# Evaluation of WiMAX Networks with Mobility

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*Abstract* — **The Internet access paradigm is changing and a wide range of overlapping radio access technologies, such as WiMAX, Wi-Fi, 3GPP LTE/UMTS and DVB-H, will soon be available to most users and their multi-access devices. Therefore, novel mechanisms and protocols are needed to provide seamless mobility between different wireless access technologies. This paper presents novel handover procedures, based on media independent schemes, to address seamless mobility in heterogeneous environments. We propose an enhanced Media Independent Handover Framework (eMIHF), which extends IEEE 802.21 by allowing for efficient provisioning and activation of QoS resources in the target radio access technology during the handover preparation phase, and efficiently interacting with the mobility process of the different technologies in place. We evaluate eMIHF using the ns-2 simulator, and demonstrate that the proposed handover scheme provides seamless mobility, with low latency and no packet loss.**

## I. INTRODUCTION

Ubiquitous Internet access is one of the main challenges in telecommunications. The number of Internet users is growing at a very fast pace. At the same time, the average customer uses more than one device to connect to the Internet, and downloads and uploads digital media of an unprecedented magnitude. The network access paradigm of "always connected, anytime, anywhere" is a central requirement for next generation networks. This places a tall order to operators that ought to find ways to provide broadband connectivity to their subscribers irrespective of their location and access device. Therefore, taking into account the convergence scenario envisioned in the telecommunications area, it is essential that different wired and wireless access technologies can work together, allowing mobile users to handover between them seamlessly.

IEEE has been working on a standard which enables Media Independent Handovers (MIH) – IEEE 802.21 draft standard [1]. IEEE 802.21 defines an abstract framework that optimizes and improves horizontal and vertical handovers by providing information about the link layer technologies to the higher layers. For the successful support of seamless, make-before-break handovers, one of the most important requirements is QoS support. Presently, MIH provides QoS resources querying for the candidate access technologies and, after the target access technology is selected by the mobility decision algorithm, MIH offers the capability to enforce the QoS resources. Since the time interval between the resources query and activation may be not negligible and the network conditions in the target access technology can change during this period, the MIH framework must be able to provision QoS resources in the target network prior to their activation, guaranteeing their availability for future activation. Moreover, the MIH framework is a general framework, but needs to be integrated with the specific access technologies and their mobility processes, enabling a coherent inter-technology handover process.

This paper presents novel handover procedures to address seamless mobility in heterogeneous environments. The proposed scheme is an enhanced version of the IEEE 802.21 MIH platform, called Enhanced Media Independent Handover (EMIH) framework. The proposed EMIH extends the original MIH version by adding the capacity to efficiently provision and activate QoS resources in the target radio access technology during the handover preparation phase, and efficiently interacting with the mobility process of the different technologies in place, and therefore guaranteeing a coherent make-before-break handover. Furthermore, the proposed scheme also addresses the translation and adaptation of the QoS parameters from the serving to the target access technology, enabling the enforcement of the QoS policies in the target network during the handover preparation phase. Moreover, this also includes triggering the correct MAC layer primitives in the radio access technology for mobility and QoS management purposes.

To evaluate the efficiency of the proposed solution we implemented the EMIH framework, extending version 9 of the IEEE 802.21 MIH platform for ns-2 [2]. A mobile initiated handover has been implemented between Wi-Fi [3] and WiMAX [4], integrated with the Fast Mobile IPv6 (FMIPv6) [5] mobility management protocol, targeting forthcoming IPv6 networks and demonstrating the value of our solution in a mobile heterogeneous environment with QoS requirements.

The remainder of this paper is organized as follows. Section II describes the most relevant related work published by vendors, standardization bodies, research projects and the academic community. Section III provides a high-level description of the EMIH framework entities and services. Thereafter, Section IV describes the proposed seamless mobility scheme, focusing on the integration of the EMIH framework within a Wi-Fi to WiMAX handover process. Section V presents the performance evaluation results and, finally, Section VI concludes the paper and discusses open issues for future work.

## II. RELATED WORK

Typically, mobility solutions provided by vendors, such as Intel and Motorola [6], are based on proprietary mechanisms. Hence, interoperability between different vendor offerings is not guaranteed, introducing disadvantages in maintenance and operation for both operators and consumers. Nevertheless, the trends are changing and manufactures are adopting standardized solutions, as recently demonstrated by Intel in [7]. Here, a seamless mobility solution between WiMAX and Wi-Fi was demonstrated, using the upcoming IEEE 802.21 framework.

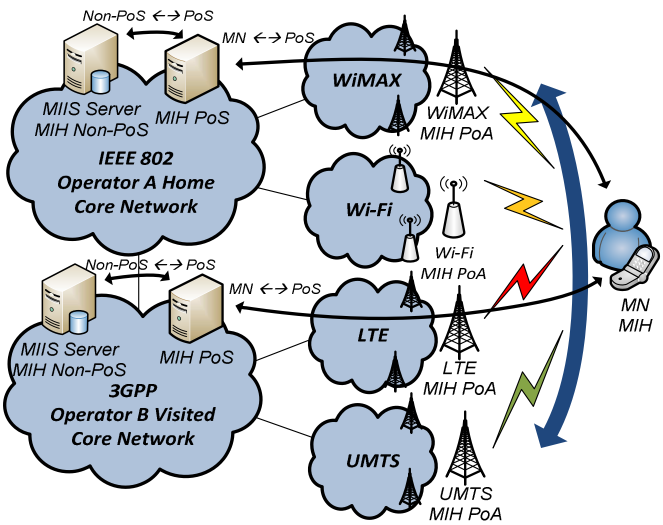
With respect to standardization bodies, 3GPP and WiMAX Forum are also addressing interoperability issues, another indication of the high level of interest in this topic. Up to now, both groups focus on their own solutions to address the issues at hand and hence compromising any possibility for seamless interaction with forthcoming access technologies. Recently, though, standardization bodies have started to change their approach for inter-technology handovers, evaluating the impact of IEEE 802.21 within their respective architectures.

In what concerns European funded projects, the Ambient Networks [8] has defined a novel trigger-based architecture for handover optimization [9]. Interesting results are presented, demonstrating a Host Identity Protocol (HIP) [10] handover between Ethernet and Wi-Fi. For mobile networks, the DAIDALOS project [11] caters for next generation environments, where the seamless integration of heterogeneous network technologies is envisaged. The IEEE 802.21 platform is considered as the means to implement protocol operations for seamless handovers, and further extended to support QoS provisioning along heterogeneous access networks [12]. However, results are yet to be presented that assess the feasibility and efficiency of the approach.

Due to the relevance of mobility interoperability in future networks, a significant amount of related work has been published by the academic community as well. In [13] and [14], vertical handover schemes based on IEEE 802.21 are presented. Nevertheless, both proposals lack interaction between the MIH framework and the access technologies QoS specificities. Furthermore, performance measurements are not given. In [15], a vertical handover scheme between UMTS and WiMAX, employing the 802.21 framework, is proposed. To guarantee service continuity, the authors define a new message for the IEEE 802.21 framework, which supports passive reservations during the HO preparation phase. However, resource activation is performed only after the physical handover is executed, delaying the packet delivery to the target access technology.

## III ENHANCED MIH FRAMEWORK

The IEEE 802.21 main goal is to optimize mobility mechanisms in heterogeneous access environments. Towards this aim, it defines a Media Independent Handover (MIH) framework, which provides standardized interfaces between the access technologies and the mobility protocols from the higher layers in the protocol stack. The envisaged heterogeneous environment is illustrated in Fig. 1. A multi-operator, multi-technology network employing WiMAX, Wi-Fi and 3GPP UMTS/LTE is shown, including the IEEE 802.21 Point of Attachment (PoA) and Point of Service (PoS). PoA is the access technology attachment point, whereas PoS is the MIH entity that communicates with the multimode terminal.




MIH in a heterogeneous access network

IEEE 802.21 introduces a new entity called MIH Function (MIHF), which hides the specificities of different link layer technologies from the higher layer mobility entities. Several higher layer entities, known as MIH Users (MIHUs) can take advantage of the MIH framework, including mobility management protocols, such as FMIPv6 [5], Proxy Mobile IPv6 (PMIPv6) [16] and Session Initiation Protocol (SIP) [17], as well as the other mobility decision algorithms. In order to detect, prepare and execute the handovers, the MIH platform provides three services: Media Independent Event Service (MIES), Media Independent Command Service (MICS) and Media Independent Information Service (MIIS). MIES provides event reporting such as dynamic changes in link conditions, link status and link quality. Multiple higher layer entities may be interested in these events at the same time, so these events may need to be sent to multiple destinations. MICS enables MIHUs to control the physical, data link and logical link layer. The higher layers may utilize MICS to

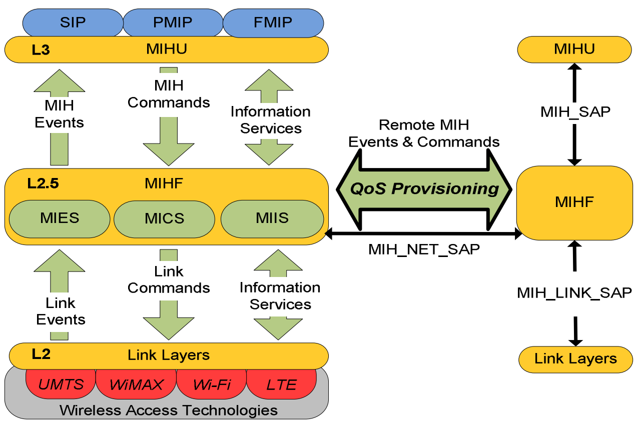



Figure 1. Enhanced Media Independent Handover Framework

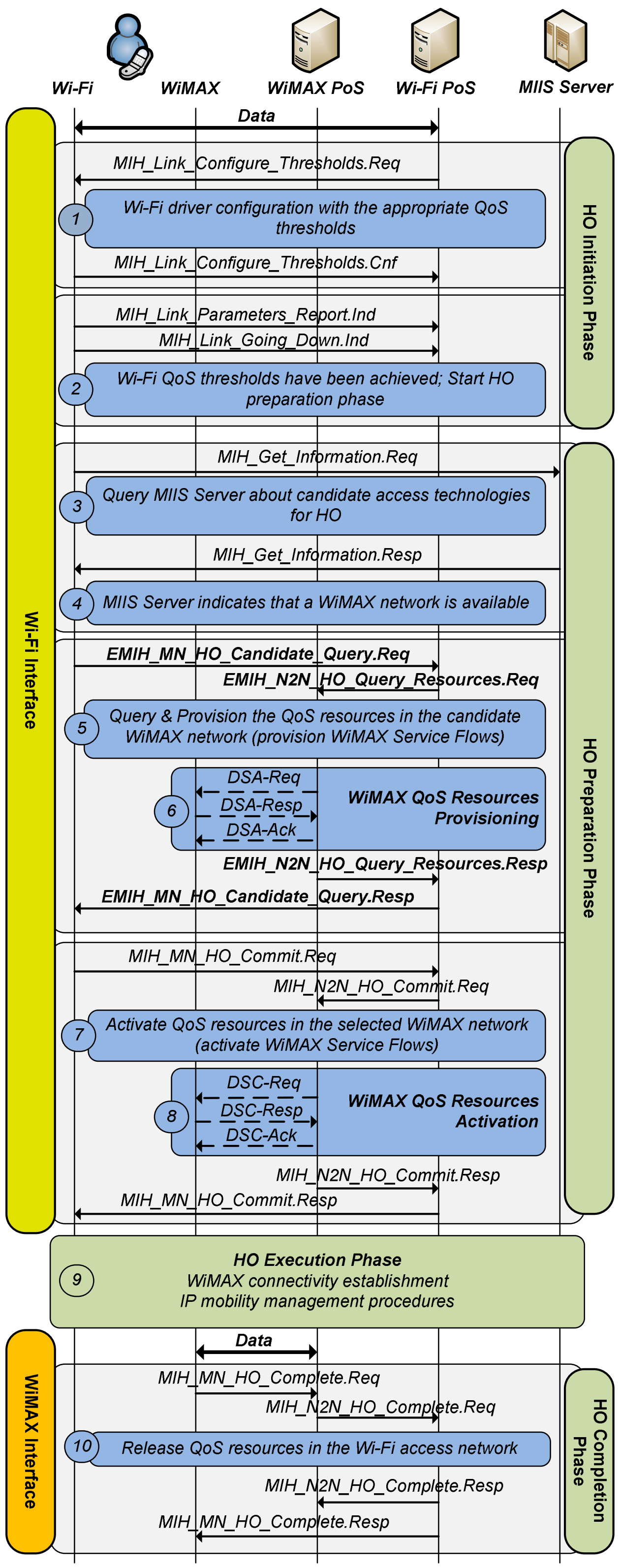
determine the status of links and/or control a multimode terminal. Furthermore, MICS may also enable MIHUs to facilitate optional handover policies. Events and/or Commands can be sent to MIHUs within the same protocol stack (local) or to MIHUs located in a peer entity (remote). Finally, MIIS provides a framework by which a MIHF located at the MS or at the network side may discover and obtain network information within a geographical area to facilitate handovers. The objective is to acquire a global view of all the heterogeneous networks in the area in order optimize seamless handovers when roaming across these networks.

Fig. 2 illustrates our proposed enhanced MIH Framework (eMIHF), which is based on IEEE 802.21. eMIHF extends IEEE 802.21 by allowing for provisioning QoS resources in the target radio access technologies *during* the handover preparation phase. Moreover, eMIHF integrates the specific mobility processes of the access technologies. Resource provisioning is integrated within the eMIHF query resources phase. In other words, when the resources of the available access technologies are queried, they are also provisioned, ensuring their availability for future activation. Instead of defining additional messages, our solution proposes modifications to the *MIH_MN_HO_Candidate_Query.Req/Resp* and *MIH_N2N_ HO_Query_Resources.Req/Resp* MIH messages, used to query the resources of the target access technologies. Therefore, we rename the corresponding messages to *EMIH_MN_HO_ Candidate_Query.Req/Resp* and *EMIH_N2N_HO_Query_ Resources.Req/Resp*, respectively, and add three new fields. The ***query/provision*** field in query request messages indicates whether the resources should be only queried, or if they should be queried and provisioned. The ***provision_timer*** field in the query request messages indicates the amount of time that the resources should be provisioned in each one of the target access technologies. Finally, the ***provision_result*** field in the response query messages indicates if resource provisioning in the target access network was successful or not. In terms of mobility management, we integrate the specific technologies mobility processes. In this paper we present the integration of WiMAX and Wi-Fi with IEEE 802.21 enabling support for inter-technology handovers, as explained next.

## IV. PROPOSED HANDOVER SCHEME BASED ON EMIH

In the previous section, the basic functionalities of IEEE 802.21 have been presented, as well as the enhancements provided by the proposed eMIH framework. In this section we demonstrate a practical use case of the eMIHF involving a handover from Wi-Fi to WiMAX. Fig. 3 presents the handover signaling diagram, including the EMIH communication between the involved network entities, as well as the WiMAX QoS management messages. The presented handover scenario involves a multimode terminal, with support for Wi-Fi and WiMAX, an eMIHF PoS for Wi-Fi and WiMAX, and the MIIS Server. As depicted in Fig. 3, the handover process is split into four phases: initiation, preparation, execution and completion.

Initially, the terminal exchanges data via Wi-Fi. During the **HO Initiation Phase** the Wi-Fi PoS configures the Wi-Fi interface of the multimode terminal (Fig. 3; step 1) with the set of QoS parameters required for the Wi-Fi link (*MIH_Link_ Configure_Thresholds*). As a result, the Wi-Fi interface will periodically notify the registered MIHUs about its QoS parameters, with *MIH_Link_Parameters_Report* events. Besides these periodical notifications, the Wi-Fi interface triggers this event if the configured thresholds are crossed and are no longer satisfied by the wireless interface. Another possibility is to trigger the *MIH_Link_Going_Down* event when the air link conditions start degrading, and it is predictable that within a certain period of time the connection will be lost. With this procedure, both terminal and network entities have sufficient information about the Wi-Fi interface status in real time and, if necessary, can trigger the HO preparation phase before the Wi-Fi link goes down (2). Both mobile-initiated and network-initiated handovers are supported using this mechanism.




Wi-Fi to WiMAX handover signaling diagram based on EMIH

In the beginning of the **HO Preparation Phase**, the terminal queries the MIIS Server (*MIH_Get_Information*) (3) for available access technologies in the surrounding geographical area. The MIIS Server indicates that a WiMAX network is available (4) and, as a result, the terminal activates the WiMAX interface. After detecting a neighbor WiMAX network, the terminal must query the WiMAX network about the available resources, and subsequently activate these resources. Nevertheless, during the time interval between the resources querying and their activation, the network conditions might change and said resources may no longer be available. Therefore, it is essential to provision the required QoS resources in the WiMAX access network prior to their activation. The proposed framework solves this problem by allowing the target access network to provision the QoS resources during the query process (*EMIH_MN_HO_Candidate_Query* and *EMIH_N2N_HO_Query_Resources*) (5). To provision the QoS resources in the WiMAX segment, the WiMAX Base Station translates the EMIH QoS parameters to the specific WiMAX QoS parameters and thereafter triggers the *Dynamic Service Addition* (DSA) WiMAX MAC management messages [4], that is *DSA-Req/Resp/Ack* (Fig. 3; step 6).

When the provision process is completed successfully, the mobility decision algorithm selects the target network (in this case WiMAX) and initiates the resources activation phase (*MIH_*_HO_ Commit*) (7). During this process, the *Dynamic Service Change* (DSC) WiMAX MAC management messages are used [4] (*DSC-Req/Resp/Ack*) to activate the previously provisioned QoS resources (8).

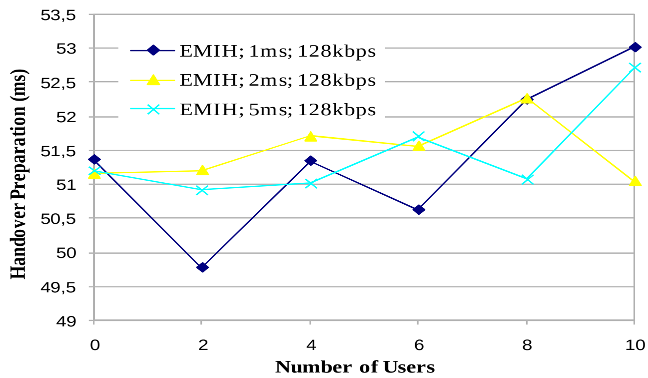
After the resource activation is completed, the terminal starts the **HO Execution Phase**. This implies the physical handover from Wi-Fi to WiMAX, as well as the mobility management procedures at the IP level (9). Finally, data starts flowing through the WiMAX air link and the **HO Completion Phase** is triggered. During this phase, the resources allocated in the previous radio access technology (Wi-Fi) are released (*MIH_*_HO_Complete*) (10).

## V. EVALUATION

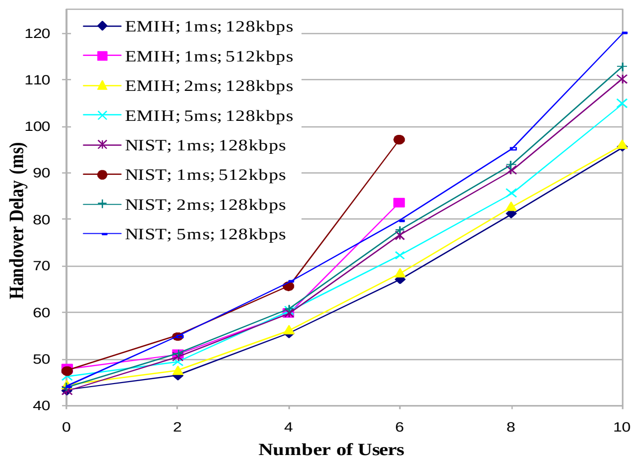
In order to evaluate eMIHF, we revisit the scenario illustrated Fig. 1. In this paper we focus on a mobile-initiated handover from Wi-Fi to WiMAX and evaluate the efficiency of the proposed framework in terms of handover delays and packet loss. The scenario involves several "background" users, which are distributed in the Wi-Fi and WiMAX access networks, each generating background flows with variable data rates between 128 kb/s and 512 kb/s. Similarly, the multimode terminal has an ongoing data flow of 512 kb/s and uses the most commonly used MTU size of 1500 bytes.

The NIST mobility package [18] for the ns-2 simulation platform [2] provides handover support in heterogeneous environments. Nevertheless, this package lacks a full implementation of the IEEE 802.21 MIH framework. Therefore, one of the main challenges in our work was to implement the IEEE 802.21 EMIH framework, extending version 9 of the IEEE 802.21 MIH platform, for the ns-2 environment. In order to have a reference point for results comparison, we provide the measurements obtained with the proposed framework as it is currently implemented in ns-2, as well as with the NIST mobility package. In the following figures, the presented values represent the average of ten independent runs in the ns-2 simulator.

Fig. 4 depicts the time required for the handover preparation phase. The multimode terminal speed varies between 1, 2 and 5 m/s, maintaining always the same data rate for the background traffic (128 kb/s). The handover preparation phase comprises the time interval between the *MIH_Link_Going_Down* event and the *MIH_MN_HO_Complete.Resp* message (see Fig. 3), indicating the successful resource activation conclusion. As shown in Fig. 4, the time required for the handover preparation phase does increase when the number of background users increases from none to 10, but not significantly. Moreover, the user speed does not have a detrimental effect, at least for this level of velocity. Without background users, the required time for the HO preparation phase is approximately 51 ms, whereas with ten background users, the HO preparation phase takes around 53 ms, a slight increase of less than 4 per cent. Recall that the NIST mobility package does not include the handover preparation phase, and as such it is not presented in Fig. 4.



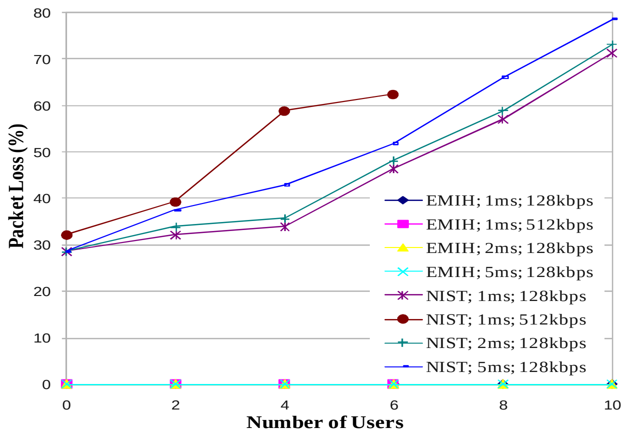

EMIH handover preparation phase




Handover delay

Fig. 5 illustrates the execution phase of the handover from Wi-Fi to WiMAX. Basically, it represents the handover delay, which is the duration from the time that the last packet is received at the Wi-Fi interface until the first packet is received on the WiMAX interface. Background flows with data rates of 128 kb/s and 512 kb/s have been used for 1, 2 and 5 (m/s) speeds. The handover delay has a minimum of 45 ms without background users, and a maximum of 120 ms for 10 users. We can also verify from Fig. 5 that the maximum handover delays are observed when the multimode terminal roams at higher velocities. This behavior is due to the time required to perform ranging and registration procedures in the WiMAX technology, which increases significantly for higher mobility speeds. We also notice that, usually, the handover delay is improved in our proposed eMIH framework.

Finally, Fig. 6 presents the packet loss during the handover execution phase. Clearly, since the WiMAX link has the required QoS resources already allocated, and the packets are buffered during the handover execution time, we observe no packet loss for eMIHF, the approach proposed in this paper. On the other hand, despite the packets are also buffered for the NIST approach, the QoS resources have not been previously allocated, which creates packet losses in the order 30% to 80% in the handover period. Therefore, the resources must be allocated after the handover execution implying packet loss during this period.




QoS performance – handover packet loss

## VI. CONCLUSION AND FUTURE WORK

Due to the advent of a wide range of novel radio access technologies, novel mechanisms must be developed to ensure seamless mobility for the users. This paper presented an enhanced version of the IEEE 802.21 MIH, called eMIHF, which addresses seamless mobility in heterogeneous environments. Our proposed framework extends the soon to be ratified IEEE 802.21 standard by providing the capability to provision QoS resources in the target network during the handover preparation phase, and integrating the mobility process of the several technologies with IEEE 802.21.

To evaluate the EMIH framework, an implementation of the IEEE 802.21 EMIH platform has been made for the simulation platform ns-2. Our results show that, although the eMIHF approach requires a preparation phase before the handover is executed, it provides a mobility solution without packet loss and with minimum handover delay. Moreover, it enables the seamless and independent support of mobility between heterogeneous networks.

In the near future, we will focus on the standardization of the proposed EMIH, as well as on its integration with existing access technologies. Most likely, the changes will involve enhancing existing media-specific service access points, and integrating other technologies, such as DVB and UMTS.

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