

# WiMAX-EVDO Interworking Using Mobile IP

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## ABSTRACT

WiMAX, a fourth-generation wireless-access technology, has made significant progress both in the standard forums and with wireless network carriers. To ensure service continuity to a legacy end user, it is important for a WiMAX mobile device to interwork with existing third-generation access networks before it is uniquely and ubiquitously deployed. This article addresses this issue and shows how interworking can be achieved with EVDO wireless-access technology, using mobile IP in a dual mode terminal. We present a network architecture solution and detailed call flows.

## INTRODUCTION

WiMAX is a fourth-generation access-network technology that has gained significant importance and momentum over the last few years. Many carriers have announced that they would adopt WiMAX, and efforts are underway to deploy these networks in many parts of the world. However, full ubiquitous coverage without service loss is not expected for several years. In the interim, a WiMAX mobile station (MS) must *interwork* (i.e., work in conjunction) with the existing third-generation networks like code-division multiple-access 2000 (CDMA-2000) 1x evolution data optimized (EVDO) to ensure service availability where WiMAX network coverage is not available. Note that an MS must be active in only one network (not both) at any given time, even if service is available in both access networks.

One can consider two different kinds of interworking — the *nomadic* approach and the *full-mobility* approach. In the nomadic approach, session continuity between different access technologies is not required. That is, data sessions that exist in the networks of one access technology are not carried over to the other technology when the user switches between the two. In fact, Internet Protocol (IP) sessions that exist in the first network are terminated before the user enters the second. To ensure the user has service in only one network, the IP sessions in the first network are terminated according to the following:

- After the user successfully completes the authentication procedure in the second network

- Before the user obtains an IP address in the second network

Similarly, *service continuity* is not required during handoff across different access technologies. In fact, an end user notices a service disruption during an inter-technology handoff.

On the other hand, in the full-mobility approach, there is seamless mobility across networks of different access technologies — the users can maintain their IP sessions and have service continuity without experiencing any significant degradation in their services (e.g., voice over IP or video on demand), other than the possible difference in access-technology performance.

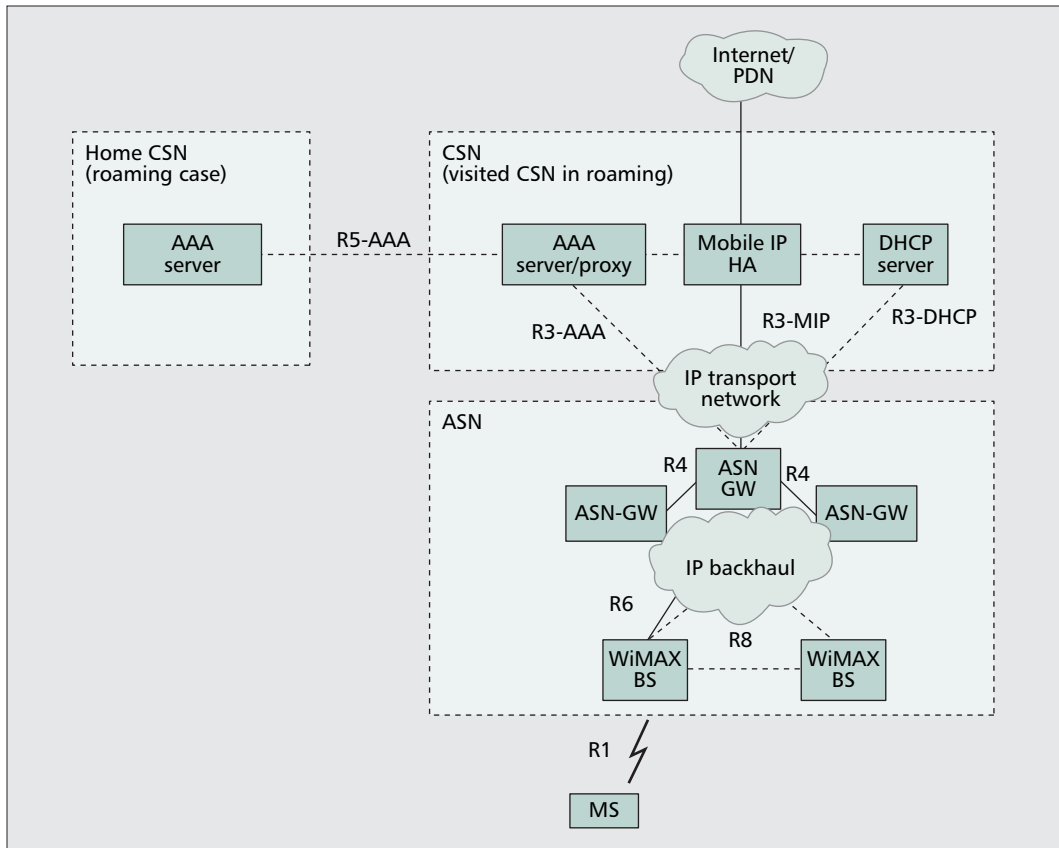
The MS that is used for this interworking solution is a dual-mode device with two separate radios including access-specific media access control (MAC) and physical layers.<sup>1</sup> The MS behaves in the same way as any other WiMAX-only device in a WiMAX network and an EVDO-only device in an EVDO network. That is, it complies with both the WiMAX standards [1, 2] and the EVDO standards [3–5] for network discovery and selection, network entry, authentication, and mobility when it operates in either one of these networks. An MS using a nomadic approach need not have a unique IP address in both access networks, whereas an MS using the full-mobility approach must have a unique IP address in both networks to ensure session continuity.

This article addresses the full-mobility approach and presents a solution using mobile IP (MIP), as specified in [6]. We use a *loosely coupled network architecture*, where the EVDO core network, with its network elements such as the home agent (HA) and the authentication, authorization, and accounting (AAA) server are shared by both WiMAX and EVDO access networks. This enables common authentication and billing for both networks using the same authentication, accounting, and billing servers. This model is ideally suited for service providers who use a phased approach when evolving from third-generation to fourth-generation networks. Although this document deals specifically with WiMAX-EVDO interworking, its concepts can be extended to interworking with other access technologies (e.g., WiFi and wireline networks).

The rest of this article is organized as follows: The next section compares WiMAX and EVDO networks. We then describe the network archi-

<sup>1</sup> It is possible to have a single radio for both WiMAX and EVDO on a single device, but there are several open issues and challenges that must be addressed and solved before this is viable.

Mobile WiMAX provides a broadband wireless system that enables convergence of mobile, fixed, and nomadic broadband networks. This convergence is achieved by a reuse of a common air interface and flexible network architecture to support fixed, mobile, and nomadic networks.



■ **Figure 1.** Mobile WiMAX network architecture.

ture, interworking using MIP, and the functionalities of various network elements such as the HA, foreign agent (FA), AAA server, and MS. Then we provide detailed call flows of inter-technology handoff and explain the various steps involved in the handoff. The following section discusses related work accomplished by others in this area, and the final section presents the concluding remarks.

## NETWORK ARCHITECTURE

In this section we discuss the high-level network architecture of WiMAX and EVDO.

### WiMAX NETWORK

Based on the IEEE 802.16e air interface [7], mobile WiMAX provides a broadband wireless system that enables convergence of mobile, fixed, and nomadic broadband networks. This convergence is achieved by a reuse of a common air interface and flexible network architecture to support both fixed, mobile, and nomadic networks. IEEE 802.16e-2005 [7] supports scalable orthogonal frequency-division multiple access (OFDMA), which is essential for supporting multi-access systems with guaranteed and differentiated quality-of-service (QoS) capabilities. The Network Working Group (NWG) of the WiMAX Forum specifies the end-to-end system architecture, detailed protocols, and procedures beyond the air-interface standards covered by [7]. Figure 1 shows the end-to-end mobile WiMAX network architecture as specified by the NWG release 1.0 v. 3.

The mobile WiMAX network consists of the access-services network (ASN) and the connectivity-services network (CSN). The core elements in the ASN are the base station (BS) and the ASN gateway (ASN-GW), connected over an IP cloud. The functionality across the ASN-GW and the BS is split and signaled through the R6 interface (Fig. 1). The ASN-GW provides security anchoring, network-access-server (NAS) functionality, traffic accounting, and a mobility proxy client for the mobile station. The MIP HA in the CSN is used as a global mobility anchor and is an optional element depending on deployment choices. In the simplified form (also known as simple IP), the user traffic bypasses the HA in the CSN. The user traffic in the ASN is tunneled as a payload between the BS and the ASN-GW. Mobility between the ASN-GW and the HA is handled with the Proxy Mobile IP protocol (PMIP) [6]. If not limited by a deployment model, a WiMAX BS can potentially connect over the R6 interface to any ASN-GW that it can reach through IP connectivity. Such R6 connection flexibility helps to reduce mobility-related signaling in the network because the same ASN-GW can serve the user's active IP session while the user is moving across several different BSs (e.g., ASN-GW relocation is possible but rarely required). The R8 interface can facilitate a user-context transfer and hand-over optimization when the user moves from one BS to another.

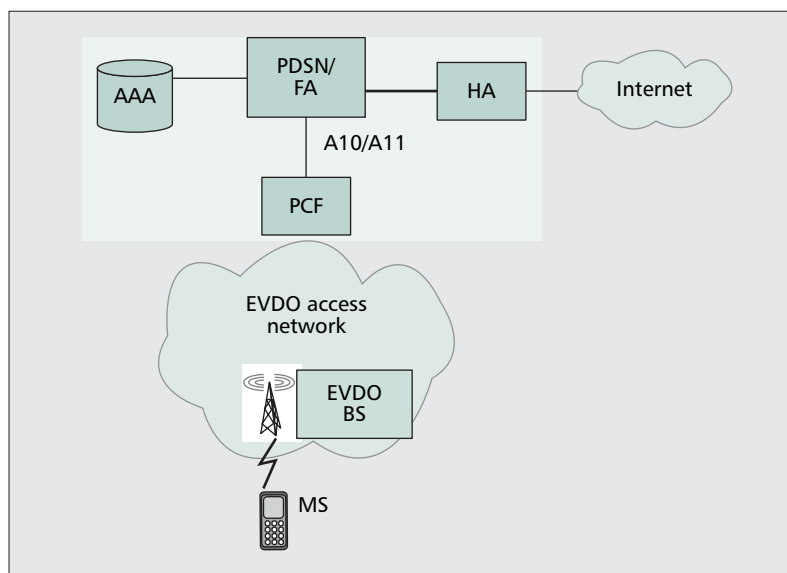
Mobility in the WiMAX network is enabled by interfaces R3, R4, R6, and R8 (Fig. 1). Several mobility scenarios can be supported including intra-ASN-GW, inter-ASN-GW, and anchored-

CSN mobility. The anchored-CSN mobility scenario is a deployment option for operators. As MSs move across BSs, they can be anchored at a specific ASN-GW, and mobility can be handled by this ASN-GW. There are other scenarios where MSs must be handed across ASN-GWs by means of lateral context transfers through R4. The details of such handoffs are given in [1, 2].

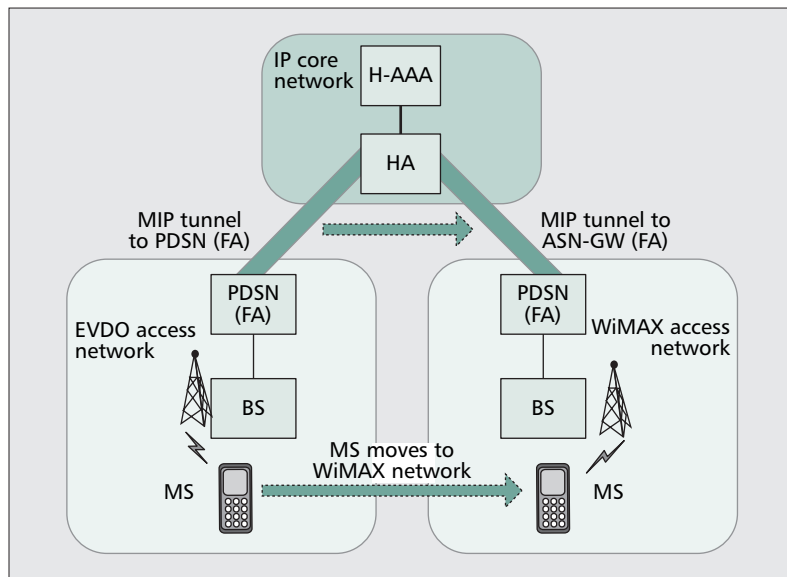
### EVDO NETWORK

The EVDO network architecture model is detailed in [3, 4]. The key components of the EVDO access network are the:

- Base transceiver system (BTS) that consists of radio devices, the antenna, and equipment.
- Base station controller and packet control function (BSC/PCF) that provides control and management for one or more BTSs and relays packets to the appropriate packet data-serving node (PDSN).



■ Figure 2. EVDO network architecture.



■ Figure 3. Interworking network architecture using MIP.

- PDSN that accepts MIP registration requests from an MS and provides Internet access. The PDSN also serves as an FA and helps in creating a MIP tunnel with the HA.
- AAA server for validation of user credentials and generation of accounting records.

Unlike a WiMAX network, EVDO requires a point-to-point protocol (PPP) layer between the MS and the PDSN for both the default packet application and multi-flow packet applications. An EVDO MS always performs MIP registration following a PPP negotiation. This implies that the MS must trigger a PPP negotiation that makes the link set-up time on EVDO a little longer than in WiMAX. Additionally, EVDO has a unicast access terminal identifier (UATI) session [8] and a PPP session. The lifetime of a UATI session can be longer than a PPP/MIP session, but a PPP session can exist only if the MS already has a UATI session. This is important because the air-interface session set up (including negotiation of session parameters and protocols) takes a few seconds on average and is considered a time-consuming procedure. To reduce the hand-off time, pre-establishing an air-interface session and leaving it idle (without a PPP/MIP session) while the MS is active in a WiMAX network is desirable. This has implications for the dual-mode device behavior: assuming that EVDO coverage is everywhere and WiMAX coverage is spotty, the device periodically can register with the EVDO network to ensure that its UATI session is kept alive to avoid extra hand-off time. However, monitoring and transmitting on both technologies consumes more battery power on the MS. This is a trade-off between the MS battery life coupled with additional complexity and the hand-off performance.

### NETWORK ARCHITECTURE FOR INTERWORKING

The network architecture, which supports full mobility with session and service continuity across WiMAX and EVDO networks, is shown in Fig. 3. The figure shows WiMAX and EVDO access networks sharing one IP core network. As explained below, this is a loosely coupled model, that is, the WiMAX and EVDO networks have separate and independent data paths to the core network. This architecture supports full mobility across the two access networks during inter-technology handoffs by maintaining a MIP tunnel between the HA in the core network and the FA in the access network.

MIP is a well understood and well defined concept [6]. It is used to access any MS using a unique IP address assigned in its home network by an HA. The MS that roams in a foreign network registers itself through an FA with the HA. If the registration is successful, the FA assigns a temporary care-of-address (CoA) to the MS. The HA creates a MIP tunnel to the FA. That is, the HA creates an extra IP header to the CoA of the MS over the IP packets addressed to the MS home address (HoA). Any correspondent node (CN) can still reach the MS by its

HoA. The packets originating from the CN are routed to the HA and then through the MIP tunnel to the FA and to the MS. Hence, the MS still can be reached by its HoA in the foreign network. The details are given in [6].

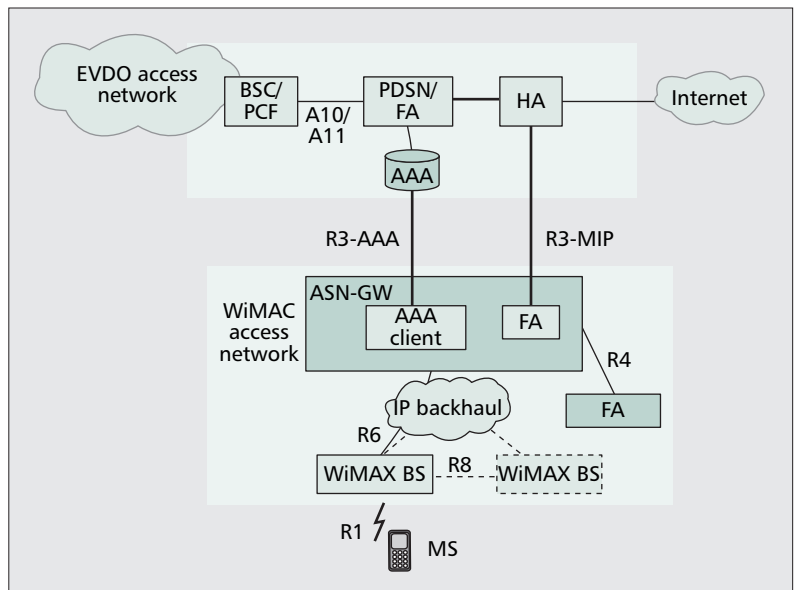
The concept of MIP tunnels can be extended to enable interworking during handoff across different access networks. For example, whenever an MS enters a WiMAX network from an EVDO network, the HA creates a new MIP tunnel with the FA in the WiMAX network. Incoming packets of ongoing applications (e.g., video on demand, voice over IP, etc.) to the MS are now directed by the HA through the MIP tunnel with the FA in the WiMAX network. Similarly, whenever the MS enters an EVDO network from a WiMAX network, the HA creates a MIP tunnel with the FA in the PDSN and tears down the tunnel with the FA in the ASN-GW. The existing IP sessions between the MS and the core network are still active. The end result is that there is an IP session continuity and hence, service continuity to the end user during the inter-technology handoffs.

Inter-technology handoffs can be implemented in three different ways — the first of these is *break before make*, where the link in the serving access network is torn down before a new link is set up in the target access network; the second is *make before break*, where the link in the target access network is made first, before it is torn down in the serving access network; and the third is *make-before-break-with-simultaneous-bindings*, where the link in the serving and target access networks are maintained for a brief period of time before the link in the serving network is torn down. *Make before break with simultaneous bindings* accounts for the best service continuity with a minimum packet loss during handoffs, followed by *make-before-break*, and then *break-before-make*. However, there are additional algorithms (e.g., duplicate packets coming along the two links) required for *make-before-break-with-simultaneous-bindings* that must be included for a successful implementation.

### LOOSELY COUPLED NETWORK ARCHITECTURE

There are two interworking models for the integration of two disparate access networks. The first is a tightly coupled model where two access networks are tied together at the lower, usually transport, layer and communicate with each other for a connection transfer. That is, the ASN-GW of the WiMAX access network is connected to the IP core network through the PDSN, and the EVDO core network treats the WiMAX network as an extension of an EVDO access network. The MS must implement an EVDO protocol stack on top of the WiMAX network protocol stack to enter the EVDO core network through the WiMAX access network. There are no practical standards at this time that define the tightly coupled model for WiMAX and EVDO networks, and the complexity of implementing this model must be evaluated carefully vis-à-vis the benefits that are present in this model.

The second is a loosely coupled model, where the two access networks are separate from each



■ Figure 4. Loosely coupled architecture.

other, and the core network interacts with two different access networks. As specified in the WiMAX standards [1, 2] and the Third Generation Partnership Project (3GPP) 2 standards [3–5], each network follows its unique network entry procedures, authentication methods, intra-technology mobility, paging, and so on. Figure 4 shows a loosely coupled network model. As shown in the figure, the WiMAX and EVDO networks are connected to a common IP core network, thus enabling common billing for both the networks and access technology specific authentication using the same AAA server. An end user can use the same application services (for example, video on demand) in either one of the two access networks because the two access networks have access to the same applications through the common IP core network, as shown in Fig. 3. The data paths are separate for WiMAX and EVDO access networks. This is useful when the same provider owns the same core network and can serve disparate access networks — an essential feature during transition from third-generation to fourth-generation wireless networks.

### CLIENT MIP AND PMIP MODELS

The MIP protocol, used to implement interworking among different access networks, can be classified into two different types — client MIP (CMIP), where the client (MS) implements MIP, and PMIP, where the MS uses simple IP (Dynamic Host Configuration Protocol [DHCP]) to obtain an IP address, and the network implements the MIP on its behalf. WiMAX networks support both CMIP and PMIP, whereas EVDO supports only CMIP. The difference in these two models is how the MS registers itself and obtains its IP address, and how the network completes the registration. In a CMIP model, the MS integrates an additional MIP stack. The following example is using MIP version 4. The MS sends a MIP registration request message during network entry. Unlike CMIP, in a PMIP-based net-

*Inter-technology handoff is initiated by the MS in the loosely coupled interworking architecture. The MS supports both break-before-make and make-before-break types of handoffs and exits gracefully from the previous network after the handoff is complete.*

work, an MS does not implement a MIP protocol stack. Instead, the MS uses a DHCP DISCOVER message, and the network (ASN-GW), on behalf of the MS, sends a MIP registration request to the HA. The detailed call flow for CMIP-based handoff and the detailed call flow for PMIP-based handoff are given in the next section.

The mobility session is associated by the network-based HA with the identity of the mobile subscription or network access identifier (NAI) of the MS. When CMIP mode is available in both the EVDO and WiMAX access networks, the dual-mode MS uses the same NAI in both the WiMAX and EVDO networks. When PMIP mode is used in WiMAX and CMIP mode is used in the EVDO network, the dual-mode MS uses a pre-provisioned NAI as an identifier for both the CMIP (in EVDO) and the simple IP (in WiMAX) networks. The PMIP client in the WiMAX network maintains the association of the mobility session with the same NAI. For the entire duration of the IP session, the dual-mode device uses the same NAI that is pre-provisioned for access in the EVDO system, including for access authentication in the WiMAX system.

#### FUNCTIONALITY OF VARIOUS COMPONENTS

This section discusses the functionality of various network elements to support interworking between WiMAX and EVDO networks.

**HA** — To enable interworking, the HA supports several functions. It enforces the use of the same NAI on both the WiMAX and EVDO networks to maintain the session continuity throughout the inter-technology handoff. The HA treats a registration request message as a new registration if the NAI in the message does not match the NAI in the existing mobility bindings. The HA also can support simultaneous bindings for the WiMAX and EVDO seamless handoff. To ensure seamless session transfer while the inter-technology handoff is in progress, the HA maintains both the old and the new bindings through both technologies for a brief period of time. The HA also supports session revocation and releases the resources of the prior access technology after the transition is over.

**MS** — An MS that is used for interworking between WiMAX and EVDO networks supports the following features and functionalities.

The MS supports dual radio with two separate MAC and physical layers — one for WiMAX and the other for EVDO. This allows independent network access through both radio links, possibly with simultaneous bindings during handoffs. The MS uses the same NAI in both WiMAX and EVDO networks for the whole duration of the mobility session. It uses CMIP procedures compliant with IS-835D [3, 4] in EVDO networks and MIP procedures compliant with WiMAX [2]. After the MS enters a network (WiMAX or EVDO), it behaves as a single-mode device in that particular network, except that a connection manager (CM) function on the MS continues to monitor the signal strength in the other network for possible handoffs. The MS is accessible with the same IP address (HoA) to

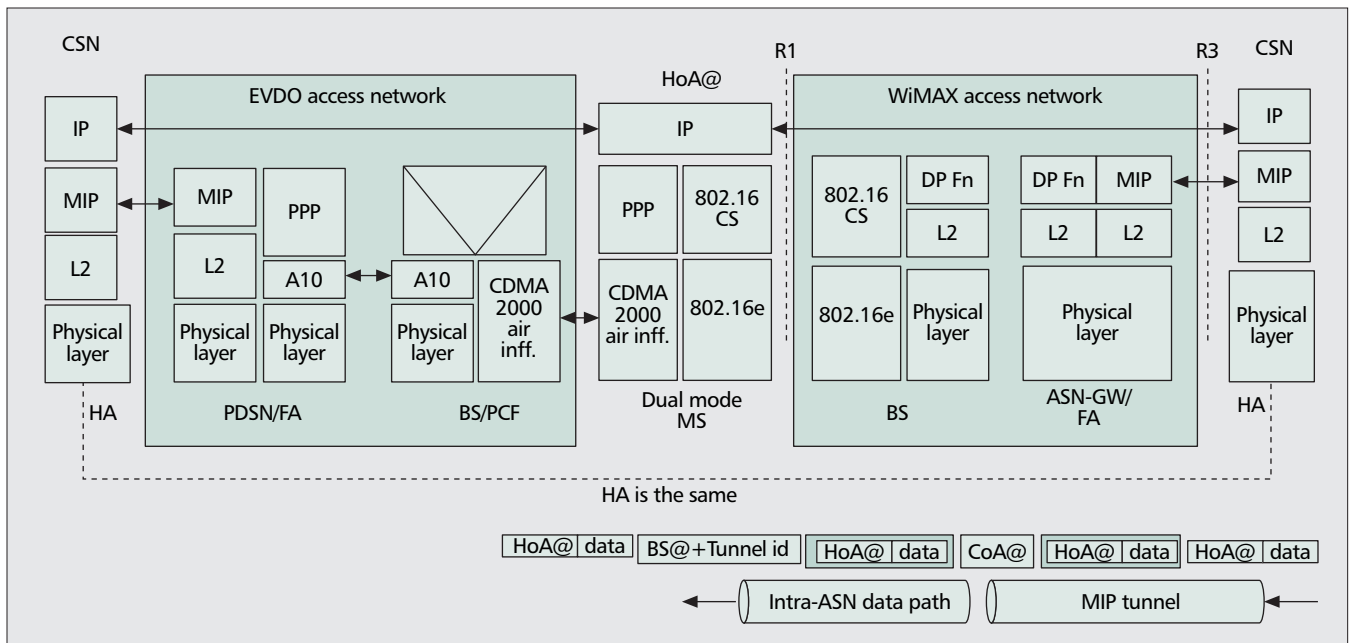
any correspondent node through the assigned HA, maintaining IP session continuity without significant service disruption during inter-technology handoffs. For QoS support, the MS uses a network-initiated QoS in WiMAX networks and a mobile-initiated QoS in EVDO networks.

The CM function is an important component of the MS and is primarily responsible for monitoring the signal strength in both the WiMAX and EVDO networks. The CM facilitates the connection to the network and triggers handoffs between heterogeneous networks. That is, it decides if the MS must switch over to a different network, based on configuration parameters that are either provisioned in the network for the MS and/or set by the user. Inter-technology handoff is initiated by the MS in the loosely coupled interworking architecture. The MS supports both break-before-make and make-before-break types of handoffs and exits gracefully from the previous network after the handoff is complete.

**AAA** — The AAA server supports the following features for WiMAX to EVDO interworking. It authenticates WiMAX terminals as specified in [1, 2] and EVDO terminals as specified in [3, 4].

For EVDO, the AAA server validates the mobile node (MN)-AAA authentication extension (AE) included by the MS in the CMIP registration request, as per the X.S0011-D specification [9]. This extension is computed using the previously established security association between the MN in a mobile terminal and the AAA server and therefore, identified by the secret key called MN-AAA key. Similarly, the associated authentication extension is called MN-AAA AE. After the MN-AAA AE is validated by the home-AAA (H-AAA), the H-AAA assigns the HA for the session and associates the respective security association between the MN and the assigned HA, called the MN-HA key with specific mobile binding during this session. This MN-HA key is identified with a specific, unique value of the security parameter index (SPI) so it can distinguish this key from any other MN-HA key associated with the same session. The EVDO standard does not specify how the MN-HA security association is established. For example, it could be pre-configured in advance and selected by the AAA as active after the MN is authenticated using the MN-AAA AE. Alternatively, the MN-HA key could be computed from the MN-AAA key.

For WiMAX, the AAA server authenticates the MS using one of the selected EAP methods such as EAP-authentication and key agreement (AKA), EAP-tunneled transport-layer security (TTLS), and so on. After authentication succeeds, the H-AAA assigns the HA to the MS for the MIP session, generates the MN-HA key as per WiMAX NWG specifications [2], and associates the MN-HA key with a specific mobile binding during this session. The WiMAX specifications clearly define that the MN-HA key is computed from the successful result of the EAP access authentication. Specifically, the extended master session key (EMSK) generated by the EAP method is used to compute the intermediate MIP root key (MIP-RK), which in turn is used to generate the MN-HA



■ **Figure 5.** Mobile IP data plane for EVDO and WiMAX using a dual mode MS.

key, tightly coupled with the identities of the MN (reported NAI) and the HA (the assigned HA IP address). This MN-HA key is identified with a specific, unique value of the SPI so it can distinguish this key from any other MN-HA key associated with the same session. To avoid possible collisions of SPI values, the SPIs also are computed deterministically from the MIP-RK. During network entry, the HA assignment is determined by the AAA server, and its address is sent to the authenticator in a remote authentication dial-in user service (RADIUS) `Access Accept` message. In EVDO, the HA address is sent to the PDSN, whereas in WiMAX, it is sent to the ASN-GW, which also acts as the session authenticator. The AAA server stores the assigned HA address as an additional correlated parameter for the NAI of the session. It returns the same HA address for this MS when there are subsequent binding requests for the HA (possibly from a different access network).

### NETWORK PROTOCOL STACK

Figure 5 shows the data plane for both WiMAX and EVDO networks. It shows a dual-mode MS that has two protocol stacks, one for each technology. Note that here we show both protocol stacks for comparison and ease of understanding. However, the MS is active in only one network at any given time. The figure shows the MIP layer in the protocol stack between the FA and HA. A packet sent from a correspondent node (external IP device) to the MS HoA is routed to the HA. The HA knows the CoA of the MS and has an active MIP tunnel with the FA (in either the WiMAX or EVDO network). The HA adds an IP header with the CoA to the original packet and delivers it to the FA through the MIP tunnel. The FA, in turn, strips off the CoA header and delivers the original packet to the MS. The details of this procedure can be found in [6].

### QoS ISSUES

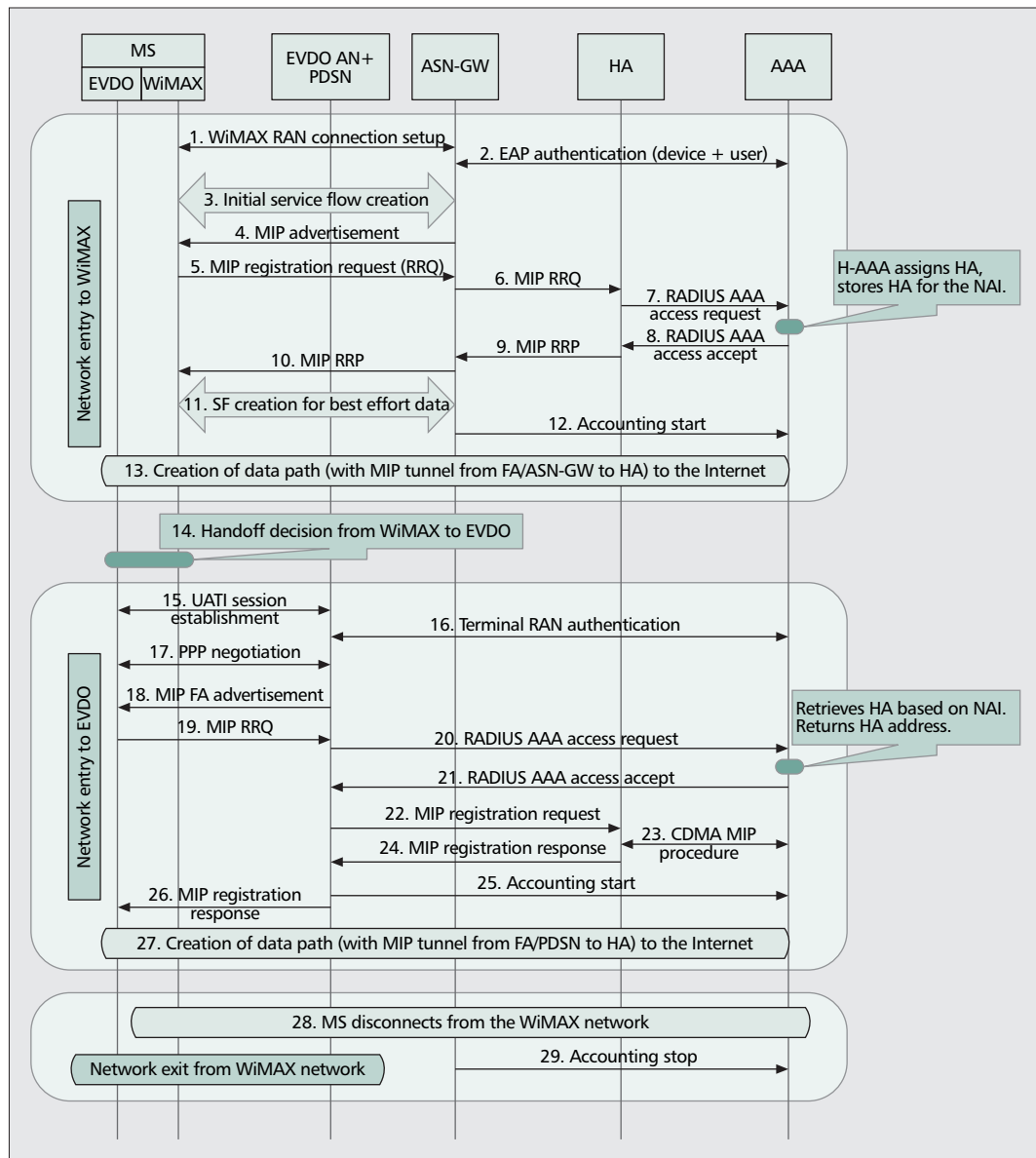
EVDO supports a device-initiated QoS model, whereas the WiMAX initial release supports a network-initiated QoS model;<sup>2</sup> the QoS classifier is obtained mostly from the MS in EVDO (the details are given in [3, 4]). In WiMAX [1, 2], the MS does not send a QoS classifier to the radio-access network. QoS classification information must come from the network. Interworking between EVDO and WiMAX with the same QoS class for an application (e.g., voice over IP) across these two access technologies after handoff requires additional signaling from the network. It is possible to maintain the same QoS class when the handoff happens from WiMAX to EVDO because the MS in an EVDO network can request the same assigned QoS. However, maintaining such a QoS class when transferring from EVDO to WiMAX would require further algorithms not presently developed.

### CALL FLOWS

In this section, we explain the call flows for inter-technology handoffs. As discussed in the previous section, MIP can be implemented in WiMAX in either the client (MS) using CMIP or in the network using PMIP. However, MIP implementation in EVDO uses only CMIP. In this section, we explain all the possible scenarios for handoffs. All the call flows explained in this section use the make before break scheme. The call flows for break before make are similar to the corresponding call flows shown below, except that the MS exits the serving access network (e.g., EVDO) before entering the target access network (e.g., WiMAX). There are some open issues with make-before-break-with-simultaneous-bindings, for example, duplicate packets arriving at the MS simultaneously when both networks are active during handoff and must be solved.

<sup>2</sup> Mobile-initiated service flows are currently being developed in the WiMAX Forum.

During WiMAX connection set up, EAP authentication is performed with the AAA server(s) using the MS initial NAI. Multiple AAA servers may be involved in cases like roaming. In such a case, the access request message is directed by the AAA server in the visited network to the H-AAA, which eventually authenticates the user.



■ Figure 6. WiMAX to EVDO handoff using CMIP in WiMAX networks.

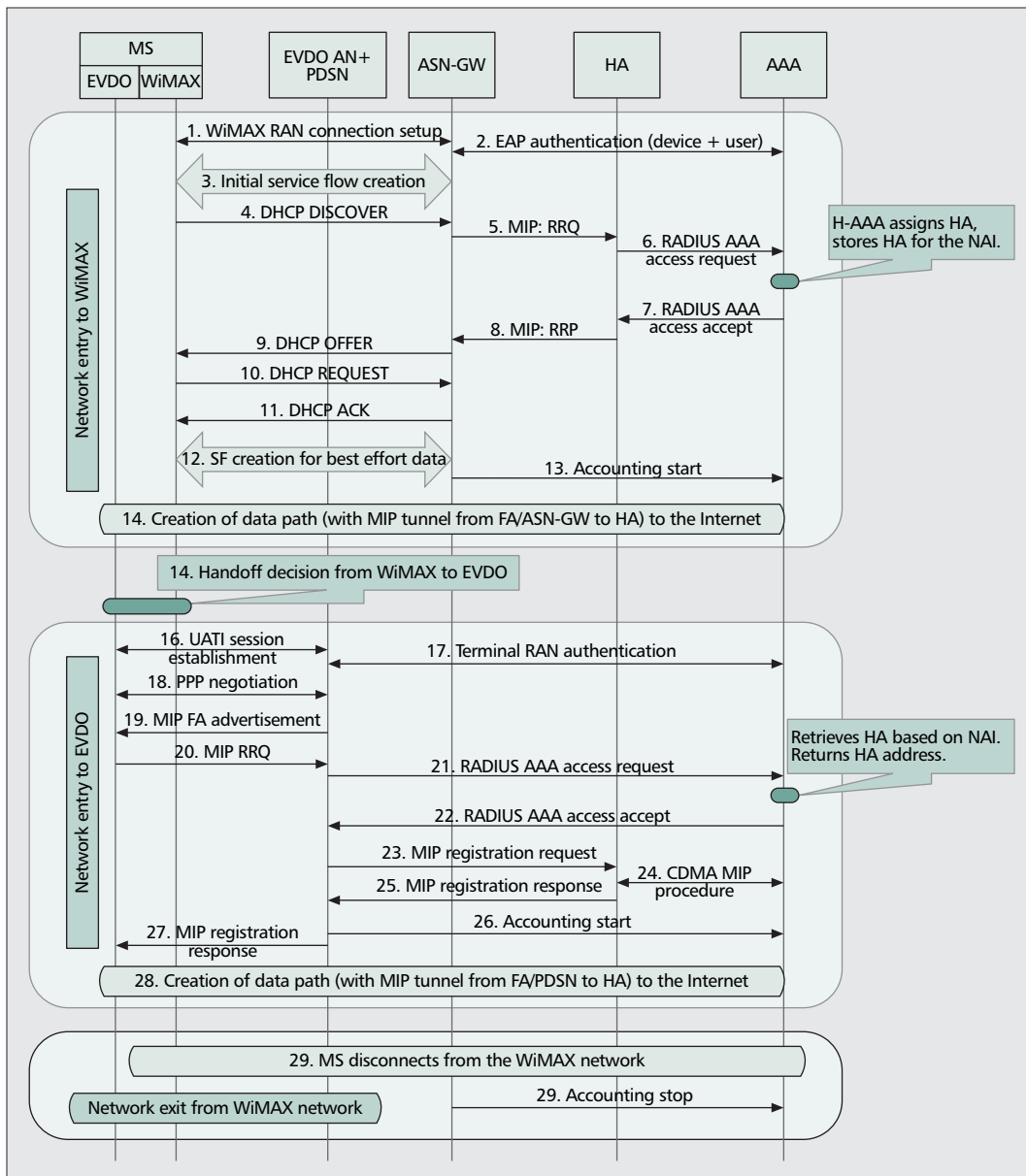
### HANDOFFS USING CMIP IN WiMAX

In the following, we explain the call flows for WiMAX-EVDO handoffs (and vice versa) using CMIP in both WiMAX and EVDO.

**WiMAX to EVDO Handoff** — MS performs WiMAX radio-access-network (RAN) connection set up using initial ranging, device authentication, and user authentication. The details of these steps can be found in [1, 7]. During WiMAX connection set up, EAP authentication is performed with the AAA server(s) using the MS initial NAI. Multiple AAA servers may be involved in cases like roaming. In such a case, the access request message is directed by the AAA server in the visited network to the H-AAA, which eventually authenticates the user. Upon successful access authentication (i.e., EAP success), the H-AAA assigns an HA for the MS session. The ASN-GW initiates initial service flow (SF) creation (for downlink and uplink) for

IP connectivity establishment. The HA uses the MN-HA key (received in step 8 of Fig. 6) to compute the MN-HA AE key, assigns the HoA to the MS, and responds with a MIP Registration Response (RRP) message to the ASN-GW (step 9 in Fig. 6). A data path is established between the MS and HA through the FA located in the ASN-GW for IP traffic originating or terminating in the MS.

In step 14 the MS decides to switch over to the EVDO network, based on the signal strength and/or other configured parameters. The details of initial network entry to the EVDO network are given in [3]. The MS builds a MIP Registration Request (RRQ) message using either all zeroes (or all ones), dynamic HoA assignment, or including its own value of the HoA already assigned during the WiMAX initial access. The MS also includes MN-FA challenge extension, MN-AAA AE, and NAI extension as per the X.S0011-D specification 1. The NAI used in this message must be the same one used



The HA detects that there is an existing mobility binding for the MS by checking the NAI, but there is no known security association (MN-HA key) to validate the RRQ message. The HA communicates with the AAA and using the NAI and SPI obtains the MN-HA key and validates the RRQ message.

■ **Figure 7.** *WiMAX to EVDO handoff using PMIP in WiMAX networks.*

by the MS in the WiMAX network. The MS then sends this message to the PDSN/FA through the EVDO RAN. Using the NAI value, the H-AAA identifies the HA assigned to the MS in the WiMAX network. It returns the same HA address that was used for this session over the WiMAX network in a RADIUS *Access Accept* message to the PDSN. After the user is authenticated by the AAA, the PDSN forwards the MIP RRQ to the HA, using the address of the HA it received in the *Access Accept* message. To indicate to the HA that the message is associated with an MS in an EVDO network, it does not include an access technology extension in the message. The HA detects that there is an existing mobility binding for the MS by checking the NAI, but there is no known security association (MN-HA key) to validate the RRQ message. The HA communicates with the AAA and using the NAI and SPI obtains the MN-HA key and validates the RRQ message.

For more details, see the X.S0011-D specification [9]. Upon successful validation of the RRQ message, the HA assigns the same HoA to the MS and sends a MIP RRP message to the PDSN/FA. The HA uses the MN-HA key it received to sign the MN-HA Authentication Extension. The PDSN then forwards the MIP RRP message to the MS, which validates the received RRP by checking the MN-HA AE in it. At this point, a data path is created from the MS to the HA through the FA located in the PDSN. After the MS successfully enters the EVDO network, it disconnects itself from the WiMAX network.

**EVDO to WiMAX Handoff** — The call flow for EVDO to WiMAX handoff is similar to the one shown in Fig. 6, except that the MS enters the EVDO network first. It uses the procedure for EVDO network entry (as explained in Steps 15–27 of Fig. 6). The MS then enter a WiMAX

Although the interworking model that we presented in this article is specific to WiMAX and EVDO, the ideas presented here can be easily extended to other access networks like WiFi, UMTS, long-term evolution, and so on.

network using the procedure for WiMAX network entry (as explained in Steps 1–13 of Fig. 6), before it exits the EVDO network.

### HANDOFFS USING PMIP IN WiMAX

Here, we explain the call flows for WiMAX-EVDO handoffs (and vice versa) using PMIP in WiMAX and CMIP in EVDO networks.

**WiMAX to EVDO Handoff** — The initial ranging and authentication procedures of an MS in a WiMAX network are the same as those explained in the previous section. After it is authenticated, the MS sends a DHCP DISCOVER message to discover the DHCP servers in the network. The DHCP proxy in the ASN-GW receives the DHCP DISCOVER and determines the MS associated with the data path over which the DHCP message was received. The PMIP client, on behalf of the MS, generates a MIP RRQ message using the initial NAI and sends it to the HA. The RRQ message contains a *PMIP access-technology type extension*, indicating that the MS is in a WiMAX access network. The MIP RRQ message also includes the *revocation support extension*. In addition, it includes the MN-HA authentication extension, which is computed by the PMIP client and its associated SPI. The PMIP client then sends the MIP RRQ to the HA. Upon receiving the MIP RRQ message, the HA detects that there is no existing mobility binding for the MS (identified by the NAI). To validate the received RRQ, the HA retrieves the MN-HA key associated with the SPI in the MN-HA AE from the AAA. After successfully validating the RRQ (using the services of the AAA), the HA assigns a HoA address to the MS and responds to the PMIP client (ASN-GW) with a MIP RRP message. The initial network entry is completed (as per the call flows shown in Fig. 7), and a service flow is created between the MS and the WiMAX RAN. A data path is set up between the MS and the HA through the FA in the WiMAX network, and IP packets addressed to (or originating from) the MS go through this path.

In step 15, the MS decides to switch over to the EVDO network, based on signal strength and/or parameters configured in the MS for initiating the handoff. The entry to the EVDO network and the handoff is the same as shown in Fig. 6.

**EVDO to WiMAX Handoff** — The call flow for EVDO to WiMAX handoff is similar to the one shown in Fig. 7, except that the MS enters the EVDO network first. It uses the procedure for EVDO network entry (as explained in Steps 16–28 of Fig. 7). The MS then enters a WiMAX network using the procedure for WiMAX network entry (as explained in Steps 1–14 of Fig. 7) before it exits the EVDO network.

### RELATED WORK

Interworking among different protocols and disparate networks has been actively studied, well understood, and solved for various networks. Buddhikot *et al.* [10, 11] presented an interworking model to integrate 802.11 networks into

third-generation wireless networks (EVDO) using CMIP in their IOTA project. We use similar ideas to enable interworking between WiMAX and EVDO, but the network model is significantly different. Ala-Laurila *et al.* [12] proposed a solution that combines the global system for mobile communications/general packet-radio service (GSM/GPRS) subscriber-management and billing mechanisms with 802.11 access technology [12]. Isukapalli *et al.* [13] use the home location register (HLR) to provide interworking among different cellular networks (e.g., CDMA 1x) and IP networks using Session Initiation Protocol (SIP) as part of their SuperDHLR product. The 3GPP technical specification (TS) 33.402 is being developed to describe interworking between the 3GPP evolved packet core (EPC) and non-3GPP access systems. We address interworking between different protocols in the same way like the other approaches mentioned above. However, this solution is completely different because it uses the MIP protocols, whereas the other approaches do not.

### CONCLUSIONS

In this article, we discussed the need for interworking and presented an interworking model between WiMAX and EVDO networks using MIP protocols that provide session continuity to a user between these two access networks. We discussed the loosely coupled network architecture with separate data paths between WiMAX and EVDO networks. We presented detailed call flows for both CMIP and PMIP implementations in WiMAX and discussed the various steps of the call flows. Although the interworking model that we presented in this article is specific to WiMAX and EVDO, the ideas presented here can be easily extended to other access networks like WiFi, the universal mobile telecommunications system (UMTS), long-term evolution (LTE), and so on.

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