

Secured Seamless Convergence across Heterogeneous Access Networks

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Abstract

Dual-mode handsets and multimode terminals are generating demand for solutions that enable convergence and seamless handover across heterogeneous access networks. The IEEE 802.21 working group is creating a framework that defines a Media Independent Handover Function (MIHF), facilitates the handover across heterogeneous access networks and help mobile users to experience a better performance during seamless handover. We also summarize a Media-independent Pre-Authentication (MPA) mechanism currently under discussion within the IETF and can be used to optimize handover performance. We present the 802.21 framework and the MPA technique and show how they can be integrated to improve the handover performance. We also describe a test-bed implementation and discuss experimental handover performance results of an 802.21-based approach in conjunction with MPA.

1 Introduction

Future network devices will need to roam seamlessly across heterogeneous access technologies such as 802.11, WiMAX, and CDMA, etc. as well as wired networks such as xDSL and cable. In addition this may involve movement between packet switched and circuit switched (PSTN) network. Figure 1 shows an example of wireless Internet roaming scenario across heterogeneous access networks that involves intra-subnet, inter-subnet and inter-domain mobility. However, supporting seamless roaming between heterogeneous networks is a challenging task since each access network may have different mobility, QoS and security requirements. Moreover, interactive applications such as VoIP and streaming media have stringent performance requirements on end-to-end delay and packet loss. The handover process stresses these performance bounds by introducing delays due to discovery, configuration and binding update procedures associated with a mobility event. Performance can also be tied to the specific access networks and protocols that are used for network access. For example, configuring a PPP interface takes more time than configuring an interface using DHCP in a LAN environment. Access network-specific authentication and authorization protocols may introduce additional delays. Traditional non-optimized handover takes up to 4 seconds delay during inter-LAN movement. In a typical deployment scenario, several hundred (~200-300) packets may be lost during the handover. Also it may take up to 15 seconds for completing authentication and connection establishment procedures if the neighboring network is either CDMA or GPRS type of network. Furthermore, movement between two different administrative domains poses additional challenges since a mobile will need to re-establish authentication and authorization in the new domain.

In order to provide an optimized secured mobility management solution for real-time communication involving heterogeneous handover, we have designed an optimization scheme that takes advantage of IEEE 802.21 [1] services and MPA (Media independent Pre-Authentication) scheme [2]. MPA enables mobile devices to pre-authenticate with adjacent networks, to proactively obtain an IP address, and to perform mobility related binding updates.

The rest of the paper is organized as follows. Related work in mobility optimization is described in Section 2. Section 3 describes the IEEE 802.21 framework, its core architecture and the functional components. An example of MPA assisted 802.21-based mobility is illustrated in Section 4. Results of a test-bed

implementation involving 802.21's Information Service (IS), Event Service (ES) and MPA framework for two different types of handover scenarios are described in Section 5. Finally Section 6 concludes the paper.

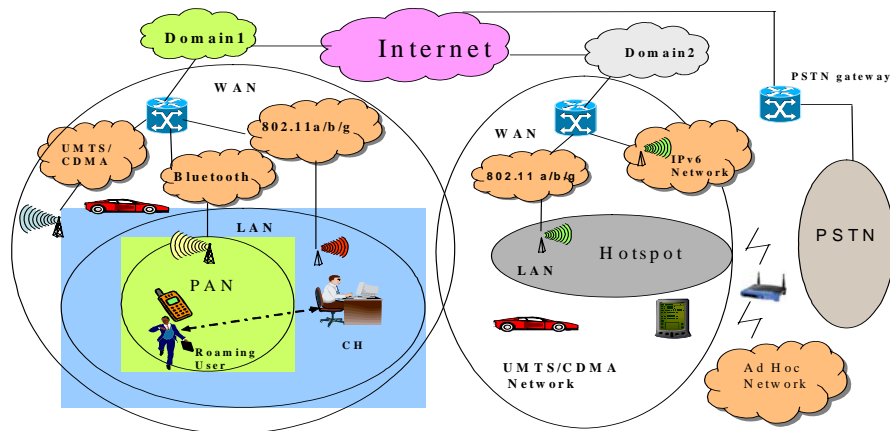


Figure 1: Wireless Internet Roaming Scenario

2 Related Work

References [3] through [9] describe mobility management techniques that support fast-handover by enhancing currently available mobility management protocols. Reference [10] attempts to reduce delay at layer 2, where as references [11] and [12] devise mechanisms to reduce handover delay layer 3 and application layer respectively. These solutions, however, do not discuss heterogeneous access scenarios. Currently, there are several initiatives to optimize mobility across heterogeneous networks. The MOBOPTS working group within the IRTF (Internet Research Task Force) and the DNA (Detecting Network Attachment) working group within the IETF have been investigating ways to support optimized handover by using appropriate triggers and events from the lower layers. References [13] and [14] describe mobility management techniques that consider both security and heterogeneous mobility. Although many of these techniques use cross-layer mechanisms and “make-before-break” algorithms to provide fast-handover, it is desirable to have a standardized method to handle mobility across heterogeneous networks in an efficient manner. The IEEE 802.21 [1] standards group is currently working towards a Media Independent Handover framework. This framework provides assistance to underlying mobility management approaches by allowing information about neighboring networks, link specific events and commands that are necessary during handover process. MPA [2] is being discussed within the IETF and has a way to improve service quality and user experience during handover events. In this paper, we discuss how MPA and 802.21 can be used together to improve handover in heterogeneous access networks. We describe how the two approaches can be integrated and present experimental results obtained on a prototype test-bed implementing the 802.21 and MPA concepts.

3 IEEE 802.21 Framework

The IEEE 802.21 framework is intended to facilitate handover between heterogeneous access networks by exchanging information and defining commands and events to assist in the handover decision making process. The framework within 802.21 helps mobile devices discover, characterize and select networks within their current neighborhoods by exchanging information about available link types, link identifiers, and link qualities of nearby network links. This process of network discovery and selection allows a mobile to connect to the most appropriate network based on certain mobile policies.

The heart of the 802.21 framework is the Media Independent Handover Function (MIHF) which provides abstracted services to higher layers by means of a unified interface. This unified interface exposes service primitives that are independent of the access technology. The MIHF can communicate with access specific lower layer MAC and PHY components, including 802.16, 802.11 and cellular, as well as with upper layer entities. The MIHF and its relationship with upper and lower layer elements are shown in figure 2. MIHF

defines three different services: Media Independent Event Service (MIES), Media Independent Command Service (MICS) and Media Independent Information Service (MIIS). In the following subsections, we describe these three main functional components in greater detail.

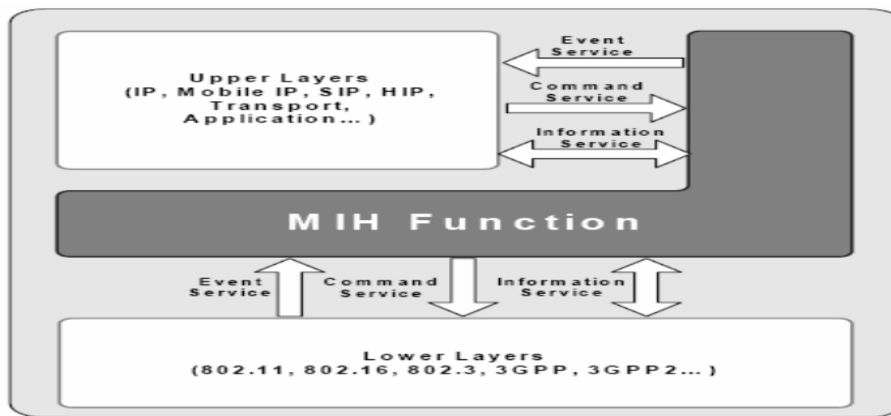


Figure 2: Media Independent Handover Function Location and Key services

3.1 Media Independent Event Service

Media Independent Event Service (MIES) provides services to the upper layers by reporting both local and remote events. Local events take place within a client whereas remote events take place in the network. The event model works according to a subscription and notification procedure. An MIH user (typically upper layer protocols) registers to the lower layers for a certain set of events and gets notified as those events take place. In the case of local events, information propagates upward from the MAC layer to the MIH layer and then to the upper layers. In the case of remote events, information may propagate from the MIH or Layer 3 Mobility Protocol (L3MP) in one stack to the MIH or L3MP in a remote stack. Some of the common events defined include “Link Up”, “Link Down”, “Link Parameters Change”, “Link Going Down”, “L2 Handover Imminent”, etc. As the upper layer gets notified about certain events it makes use of the command service to control the links to switch over to a new point of attachment.

3.2 Media Independent Command Service

The higher layers use the Media Independent Command Service (MICS) primitives to control the functions of the lower layers. MICS commands are used to gather information about the status of connected links, as well as to execute higher layer mobility and connectivity decisions to the lower layers. MIH commands can be both local and remote. These include commands from the upper layers to the MIH and from the MIH to the lower layers. Some examples of MICS commands are MIH Poll, MIH Scan, MIH Configure, and MIH Switch. The commands instruct an MIH device to poll connected links to learn their most recent status, to scan for newly discovered links, to configure new links and to switch between available links.

3.3 Media Independent Information Service

Mobiles on the move need to discover available neighboring networks and communicate with the elements within these networks to optimize the handover. The MIIS defines information elements and corresponding query-response mechanisms that allow an MIHF entity to discover and obtain information relating to nearby networks. The MIIS provides access to both static and dynamic information, including the names and providers of neighboring networks as well as channel information, MAC addresses, security information, and other information about higher layer services helpful to handover decisions. This information can be made available via both lower and upper layers. In some cases certain layer 2 information may not be available or sufficient to make intelligent handover decisions. In such scenarios, higher-layer services may be consulted to assist in the mobility decision-making process.

The MIIS specifies a common way of representing information by using standard formats such as XML (eXternal Markup Language) and TLV (Type-Length-Value). Having a higher layer mechanism to obtain the

information about the neighboring networks of different access technologies alleviates the need for a specific access-dependent discovery method. We have implemented an MIIS based on RDF (Resource Description Framework)/XML as part of our prototype.

4. Mobility optimization using 802.21 and MPA

Media-independent Pre-Authentication (MPA) is a mobile-assisted, secure handover optimization scheme that works over any link-layer and with any mobility management protocol. With MPA, a mobile node is not only able to securely obtain an IP address and other configuration parameters from a candidate target network (CTN), but is also able to send and receive IP packets using the obtained CTN IP address before it physically attaches to the CTN. This ability to communicate at layer-3 and before establishing layer-2 connectivity is a great benefit in terms of reducing handover delays.

The MPA procedure works as follows. An MPA mobile device first establishes a security association with a CTN via its existing network connection using a protocol called PANA (Protocol for Carrying Authentication to Network Access) [15]. Then the device obtains configuration information that will allow it to participate in the new network. Next, a bi-directional tunnel is established between the device and the Access Router (AR) of the CTN. IP packets can be sent over this logical tunnel. At this point, all the necessary layer-3 mechanisms have been completed to enable handover, however the device has not yet established a layer-2 connectivity with the CTN. Once this has been established, the bi-directional tunnel can be removed and the handover is complete. By pre-authenticating, pre-configuring the link and establishing a secure tunnel, the handover can complete with reduced delays and fewer lost packets.

MPA, however, does not perform network discovery and relies on outside mechanisms to discover CTNs. In this sense, MPA and 802.21 can be very complimentary with 802.21 providing network discovery and making available information to assist in the mobility decisions. MPA can ensure security associations are in place and that devices can authenticate with candidate networks before mobility decisions are executed.

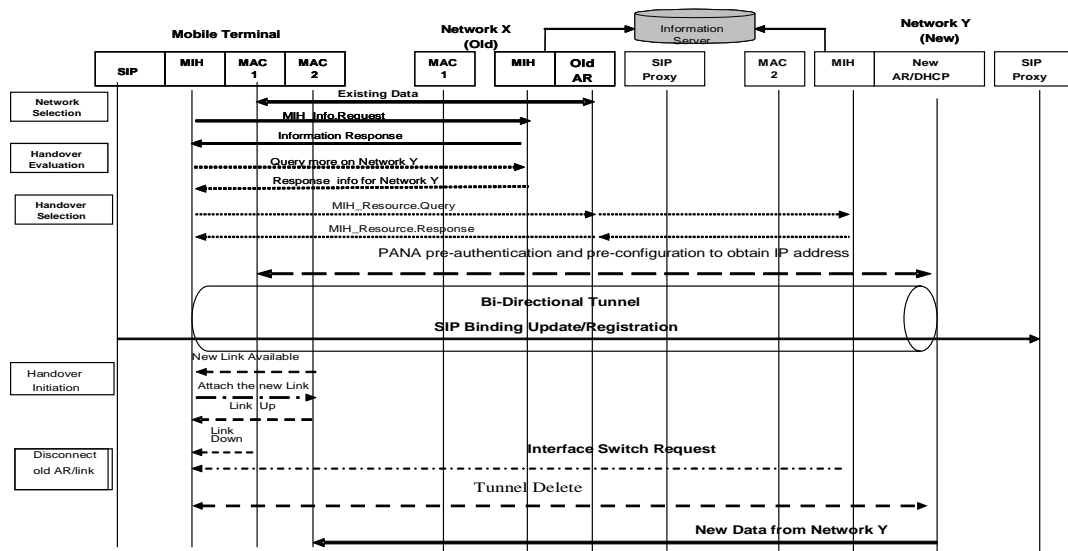


Figure 3: 802.21 assisted SIP-based mobility management for heterogeneous handover

The service primitives defined in the 802.21 framework can work with any type of L3 mobility management protocol such as SIP [16], MIPv6 [17] or MIPv4 [18]. A mobile can make use of the service primitives to communicate with policy managers, device drivers and other mobility management protocols during its movement. Figure 3 shows an illustration of how MPA and 802.21 can work with a SIP-based mobility management mechanism. As shown, the mobile has two types of interfaces (Network X and Network Y).

Initially, the mobile is using Network X as its primary interface to establish a multimedia session with a correspondent host. The mobile queries an information server to learn about available networks that are of type Y. The mobile makes an MIH query to verify that the required resources to sustain the session are available. It then selects an appropriate network and retrieves more information about that network, such as address and type of security servers, DHCP server address, MAC address of the access point, etc. With this information, the mobile initiates MPA to pre-authenticate with network Y and configure itself for operation in that network. At this point the mobile is ready to switch layer-2 connections when appropriate. Once the “Link up” event is received from the MIES, the mobile sends a binding update (e.g., SIP REINVITE) to the correspondent host. At this time, traffic to the mobile flows through the new interface and the handover is complete.

5. Implementation and Experimental Results

This section describes an implementation based on the 802.21 framework and MPA scheme, and provides evaluation results and compares these with non-optimized mobility management. Figure 4a shows the experimental test-bed with four networks defined. We have experimented with two kinds of handover scenarios: one between two 802.11 networks belonging to different administrative domains; the other between 802.11 and CDMA1xEVDO access networks. For both cases, we demonstrate how 802.21 assisted information discovery, event service and MPA framework help improve performance during handover. Case I deals with terminals equipped with a single 802.11 interface, and case II deals with terminals with two different interfaces. The event services Link UP and Link DOWN act as triggers to help the handover. We apply Link UP event notification for the handover involving 802.11 access networks, where as we apply LINK down event notification for the handover involving different types of networks. However, events such as Link_going_down and Link_going_up may be more appropriate for dual-mode devices. Figures 4b and 4c illustrate the mechanism associated with both of these cases respectively.

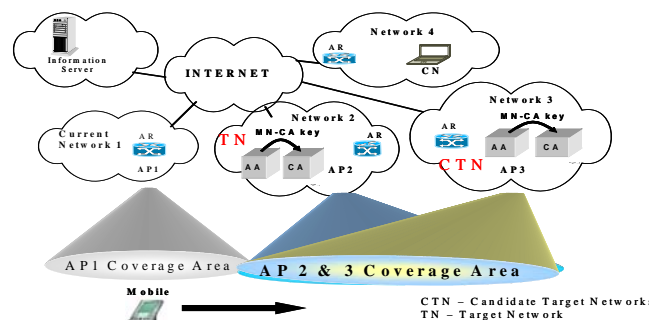


Figure 4a – Logical testbed scenario

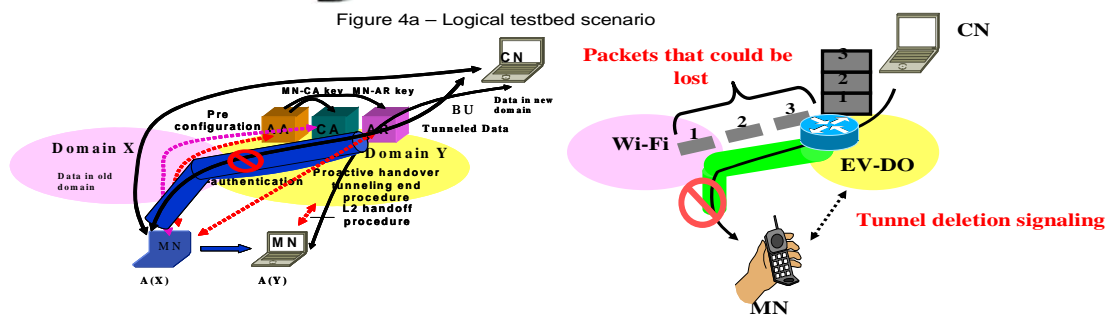


Figure 4b – Intra-technology, Inter-domain

Figure 4c – Inter-technology, Inter-domain

Figure 4: Experimental setup for MPA and 802.21 assisted handover

5.1 Intra-technology, Inter-domain handoff

In figure 4a, Network 1 is the current point of attachment (cPoA), Networks 2 and 3 are possible new points of attachment (nPoA), and network 4 is where the correspondent node (CN) resides. The mobile is initially in Network 1 and starts communicating with the correspondent node. We have used both SIP Mobility (SIP-M) [16] and MIPv6 [17] as the mobility management protocol to prove that MPA is mobility management protocol

independent. The configuration protocol is DHCP, the authentication agent (AA) is a PANA [15] Server, the configuration agent (CA) is a DHCP Relay Agent and the Next Access Router (NAR) is R2. We have used IP-IP tunneling functions for SIP mobility and have taken advantage of IPSEC tunnel for MIPv6. After a successful connection setup using SIP, voice traffic flows between the MN and the CN. This voice traffic is carried over RTP/UDP. We have used RAT (Robust Audio Tool) as the media agent and the streaming traffic is generated using a CODEC with a spacing of 20 ms between packets.

In the case of non-optimized handoff scenario (without 802.21 and MPA mechanisms), the handover delay and packet loss take place during the mobile’s movement, IP address assignment, post-authentication, and mobility binding update. The DHCP interaction takes a long time to complete the detection of duplicate IP addresses and the binding updates can be delayed if the correspondent node is too far from the mobile node. The experimental results show that 4 seconds of delay are attributed to the above factors. We observed approximately 200 packets were lost due to this delay. The situation is worse in Case II where it may take up to 15 seconds to authenticate and establish connectivity in CDMA or GPRS networks.

These delays can be reduced by taking advantage of the network discovery mechanisms of 802.21 and the pre-authentication technique of MPA. The 802.21 framework provides details of neighboring networks, including channel numbers, addresses of APs, DHCP servers, PANA servers, etc. Such information help the mobile communicate with them ahead of time and perform a proactive handover. We have used an RDF/XML-based query and response mechanisms to obtain the required information from the information server. We provide sample results of query and response and timing break down for some typical queries in Table 1. The query-response times can vary depending upon network access delays and processing times. However, since these queries are carried on prior to the handover event, they do not contribute to handover delay and also do not result in packet loss. However, this delay factor is critical in the decision making process giving an indication on how early the information query and response need to be completed for a successful handover.

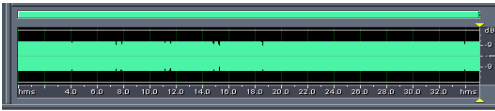
We ran experiments with Mobile IPv6, with and without Route Optimization (RO), as well as with SIP as the underlying mobility management protocol. In addition, we also examined the effects of buffering. The results are shown in Figure 5(b). Handover delays are dramatically reduced from those reported earlier; reducing the time from seconds to milliseconds. Proactive discovery of target AP also helped reduce the layer 2 delay as it avoided the scanning part. As a consequence, packet loss is also reduced due to handoff optimization at all layers. With buffering enabled, no packets were lost, as expected at the cost of additional delay. Figure 5a compares the results of the audio output with non-proactive scheme, where as figure 5b shows the handoff results with and without buffering mechanism. Dynamic buffering scheme on the edge router helps to maintain a tradeoff between the packet loss and additional delay. The highlighted numbers show that we were able to achieve 0 packet loss while keeping the delay between last pre-handoff packet and first in-handoff packet to a value within the threshold limit during the handover.

Table 1. Sample query response for MIIS

| Query | Response | Processing Delay (ms) | |
|--|--|-----------------------|------|
| | | | |
| Current PoA: AP1, Query list of 802.11 type neighboring networks with associated tariff values | Neighbor 0 PoA: ID:00:20:A6:53:B2:5E, Tariff: 20 Neighbor 1 PoA : ID:01:23:45:67:89:AB, Tariff:50 | Total | 2292 |
| | | API | 1291 |
| | | Network | 919 |
| | | Server | 18 |
| | | Client | 64 |
| Neighbor 0 selected, Query a list of network elements for Neighbor 0 | Target Network Channel: 10 SSID: ITSUMO newpoa1 Router address: 10.10.10.52 Router MACID: 00:00:39:e6:8b:ee Subnet: 255.255.255.0 DHCP Server: 10.10.10.52 | Total | 1473 |
| | | API | 991 |
| | | Network | 451 |
| | | Server | 13 |
| | | Client | 18 |



Non-802.21 assisted SIP-based mobility



802.21 assisted SIP-based mobility – Optimized handoff

| Mobility Type | MIPv6 | | | | SIP Mobility | |
|---|----------------------------------|---------------------------------|---------------------------------|--------------------------------|--------------------|-------------------|
| | Buffering Disabled + RO Disabled | Buffering Enabled + RO Disabled | Buffering Disabled + RO Enabled | Buffering Enabled + RO Enabled | Buffering Disabled | Buffering Enabled |
| L2 handoff (ms) | 4.00 | 4.33 | 4.00 | 4.00 | 4.00 | 5.00 |
| Avg. packet loss | 1.33 | 0 | 0.66 | 0 | 1.50 | 0 |
| Avg. inter-packet interval (ms) | 16.00 | 16.00 | 16.00 | 16.00 | 16.00 | 16.00 |
| Avg. inter-packet arrival time during handover (ms) | n/a | 45.33 | n/a | 66.60 | n/a | 29.00 |
| Avg. packet jitter (ms) | n/a | 29.33 | n/a | 50.60 | n/a | 13.00 |
| Buffering period (ms) | n/a | 50.00 | n/a | 50.00 | n/a | 20.00 |
| Avg. Buffered Packets | n/a | 2.00 | n/a | 3.00 | n/a | 3.00 |

5a. Audio output comparison

5b. Delay and packet loss statistic

Figure 5: MPA and IEEE 802.21 assisted handoff – Case I - Intra-technology, Inter-domain

5.2 Inter-technology, Inter-domain Handoff

Handoff involving heterogeneous access can take place in many different ways, depending upon the activity of the second interface. In one scenario, the second interface comes up when the link to the first interface is down. This scenario usually gives rise to undesirable packet loss and handoff delay. In a second scenario, the second interface is being prepared while the mobile still communicates using the old interface, and at some point the mobile decides to use the second interface as the active interface. This results in less packet loss as it uses make-before-break techniques. In the third scenario all the required state and security associations (e.g., PPP state, LCP, CHAP) are established ahead of time thus reducing the time taken for the secondary interface to be attached to the network. This third scenario may be beneficial from a battery management standpoint. Devices that operate two interfaces simultaneously can rapidly deplete their batteries. However, by activating the second interface only after an appropriate network has been selected may utilize battery effectively. Information discovery and MPA remain the same as in Section 5.1 with intra-technology handover. In this experiment we also add faster link down detection mechanism and a copy-forwarding technique at the access router to help reduce transient packet loss during the handover.

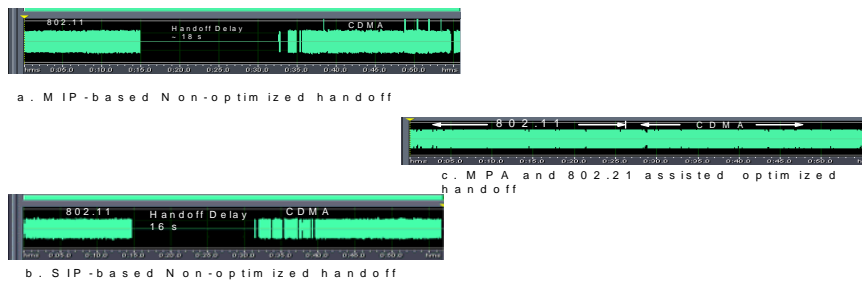


Figure 6: MPA and IEEE 802.21 assisted handoff – Case II - Inter-technology, Inter-domain handoff

The third scenario discussed above demonstrates the usefulness of 802.21's Event Service (ES), Information Service (IS) and MPA. In this scenario, the mobile is initially communicating using its first interface over technology X. It then uses 802.21 and MPA to discover a new access network of technology Y, learn the addresses of configuration elements in that network, and then proactively prepare the required state information for its second interface to use technology Y. It then sets up proactive tunnels with the required access routers in the target network and establishes the security association. Next, the device uses Link Down event notification triggers to the upper layers to initiate the handoff process to the newly available interface. Since most of the required events such as IP address acquisition, authentication, security association, and binding update have already been taken care of, the handover completes in less time.

We present results showing the usefulness of fast link detection, copy-forwarding and MPA in figure 6. As compared to non-optimized handover as shown in figures 6a and 6b that may result in delay up to 18 sec and 1000 packet loss during handover from WLAN to CDMA, we were able to achieve 0 packet loss, and 50 ms handoff delay between the last pre-handoff packet and first in-handoff packet. This handoff delay includes the time due to link down detection and time needed to delete the tunnel after the mobile has moved. However we observed about 10 duplicate packets because of the copy-forwarding mechanism at the access routers. But these duplicate packets are usually handled easily by the upper layer application.

6. Conclusions

In this paper we have presented a mobility optimization framework that takes advantage of 802.21 as well as a media independent pre-authentication framework to provide secured and seamless convergence and support heterogeneous handover. We have discussed several functional components of the IEEE 802.21 framework and their respective roles in providing the optimization. We explain a laboratory experimental setup where we have implemented some functional components of 802.21 including the MIIS and MIES functions, together with MPA technique. The implementation includes network discovery, network selection, pre-configuration, pre-authentication, and proactive handover. We presented the results of two types of heterogeneous handover scenarios: intra-technology, inter-domain; and inter-technology, inter-domain. Results obtained from these experiments illustrate that an MPA assisted IEEE 802.21 framework can provide secured seamless convergence and support different types of heterogeneous handover scenario by reducing handover delays and packet losses to a level that is acceptable for interactive VoIP and streaming traffic.

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