfs`	`C-RRM-REQ/RSP` (`SPARE_CAPACITY_REPORT`)	Radio resource management (RRM) service (802.16g)
	6. Establish basic L2 connectivity in WiMAX (Fig. 5, Step 1)	`Link_Action.req/cnf` (`LINK_POWER_UP`)	`C-NEM-REQ/RSP` (`RANGING`, `SS BASIC CAPABILITY`, `REGISTRATION`)	Network entry and exit management (NEM) Service (802.16g)
	7. Activate resources in WiMAX (Fig. 5, Step 2)	`Link_Action` (`QOS RESERVATION`)	`C-SFM-REQ/RSP` (`CREATE`)	Service flow management (SFM) Service (802.16g)
Handover Completion Phase	8. Delete resources in WiFi (Fig. 5, Step 4)	`Link_Action` (`QoS DELETION`)	`MSGCF-ESS-Link-Command` (`QoS DELETION`)	Network command (802.11u)
	9. Power-off the WiFi interface (Fig. 5, Step 4)	`Link_Action` (`LINK_POWER_DOWN`)	`MSGCF-ESS-Link-Command` (`POWER_DOWN`)	Network command (802.11u)

Table 1. *WiFi and WiMAX primitives mapping with IEEE 802.21.*

5. This implies that the physical handover from Wi-Fi to WiMAX, as well as the DHCP and MM procedures at the IP level, take place (Fig. 5, step 3). Finally, traffic starts flowing through the WiMAX air link, and the handover completion phase is triggered. During this phase, using `MIH_N2N_HO_Complete` messages, the resources allocated in Wi-Fi are released and the interface is scheduled to power off after the end of the handover (Fig. 5, step 4). This is done using `MIH_Link_Actions` (`QOS_DELETION`, `LINK_POWER_DOWN`) messages.

Suggested Mapping for Wi-Fi and WiMAX Primitives with IEEE 802.21

In the previous subsection the IEEE 802.21 procedures for a mobile-initiated network-controlled handover from Wi-Fi to WiMAX have been described. The specific mapping of the IEEE 802.21 procedures with the Wi-Fi (IEEE 802.11k/u) and WiMAX (IEEE 802.16g) link layer primitives are depicted in this subsection. Each of the handover phases and internal steps is described synchronized with the message sequence charts presented earlier. The proposed mapping, as depicted in Table 1, provides new resources query and management functionalities, as well as novel mechanisms to improve energy efficiency by extending the related information found in the IEEE 802.21 MIH standard [2].

During the handover initiation phase, the Wi-Fi thresholds are configured, and the measurement or/and handover estimation reports to higher layers are generated. The *mapping of QoS requirements* takes place in the Wi-Fi interface of the MN using the `MSGCF-Set-ESS-Link-Parameters` message (Table 1, step 1). After

Concerning power-saving, one solution is to always switch unused network interfaces off. This has been followed in the proposed handover procedure where the old interface is disabled right after the handover completion.

setting network parameters for the link, *measurement reports* may be generated each time thresholds are crossed using MSGCF-ESS-Link-Threshold-Report messages that are sent from the MSGCF toward the MIHF (Table 1, step 2). In addition, the MSGCF offers the capability to *estimate when a handover is going to happen*. This estimation, based on predictive algorithms, is reported to the MIHF with MSGCF-ESS-Link-Going-Down.indication message (Table 1, step 3).

In the beginning of the handover preparation phase, the WiMAX interface is ordered to start scanning. If the WiMAX interface is off, it *powers on* using the M-SSM-REQ/RSP (POWER_ON) message exchange between the MIHF and the WiMAX MAC. Afterward, the WiMAX MAC starts *scanning* (C-HO-REQ (HO-SCAN)) the air link (Table 1, step 4). As a result, the MN receives the WiMAX synchronization messages from the WiMAX BS. Results of this scanning function are reported back to the MIHF with C-HO-REQ (HO-SCAN).

After the scanning process is completed, the next step is to *check for the available resources* in the WiMAX network using C-RRM-REQ/RSP (SPARE_CAPACITY_REPORT) messages (Table 1, step 5). Based on the information retrieved from the MIIS and the candidate access networks, the WiMAX network is chosen as the target handover technology. Consequently, a MIH_Link_Actions.request (LINK_POWER_UP) command is sent toward the MN to *power on and establish layer 2 connectivity* with the WiMAX BS. More specifically, in WiMAX the MN is ordered to power on and perform ranging, SS basic capability, and registration procedures using C-NEM-REQ/RSP (RANGING, SS_BASIC_CAPABILITY, REGISTRATION). Since the WiMAX interface is already on from the scanning phase, the remaining three procedures are executed (Table 1, step 6). Subsequently, the resources on the WiMAX link are established using the C-SFM-REQ/RSP (CREATE) message (Table 1, step 7), and the MN can physically switch to WiMAX.

To complete the handover process, resources already established over the old AN need to be released and the MN Wi-Fi interface powered off. More specifically, the receipt of an MIH_Link_Actions.request (QOS_DELETION) message triggers the deletion of any QoS connection established over Wi-Fi. This is done using MSGCF-ESS-Link-Command (QOS_DELETION) messages between the MIHF and the Wi-Fi SME at the MN (Table 1, step 8). Finally, the scheduling of powering off the Wi-Fi interface is done with a MSGCF-ESS-Link-Command.request (POWER_DOWN) command (Table 1, step 9) and the result of this action is reported back to the MIHF with an MSGCF-ESS-Link-Command.confirm (POWER_DOWN) message.

Discussion

This section discusses the open issues that arise from the above study. The aim is to highlight the trade-offs in specific architectural choices, and describe pros and cons for each of them, as presented earlier.

The two different architectures presented earlier mainly deal with the location of PoS functionality in the network. The PoA/PoS approach is more straightforward concerning complexity since all critical MIH operations (PoS and PoA) are located in the same network node. This means that the AP or BS is in full control of the handover process, and MIH messages concerning link layer functionality (e.g., for resource management at layer 2) are directly applied without inter-MIH communication. On the other hand, the non-PoA/PoS approach assumes different locations for the PoS and PoA, which makes it necessary to either transport MIH messages between them or use standard functionality of underlying technologies for performing critical operations such as resource management. Concerning resource management, WiMAX layer 3 mechanisms are already defined by the WiMAX Forum [17], but for the Wi-Fi case this is still open.

Other criteria for favoring one of the two architectures are implementation and security. The non-PoA/PoS approach is targeted at more *closed* systems where operators are totally in charge of the traffic in their networks, and the control of the handover process is closer to the core network nodes. Placing the PoS functionality in the ASN-GW or Wi-Fi GW also makes the network more secure and less vulnerable to attacks than placing such functionality in an AP (PoA/PoS approach). Moreover, scalability and availability dictate more powerful machines with PoS functionality rather than cheaper and often faulty network nodes.

Apart from the aforementioned issues, other open areas include the way information at the MIIS server database is updated and energy efficiency in multi-radio devices. In our study we have assumed that PoA locations are already known at the MIIS server. However, if information update is needed, a mechanism performing update on a periodic basis could be used. Concerning power saving, one solution is to always switch unused network interfaces off. This has been followed in the proposed handover procedure where the old interface is disabled right after handover completion. In case of multiple candidate networks and in order to minimize power consumption, any unnecessary interfaces powered on for scanning could be powered off immediately after network selection. Another possible alternative for energy-efficient use of the wireless interfaces could be to simply keep them in power-save mode when not used.

Conclusions

The proposed Wi-Fi/WiMAX architectures and the respective IEEE 802.21 based handover procedure try to specify a comprehensive solution for optimized handover operations. Its key features are the practical approach to implementation, and the consideration of resource query, resource reservation, and power management not currently covered by the IEEE 802.21 standard. Future work will try to address more of the open issues and extend current architectures by incorporating more access technologies, such as 3GPP UMTS/LTE and DVB access technologies.

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Future work will try to address more of the open issues and extend current architectures by incorporating more access technologies, such as 3GPP UMTS/LTE and Digital Video Broadcast access technologies.