ABSTRACT
Mobile and broadband wireless access networks (e.g. 3G, B3G, WiMAX, WiFi) constant development enlarges the spectrum of possible user applications. It opens potentials for the operators to increase their service portfolio and for the users to experience context-rich and personalized services. Therefore, the interoperability between different wireless networks and the enabling of seamless Vertical Handovers (VHOs) become crucial cornerstones. This paper deals with a simulation performance analysis of VHOs utilizing the lately emerging IEEE 802.21 standard for heterogeneous access environments. The simulation results show that the implementation of the IEEE 802.21 standard yields lower VHO latencies allowing for a “make-before-break” VHO approach in heterogeneous environments.

1. INTRODUCTION
The evolution and the emerging variety of different heterogeneous wireless network platforms with different properties require integration into a single platform capable of supporting transparent and seamless user roaming, while not interrupting active communications. This process is followed by the development of new user devices designed to deal with the various network platforms and protocols. The 4G paradigm [1] defines a seamless concept which is cost effective, simple, operable and personalized according to the users’ needs. It should support the paradigm shift from technology centric to user centric concepts and should provide “anytime, anywhere, anyhow and always-on” connectivity in a seamless manner.

The key behind successful resolution of many communication challenges in future wireless systems is in the interoperability, both on network and user level, Fig. 1. [2]. The interoperability offers network providers and users a possibility to choose between alternative wireless access networks based on different criteria, Fig. 1.

A key enabling technology of the interoperability in heterogeneous networks is the lately emerging IEEE 802.21 standard [3]. Prior to its introduction, the Vertical Handovers (VHOs) in heterogeneous environments depended heavily on pure Mobile IP [4] (or related protocols) functionalities leading to high handover latencies and, thus, high disconnection times and high number of dropped packets during VHOs. The main target of the IEEE 802.21 standard is the seamless mobility through heterogeneous environments, i.e. the ability of a user to transit through different Radio Access Technologies (RATs) without the need to restart the connection every time he switches to a different network. The actual implementation of the standard requires knowledge on the network types in question, the policy rules to be followed, the roaming criteria etc.

This paper deals with a simulation performance analysis of VHOs in heterogeneous environments exploiting IEEE 802.21. Section 2 briefly elaborates on the main IEEE 802.21 framework components, while section 3 presents and discusses related work in the field and preliminary simulation results of VHO performance with the utilization of IEEE 802.21. Finally, section 4 concludes the paper.

2. IEEE 802.21 FRAMEWORK
The IEEE 802.21 is focused on handover facilitation between different wireless networks in heterogeneous environments regardless of the type of medium. The standard names this type of VHO as Media Independent Handover (MIH). The goal of IEEE 802.21 is to better and ease the mobile nodes’ usage by providing uninterrupted handover in heterogeneous networks. For this purpose, the handover procedures can use the information gathered from both the mobile terminal and the network infrastructure.

The heart of the 802.21 framework is the Media Independent Handover Function (MIHF), Fig. 2. The MIHF will have to be implemented in every IEEE 802.21 compatible device and will be responsible for communication with different terminals, networks and remote MIHFs providing abstract services to the higher layers using a unified interface (L2.5 functionalities). MIHF defines three different services: Media Independent Event Service (MIES), Media Independent Command Service (MICS) and Media Independent Information Service (MIIS). MIES provides events...
triggered by changes in the link characteristic and status. MICS provides the MIH user necessary commands to manage and control the link behavior to accomplish handover functions. MIIS provides information about the neighboring networks and their capabilities.

The IEEE 802.21 standard is still in its formative stages. However, the interest that exist both in academia and industry shows that IEEE 802.21 may be the key enabler for seamless VHO and transparent roaming in heterogeneous networks. As a result, this standard will make a major contribution towards the reconfigurable interoperability aspect of future generation wireless communications systems.

3. SIMULATION ANALYSIS OF VHO

This section presents simulation analysis of IEEE 802.21 assisted VHO. The simulation analysis uses the ns-2 [5] simulator, along with NIST’s seamless mobility package [6] extensions. These IEEE 802.21 extensions were designed in order to evaluate various link triggering mechanisms and enhance the IEEE 802.21 framework with lower level performance metrics. Additional related work in the IEEE 802.21 field may be found in [7-12], where the IEEE 802.21 framework was used to deliver lower VHO disconnection times, QoS based VHO, cross-layer based VHO and provide assistance to mobility management, respectively. This paper deals with a qualitative simulation analysis of the characteristics of IEEE 802.21 assisted VHO. Different simulation setup scenarios and different parameters affecting the VHO performance are considered. All simulations assume ideal channel model (i.e. no interference and no channel induced errors).

Simulation scenario 1

This scenario investigates the handover effects between IEEE 802.11 (WiFi) and IEEE 802.16 (WiMAX) networks. It consists of a Corresponding Node (CN) generating 1.57Mbps CBR/UDP traffic (packets of 512 bytes at an interval of 2.6ms), 2 intermediate routers, IEEE 802.11 Access Point (AP), IEEE 802.16 Base Station (BS) and a Mobile Node (MN) placed in a simulated area of 2000m x 2000m. The IEEE 802.16 BS provides full coverage over the entire simulation area, whereas the IEEE 802.11 AP covers a circular area with a radius of 40m placed inside the IEEE 802.16 covered area. The topology of the scenario is depicted in Fig. 3.

The MN is placed in the IEEE 802.11 covered area at the beginning of the simulation establishing a WiFi link with the IEEE 802.11 AP. Then, the MN starts to move with a constant speed of 1 m/s leaving the WiFi coverage area and entering the IEEE 802.16 coverage zone. The IEEE 802.21 technology is used to facilitate the VHO. Fig. 4 depicts packet jitter during the VHO defined as a time difference between two consecutive CBR packets received in the MN.

Simulation scenario 2

This scenario investigates the handover effects between IEEE 802.11 (WiFi) and IEEE 802.16 (WiMAX) networks. It consists of a Corresponding Node (CN) generating 1.57Mbps CBR/UDP traffic (packets of 512 bytes at an interval of 2.6ms), 2 intermediate routers, IEEE 802.11 Access Point (AP), IEEE 802.16 Base Station (BS) and a Mobile Node (MN) placed in a simulated area of 2000m x 2000m. The IEEE 802.16 BS provides full coverage over the entire simulation area, whereas the IEEE 802.11 AP covers a circular area with a radius of 40m placed inside the IEEE 802.16 covered area. The topology of the scenario is depicted in Fig. 3.

The MN is placed in the IEEE 802.11 covered area at the beginning of the simulation establishing a WiFi link with the IEEE 802.11 AP. Then, the MN starts to move with a constant speed of 1 m/s leaving the WiFi coverage area and entering the IEEE 802.16 coverage zone. The IEEE 802.21 technology is used to facilitate the VHO. Fig. 4 depicts packet jitter during the VHO defined as a time difference between two consecutive CBR packets received in the MN.
the MN starts to move with a constant speed of 1 m/s and enters the IEEE 802.11 coverage. Fig. 5 presents the obtained packet jitter in this simulated scenario. It is evident that the packet losses are negligible (practically there is no time gap during the VHO) and the performance of the VHO in the direction WiMAX -> WiFi yields better results than the ones obtained in Fig. 4.

Fig. 5. Packet jitter in direction WiMAX->WiFi

The simulations show that the VHO between WiFi and WiMAX using IEEE 802.21 does not perform equally in both directions. Namely, the WiFi -> WiMAX direction is more susceptible to high packet losses. If the communication is video or audio, it will manifest as a visual or audio distortion during VHO. As a result, the interoperability between WiFi and WiMAX is not as seamless as it should be. However, the opposite direction, WiMAX -> WiFi, provides better results in terms of very low packet losses and fulfills the seamless interoperability issue.

Simulation scenario 2
This scenario investigates the effects of the VHO between UMTS and IEEE 802.16 networks. The basis of the simulated scenario is the same as in Fig. 3, with the IEEE 802.11 AP and IEEE 802.16 BS changed with IEEE 802.16 BS and UMTS Node B, respectively, Fig. 6. As a result, the whole simulation area has UMTS coverage, whereas the IEEE 802.16 technology covers a circular area with a radius of 500 m inside. The MN is placed in UMTS at the beginning of the simulation establishing an UMTS link with the Node B. Then, it starts to move traversing through the WiMAX covered area, performing 2 VHOs (UMTS -> WiMAX and WiMAX -> UMTS) before stopping.

Fig. 6. Network topology for scenario 2

![Network Topology](image)

Fig. 7 shows the dependence of the handover latency on the MN’s speed for different traffic bit rates. The traffic profile is the same as in the previous scenario, i.e CBR over UDP. The handover latency is defined as the time for transfer of connection between two distinct technologies at a multi-interface terminal. It is the time difference between the moment the MN detects the coverage of another wireless technology (LINK DETECTED trigger in the IEEE 802.21 framework) and the receive of an acknowledgement packet from the CN. This acknowledgement packet assures the MN that the traffic flow is being redirected to the second interface.

![Handover Latency vs. Speed](image)

Fig. 7. Handover latency vs. node speed

It is evident that the handover latency increases with the increase of the MN’s speed. This results from the definition of the handover latency as a background process that starts from the moment the MN “senses” the new technology till the first acknowledgment packet is received through the newly activated interface. However, it is important to stress that the connection will be continuous and will not require to be reset during the actual VHO. This is owed to the IEEE 802.21 technology, which seamlessly prepares the interfaces at the MN for the VHO. The curves for different bit rates overlap due to the simulation scenario setup, i.e. there are only high capacity (100 Mbps) links in the wired part of the topology setup.

Simulation scenario 3
This scenario is very similar to the simulation scenario 1, only the WiMAX coverage of the whole simulation area is replaced with UMTS coverage. The MN movement pattern is identical, i.e. the MN starts moving from within the WiFi coverage (having established a WiFi connection) and then makes a VHO with the UMTS. A parameter of interest is the handover confidence threshold defined as a level of confidence that the handover event will take place (a general remark when dealing with handovers in mobile networks). Table 1 presents results for the number of dropped packets during the VHO for different confidence thresholds and different bit rates. It is clear that increasing the bit rate produces more dropped packets during the VHO regardless of...
the confidence threshold value, except in the extreme case (99%) where large packet drops are experienced.

Table 1. Number of dropped packets during WiFi -> UMTS VHO

<table>
<thead>
<tr>
<th>Threshold</th>
<th>R=384Kbps</th>
<th>R=192Kbps</th>
<th>R=64Kbps</th>
</tr>
</thead>
<tbody>
<tr>
<td>70%</td>
<td>12</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>80%</td>
<td>13</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>90%</td>
<td>13</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>95%</td>
<td>13</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>99%</td>
<td>33</td>
<td>17</td>
<td>5</td>
</tr>
</tbody>
</table>

This section explored the characteristics of the IEEE 802.21 framework. The results show that the VHO latency when moving from a typical higher coverage wireless technology (e.g. WiMAX) to a lower coverage wireless technology (e.g. WiFi) exhibits small values. It is an important conclusion leading to the ability of different WiMAX roaming users to connect to WiFi hotspots whenever possible in a seamless and uninterrupted manner. Also, the VHO latency depends on the MN’s speed and the handover confidence threshold, which can be used to accommodate different users in the most suitable manner.

4. CONCLUSION

Future wireless communications systems are envisioned to offer higher data rates, higher mobility support and seamless communication [13]. They will have to utilize a common platform that will unify a variety of evolving access technologies, seamless interworking and interoperability solutions and adaptive multimode user terminals [14]. The evolving 4G wireless technology is a common umbrella that covers and integrates all these requirements.

The interoperability of different wireless access systems into a single, 4G based, platform brings many benefits for both network providers and users. It can be achieved through proprietary and specific solutions or by utilizing one of the latest additions in the IEEE 802 family of standards, i.e. the IEEE 802.21 standard. The work on this standard began in 2004 and is expected to be finalized around 2010 just in time for 4G unleash.

This paper presented a preliminary simulation analysis of the major contributions of the IEEE 802.21 framework in heterogeneous scenarios. Simulation results for several different network topologies were obtained. They show that the IEEE 802.21 assistance to VHO yields very low VHO latencies in certain directions (e.g. WiMAX to WiFi), which may be used by operators having spatially coexisting networks to allow for load sharing and distribution. In the same time, the users may benefit from this scenario by choosing alternative access based on their preferences (primarily the price of the service). In addition, the results show that if no network congestion occurs, then the IEEE 802.21 assisted VHO performs equal for different user bit rates. It all leads to a common conclusion that the IEEE 802.21 allows for more consistent, seamless and transparent VHO.

Future work will be concentrated on defining appropriate network/user policies for the execution of VHO and the definition of appropriate Radio Resource Management (RRM) strategies in heterogenous environments exploiting the IEEE 802.21 framework. The resource management aspect becomes an important issue in heterogenous networks since it allows network designers, operators and users to fully use the benefits of the IEEE 802.21 technology.

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