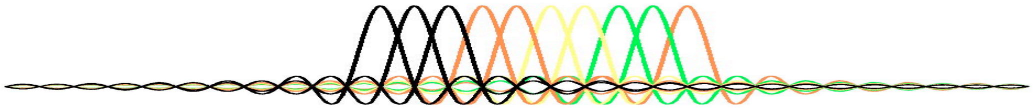


EHB 453, Introduction to Mobile Communications

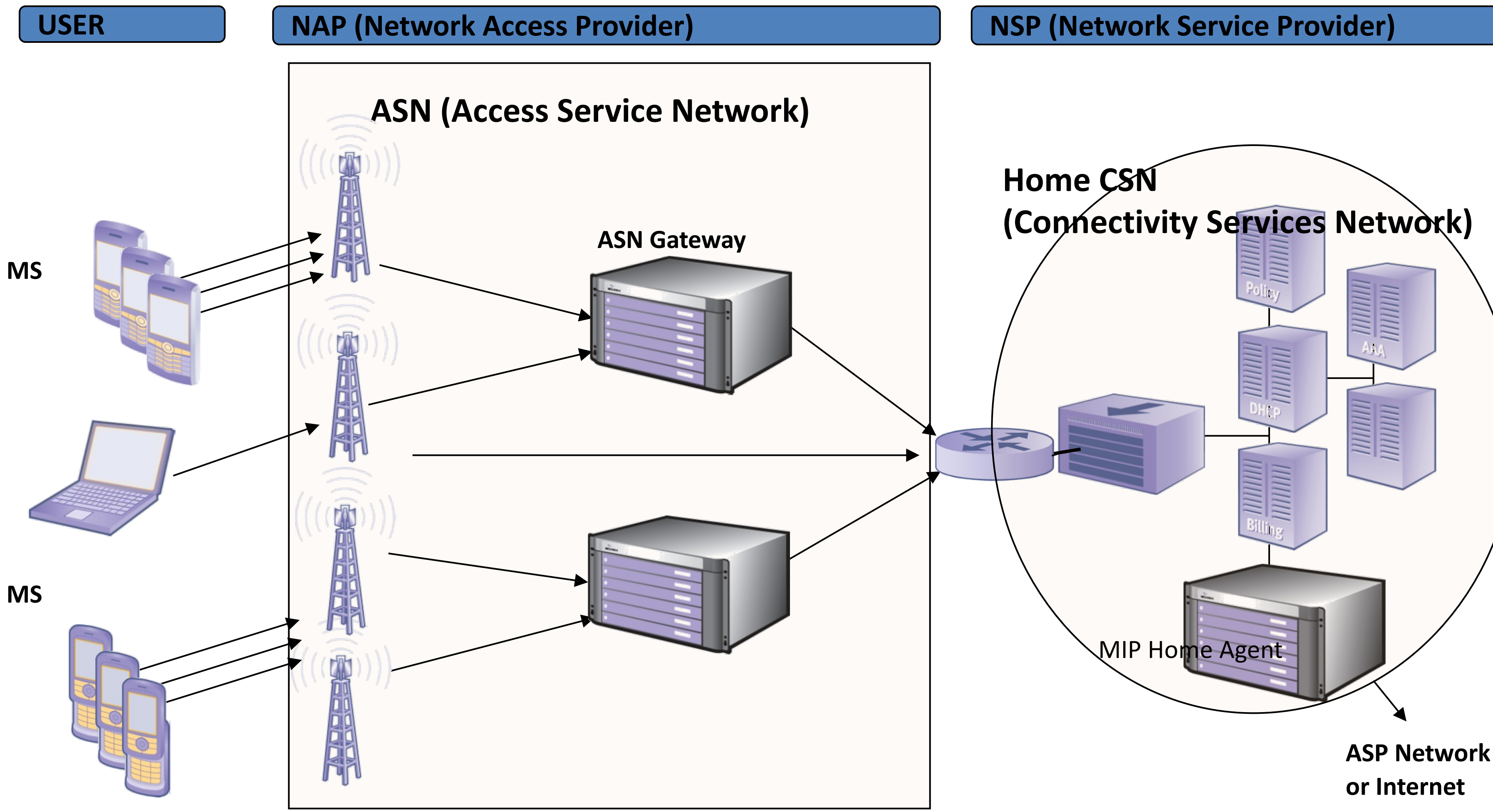
Lecture 8: WiMAX

Prof. Mustafa Ergen

Outline

- WiMAX overview
- WiMAX Physical Layer – IEEE 802.16e
- WiMAX MAC Layer – IEEE 802.16e
- WiMAX Networking Layer
- Upcoming WiMAX Features

WiMAX Forum Defined Network Reference Model



WiMAX Reference Model

- CSN: Connectivity Service Network
  - Connectivity to the Internet, ASPs
  - Authentication, authorization and accounting
  - IP address management
  - L3 Mobility and roaming between ASNs
  - Policy & QoS management based on a SLA
- ASN: Access Service Network
  - 802.16 interface w/ network entry and handover
  - Radio Resource Management & Admission ctrl.
  - L2 Session/mobility management
  - QoS and Policy Enforcement
  - Foreign Agent (FA)
  - Forwarding to selected CSN

R Interfaces

- Defining the messaging structure between different entities in the WiMAX network
  - R1: MS to Base Station, air interface (IEEE 802.16-2005)
  - R2: MS to ASN, for authentication, service authorization
  - R3: ASN to CSN, roaming interface, services, policies
  - R4: ASN to ASN
  - R5: CSN to CSN, for roaming
  - R6: BS to ASN
  - R8: BS to BS, for BS handover

Functional Architecture

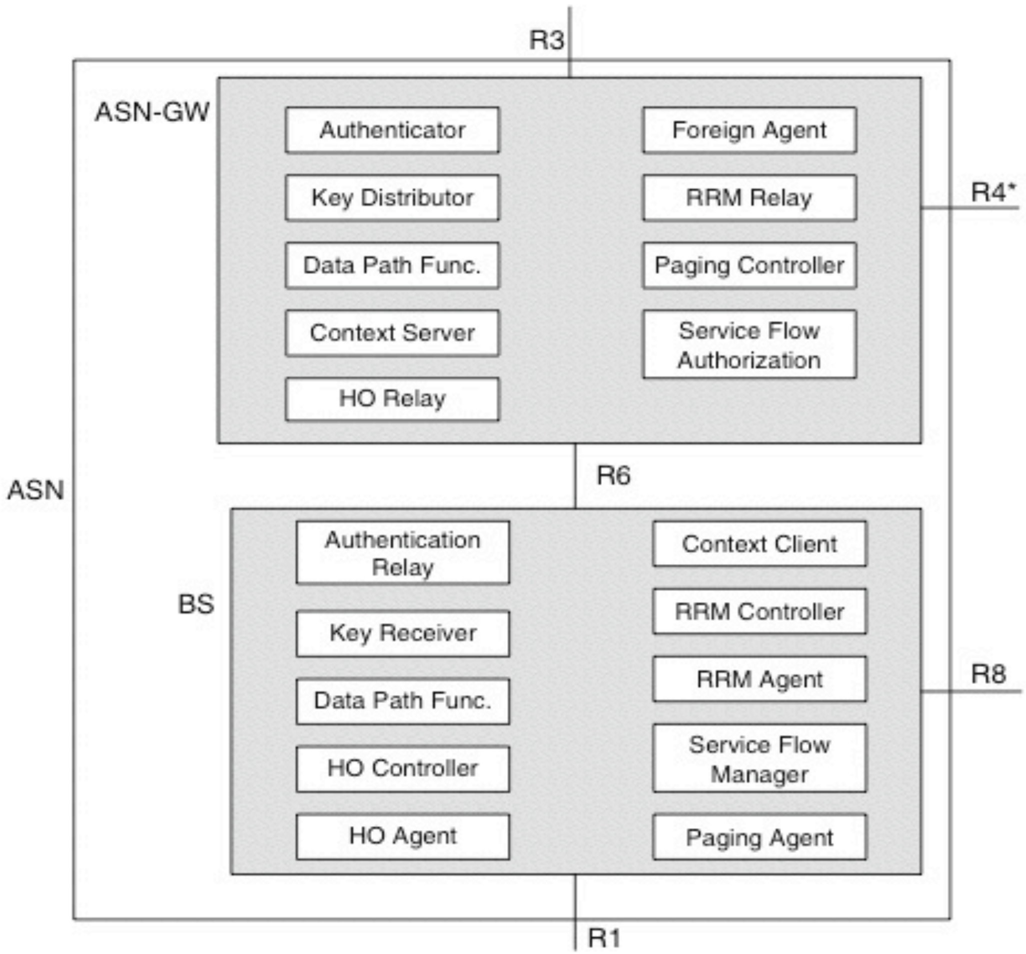


Fig. 10.3 Profile C functional architecture (© WiMAX Forum 2005–2007)

History

- IEEE defined PHY and MAC in 802.16 group
  - Wireless MAN-SC
    - First standard of IEEE 802.16
    - Single Carrier and Line of Sight (LOS) – point to point
    - Operates in 10-66GHz
  - Wireless MAN-Sca
    - Non-line of sight (NLOS) point to multipoint
    - Introduced in IEEE 802.16a-2003 and finalized in 802.16-2004
    - Operates in 2-11GHz
  - Wireless MAN-OFDM
    - 256 carrier OFDM system
    - NLOS for 2-11 GHz
    - Introduced in IEEE 802.16a-2003 and finalized in 802.16-2004
  - Wireless HUMAN
    - Unlicensed MAN with dynamic frequency selection
  - Wireless MAN-OFDMA
    - Introduced in IEEE 802.16a-2003 and finalized in 802.16-2005
    - NLOS point to multipoint
    - Up to 2048 carriers OFDMA
- WiMAX Forum defined Networking Layer

WiMAX Protocol Layering

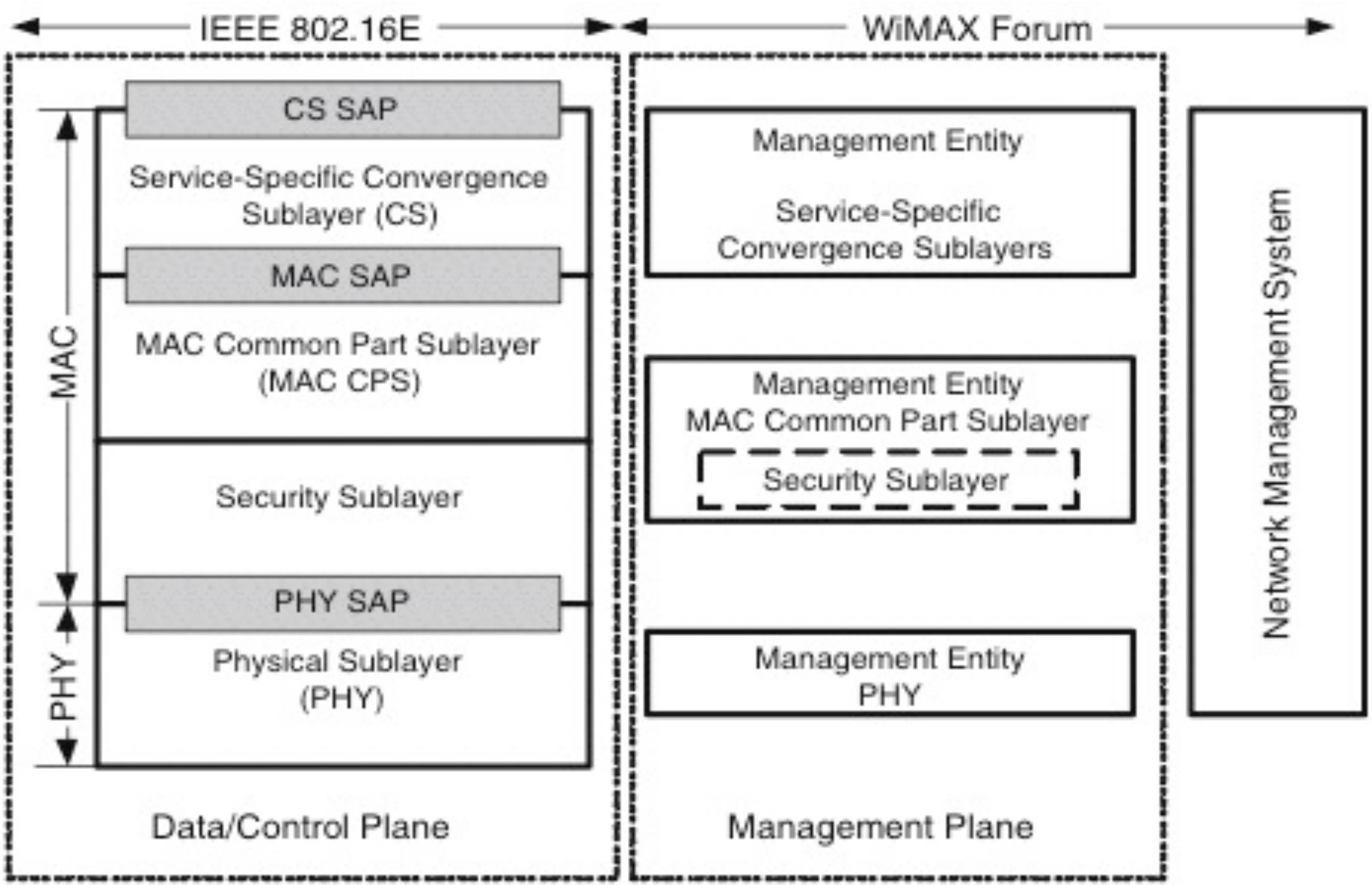


Fig. 9.2 Protocol layering

Other amendments of IEEE 802.16

- 802.16m
  - For 4G requirements of IMT-Advanced
  - Up to 100Mps data rate with MIMO
    - 2x2 MIMO is called Wave 2
    - 4x4 MIMO is called Wave 3
- 802.16j
  - Multihop relay specification
  - introducing relay stations

WiMAX PHY: IEEE 802.16e OFDMA PHY

- Transmission of a frame via OFDMA
  - OFDMA signal is made up of subcarriers
  - Subchannels is made up of subcarriers
  - Slot is composed of subchannels times symbols
  - Frame is composed of slots

- Supported coding mechanism
  - Coding, MIMO and HARQ
- Control mechanism
  - Ranging, power control and channel quality measurements

Subchannel

- Total number of subcarriers
  - Data subcarriers
  - Pilot subcarriers
  - Null subcarriers
- Subchannelization
  - For scalability, multiple access and advanced antenna array processing capabilities
  - a subset of subcarriers are called a subchannel
    - Via distributed subcarrier permutation or adjacent subcarrier permutation

FUSC: Full usage of Subcarriers

- FUSC is a distributed subcarrier permutation
  - First allocates the pilot subcarriers and then terming each remaining subcarrier to a subchannel.
  - There are 48 subcarriers per subchannel.

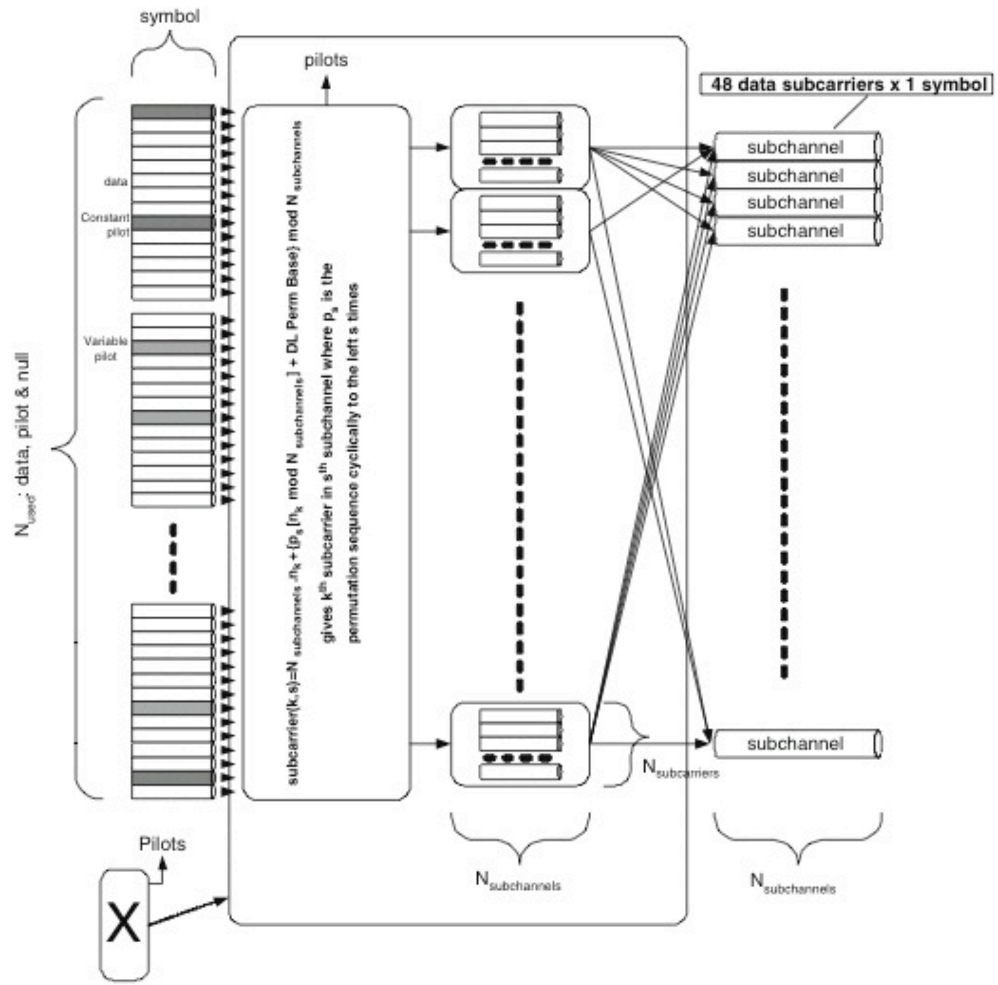


Fig. 8.1 FUSC

DL PUSC: Downlink Partial Usage of Subcarriers

- DL PUSC is distributed permutation scheme
- First divides the subcarriers into clusters of 14 adjacent subcarriers. 2 of them pilot.
- 24 subcarriers per symbol and over two symbols it is 48 data subcarriers.

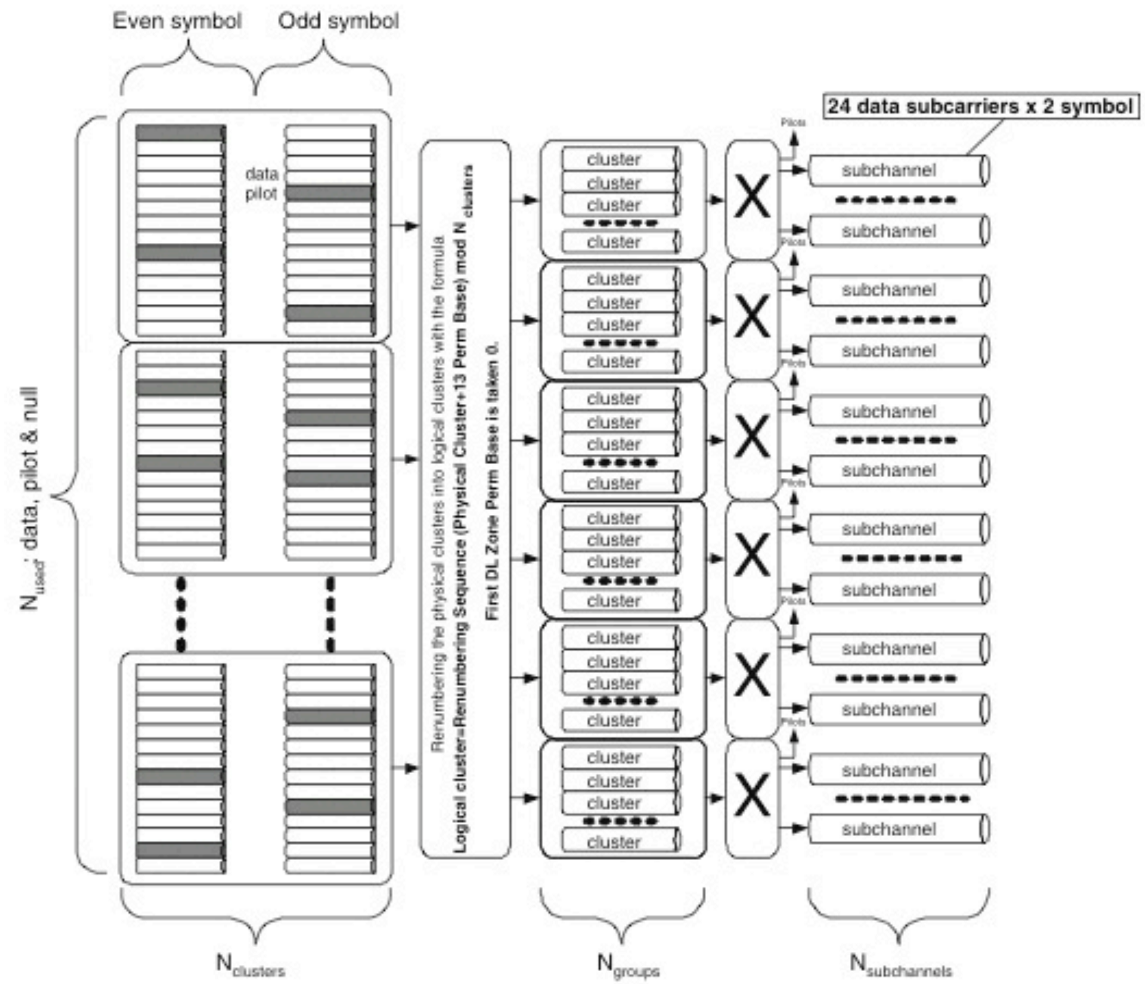


Fig. 8.2 DL PUSC

UL PUSC: Uplink Partial Usage of Subcarriers

- Usable subcarriers are divided into tiles. A tile host 8 data and 4 pilot over 4 subcarriers to 3 symbols.
- 6 tiles per group constitutes a subchannel.
- Total 48 data subcarriers.

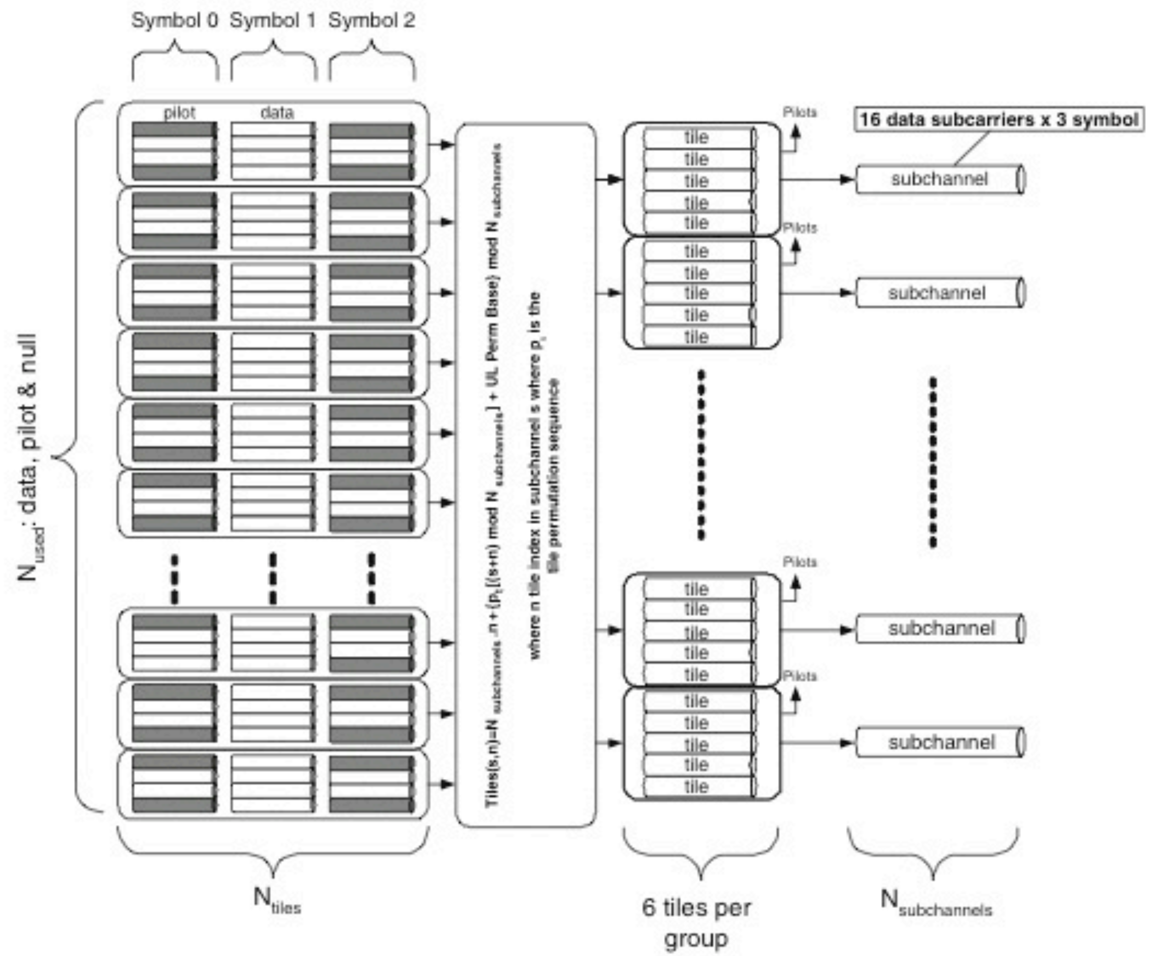


Fig. 8.3 UL PUSC

TUSC: Tile Usage of Subcarriers

- Adaptive Antenna Systems requires channel information.
- Using DL channel for UL and UL channel for DL is called channel reciprocity.
- The TUSC is permitted in DL as in UL-PUSC for AAS (Adaptive Antenna Systems)

AMC Subchannels

- Distributed subcarrier permutation leverages frequency diversity
  - Mapping of subcarrier to subchannel is randomized with formulas.
- Adjacent subcarrier permutation uses pilot and data subcarriers assigned to fixed positions.
- This is to leverage multiuser diversity so that a subcarrier can be assigned to the user with the best channel.
- A bin is created from 8 data subcarrier and 1 pilot and 6 contiguous bin is called a subchannel.

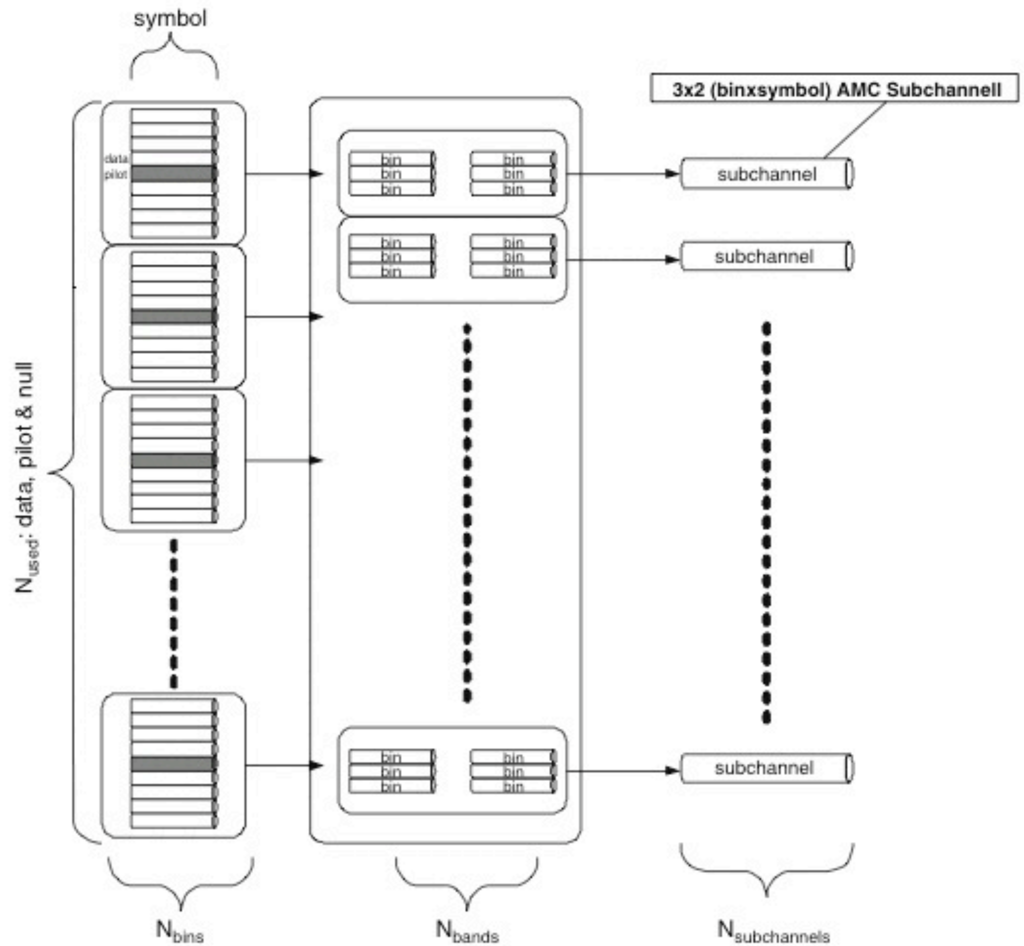


Fig. 8.5 AMC subcarrier permutation

Slot

- Subchannel concept is used to introduce the frequency component of a slot.

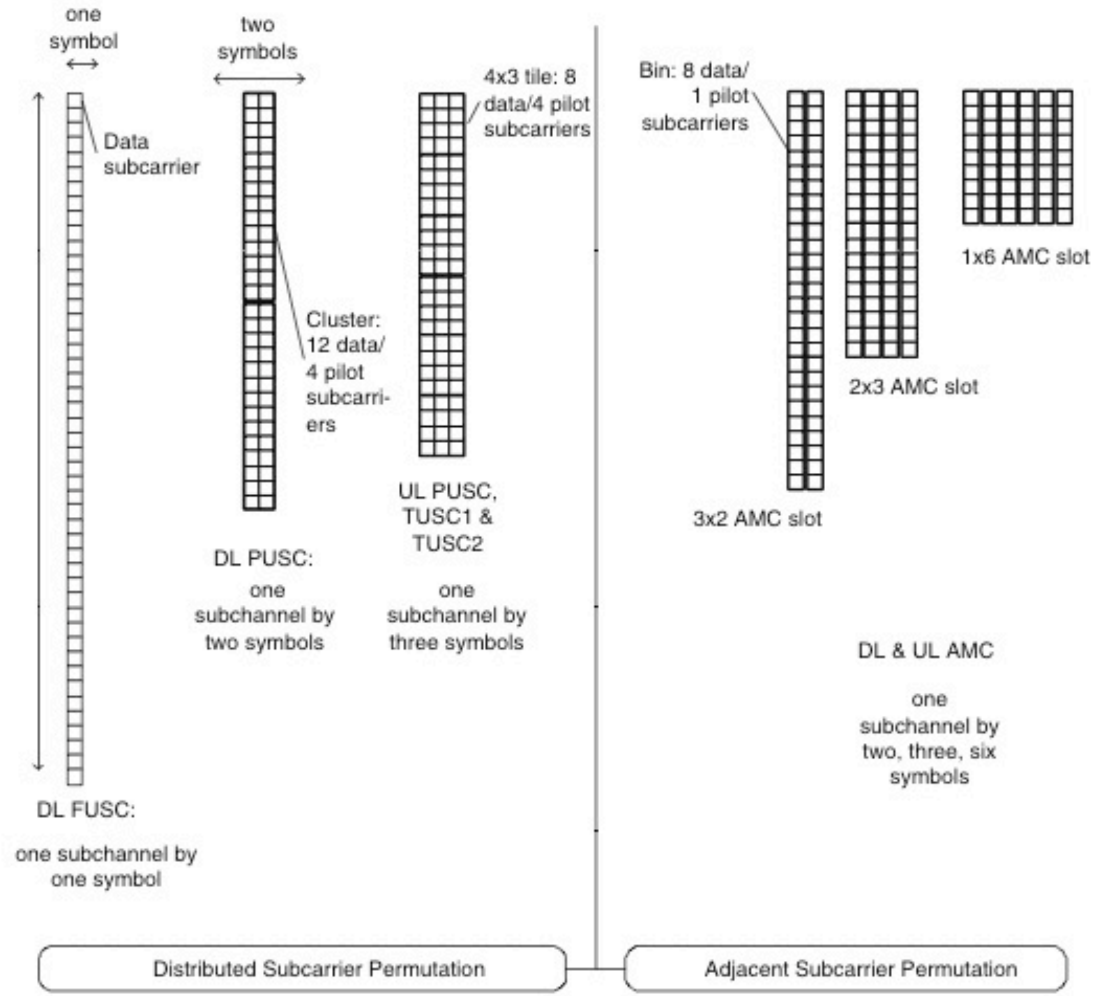


Fig. 8.6 Slot structures

One Slot is…

- Downlink FUSC with distributed subcarrier permutation: 1 SLOT = 1 Subchannel by 1 OFDMA Symbol, which is 48 data subcarriers over 1 symbol.

- Downlink PUSC with distributed subcarrier permutation: 1 SLOT = 1 Subchannel by 2 OFDMA Symbol, which is 2 clusters (48 data subcarriers) span over two symbols.

- Uplink PUSC with distributed subcarrier permutation: 1 SLOT = 1 Subchannel by 1 OFDMA Symbol, which is 6 tiles (48 data subcarriers) span over three symbols.

- Uplink and Downlink with adjacent subcarrier permutation: 1 SLOT = 1 Sub- channel by 2,3, or 6 OFDMA Symbols, which is M bins span over N symbols, where M.N = 6 and total is again 48 data subcarriers.

a Frame is ***slots in time and frequency.***

FCH is sent using QPSK-1/2.

DL-MAP is a map to indicate the slots dedicated for a subscriber for downlink.

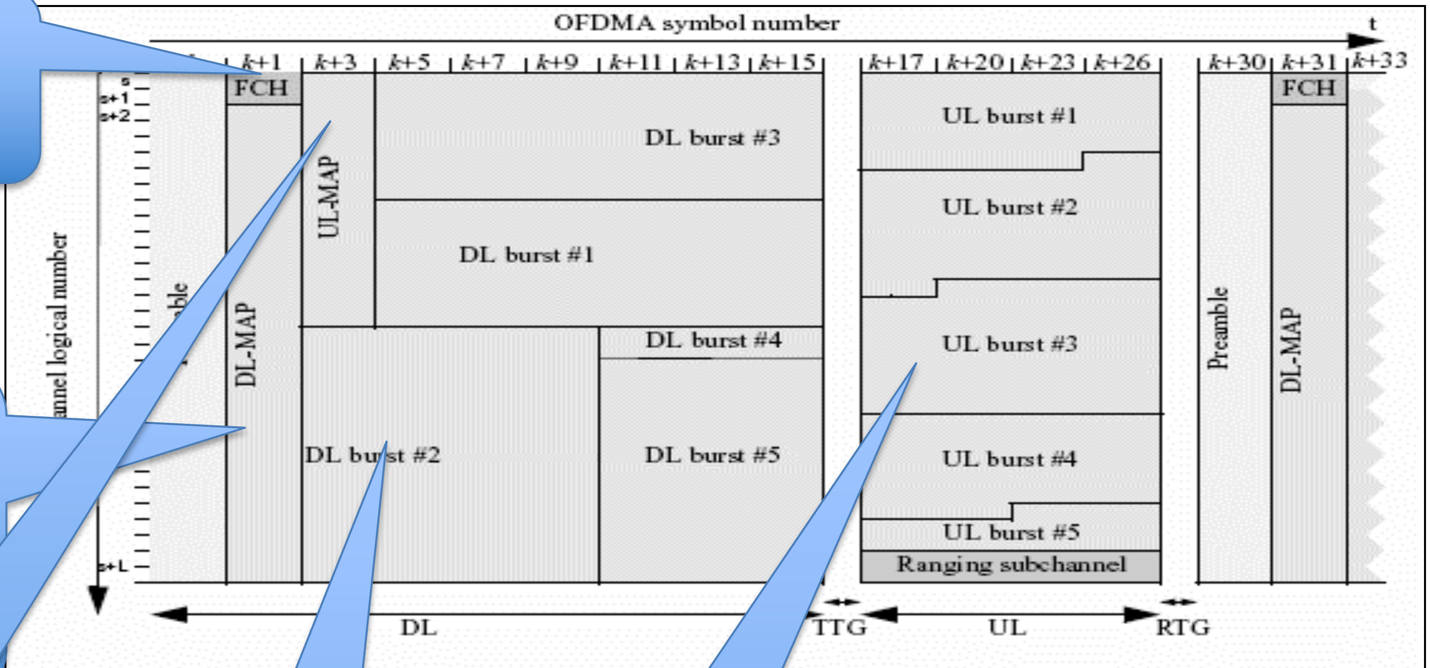


Figure —Time plan - one TDD frame (with only mandatory zone)

UL-MAP is a map to indicate the slots dedicated for a subscriber in uplink.

An allocated region and owner is indicated in DL-MAP.

An allocated region and owner is indicated in UL-MAP.

- Frame Durations can be 2, 2.5, 4, 5, 8, 10, 12.5 and 20 ms.

This is a TDD frame.

FCH, DL-MAP and UL-MAP

- FCH
  - It’s the first transmission in the downstream.
  - It indicates the length, coding and repetition-coding for the DL_MAP.
  - Also, indicates the sub-channels used in the downstream, for this FCH.
- DL-MAP
  - Indicates the allocated regions for the subscribers.
  - Subscriber only decodes that region for downlink.
- UL-MAP

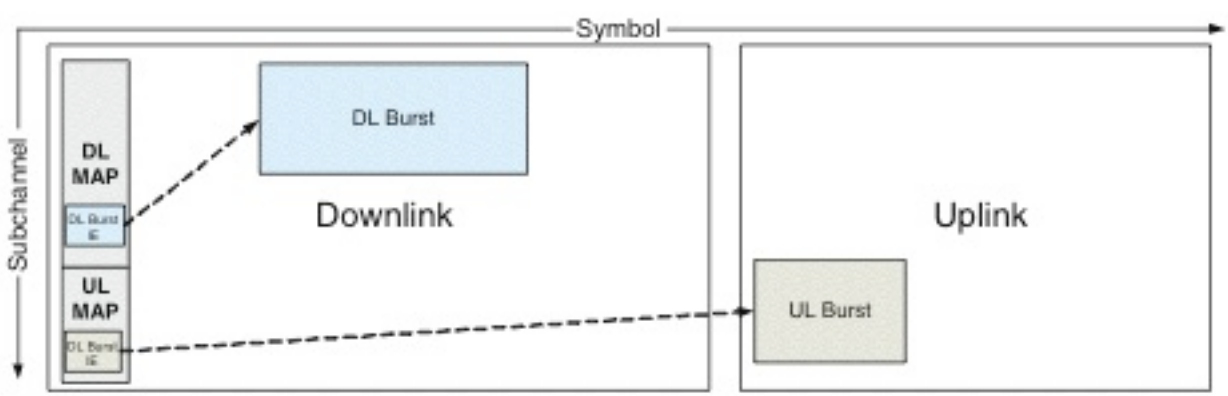


Fig. 8.8 Addressing in a frame: a MAP_IE content includes CID, symbol and subchannel offset, symbol duration and number of subchannels, and burst profile. Maximum number of bursts the MS can decode in one downlink frame is 64 and the maximum number of bursts that can be transmitted concurrently is 16

OFDMA Zones

- There could be multiple OFDMA Zones.
- PUSC is mandatory.
- Each zone to have its own DL-MAP and UL-MAP.
- Maximum of 8 zones in the downlink
- Each Zone switch indicated by a Zone_Switch_IE

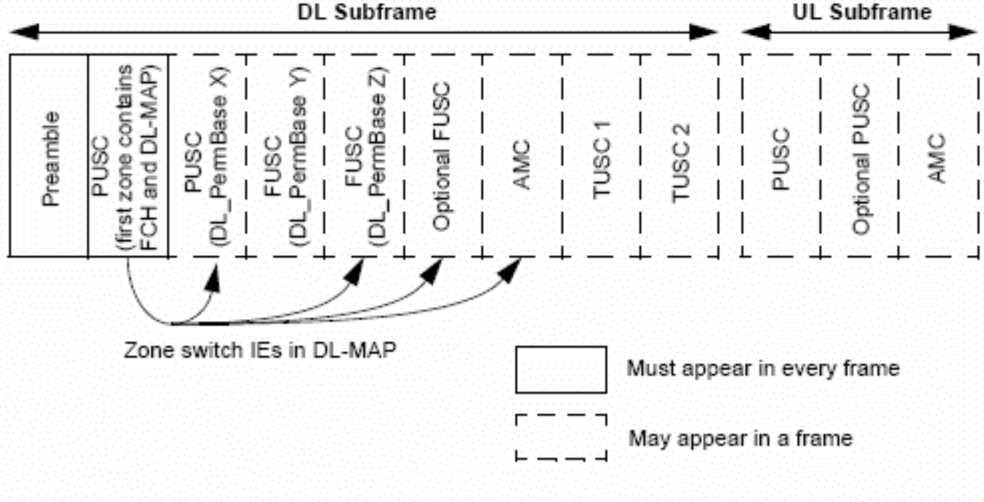


Figure 219—Illustration of OFDMA frame with multiple zones

OFDMA Data Mapping, Downlink

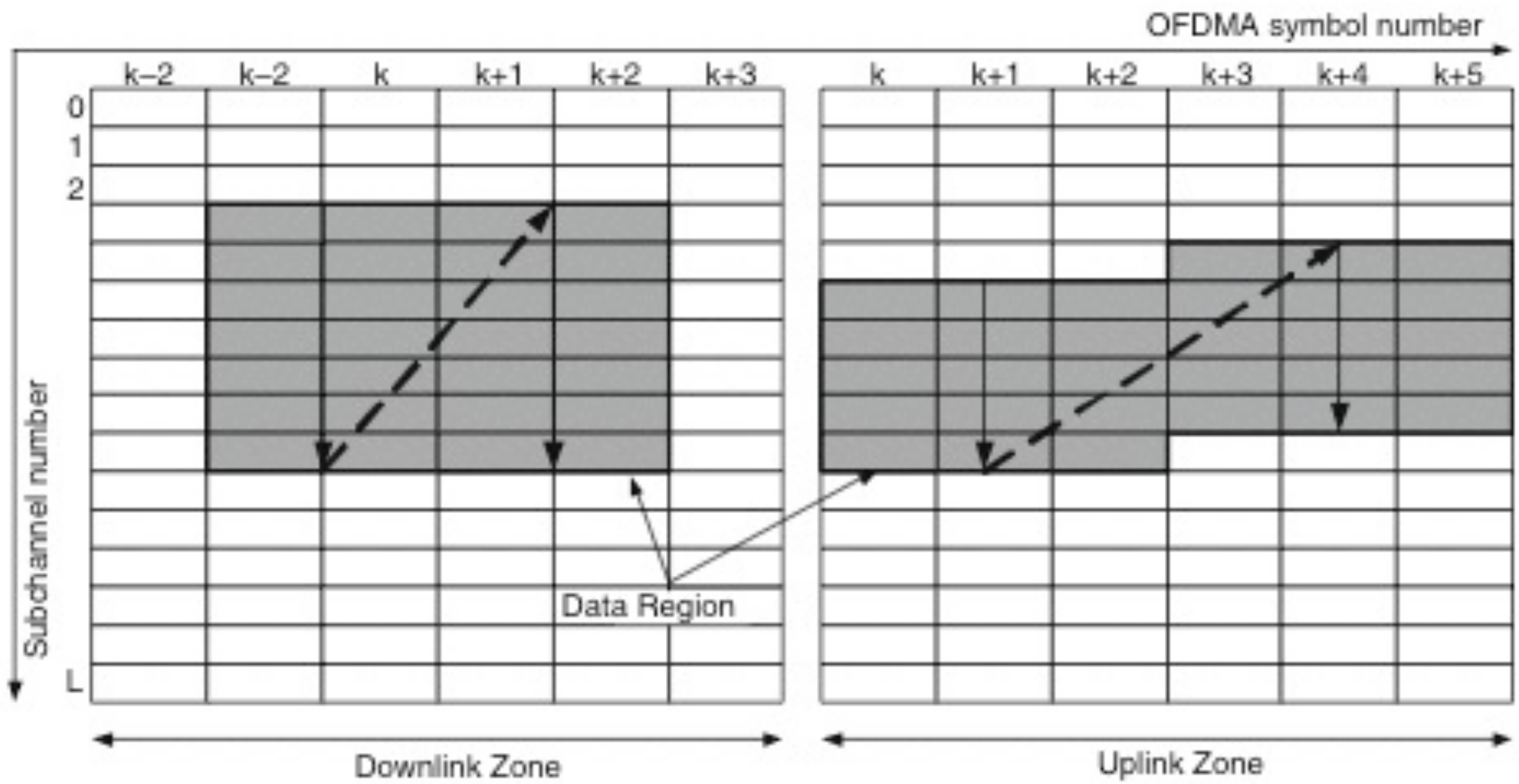


Fig. 8.7 Mapping for PUSC mode

- Data is divided into blocks to fit in one OFDMA slot.

A FDD Frame

A possible frame structure where two virtual groups are introduced. In HFDD operation, MSs that belong to a group are only allowed to transmit and receive at the assigned partition. For FDD operation, a MS may belong to both groups.

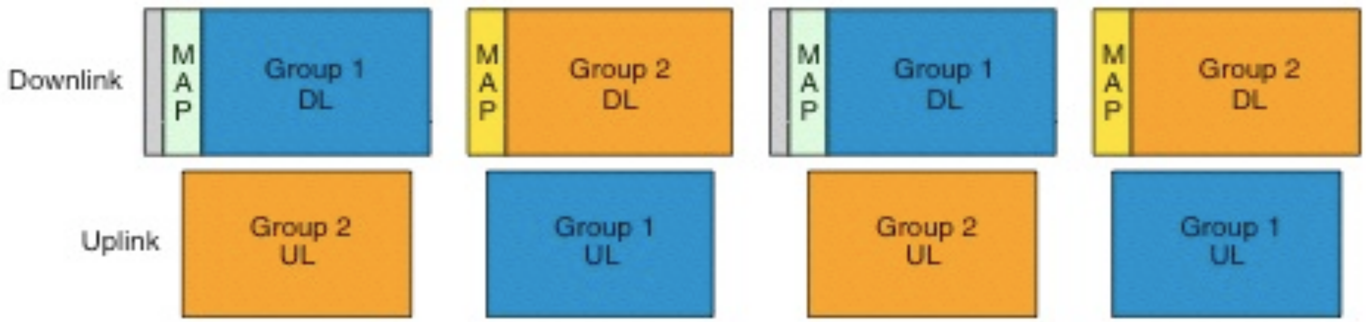


Fig. 8.11 OFDMA FDD/HFDD frame (under consideration)

Frame Structure-TDD

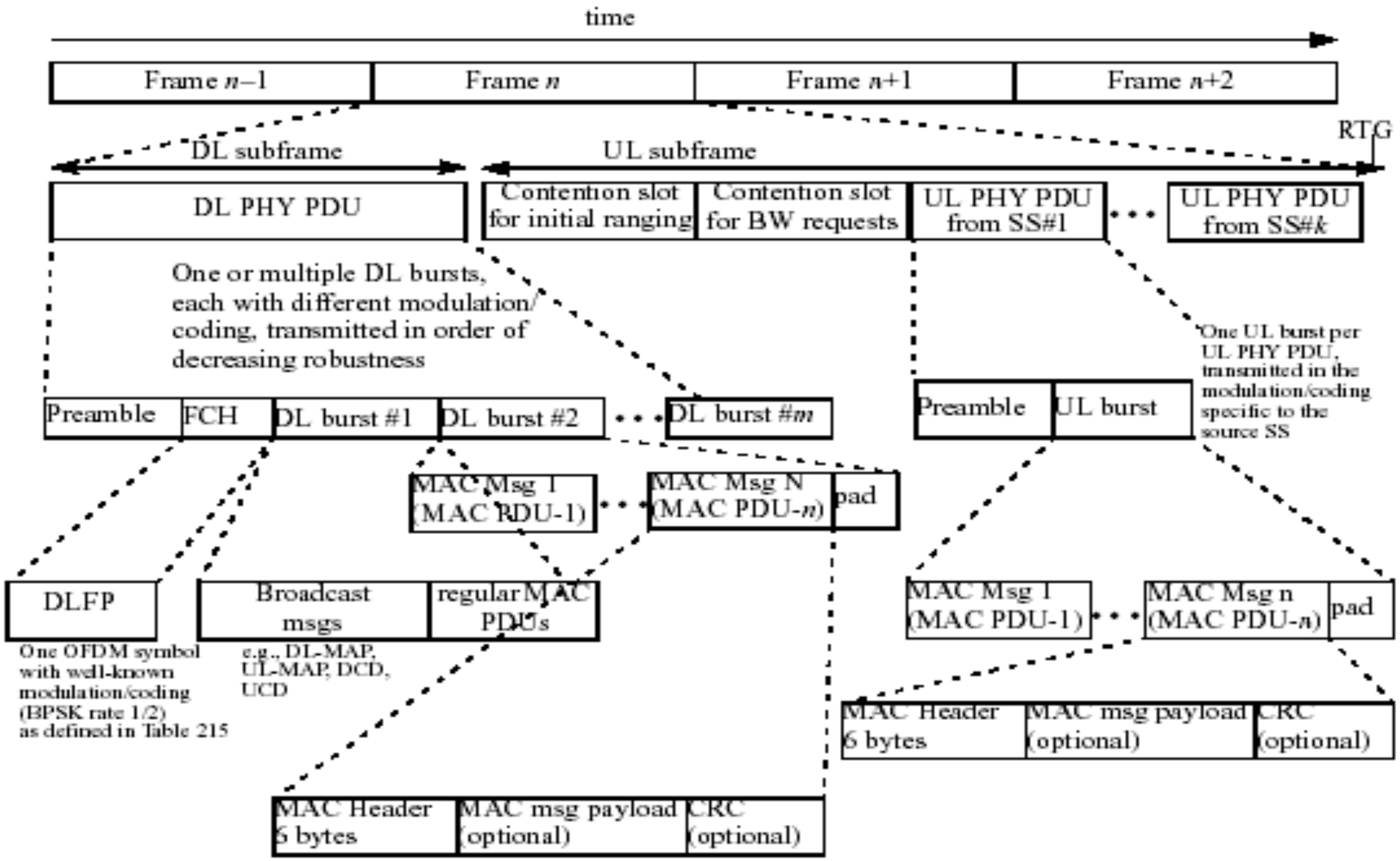


Figure 207—Example of OFDM frame structure with TDD

Frame Structure-FDD

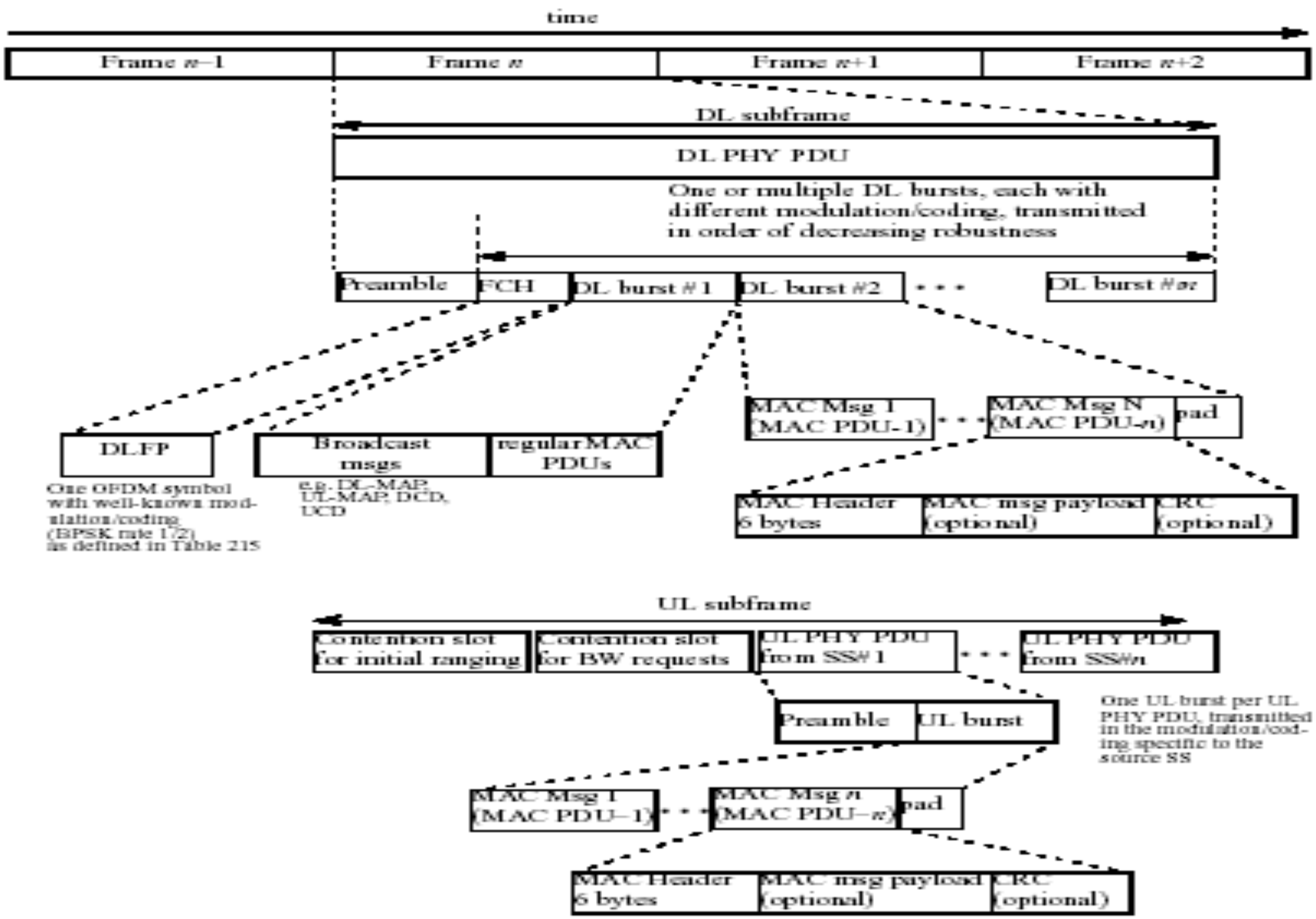


Figure 208—Example of OFDM frame structure with FDD

Segmentation

- A frame can be divided into segments in frequency axis.
- A MAC instance can be installed in one segment.

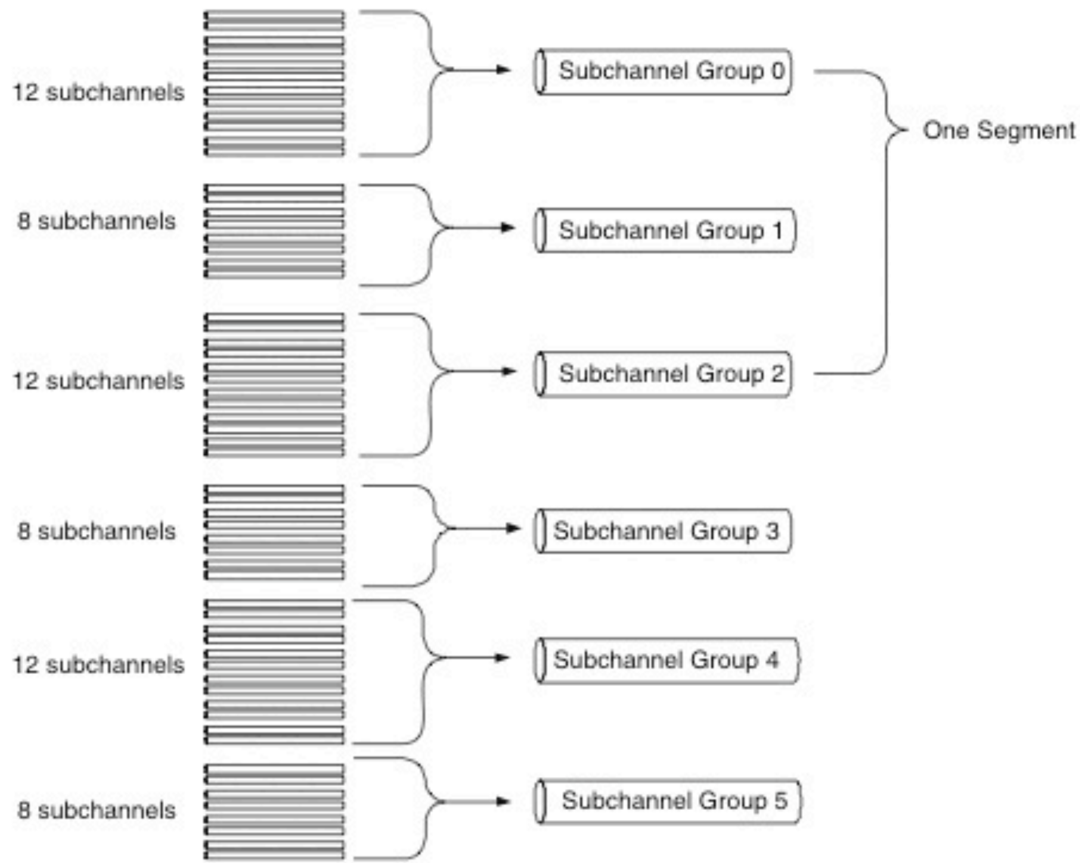


Fig. 8.12 Segment partitioning

Segmentation

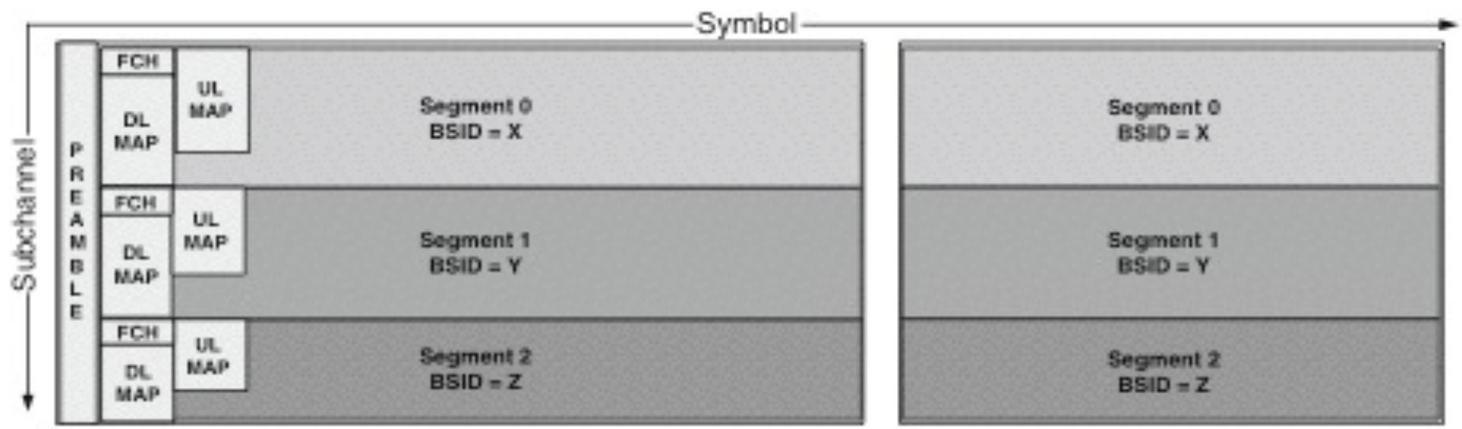


Fig. 8.13 Segment partitioning in frame

Frequency reuse with segmentation

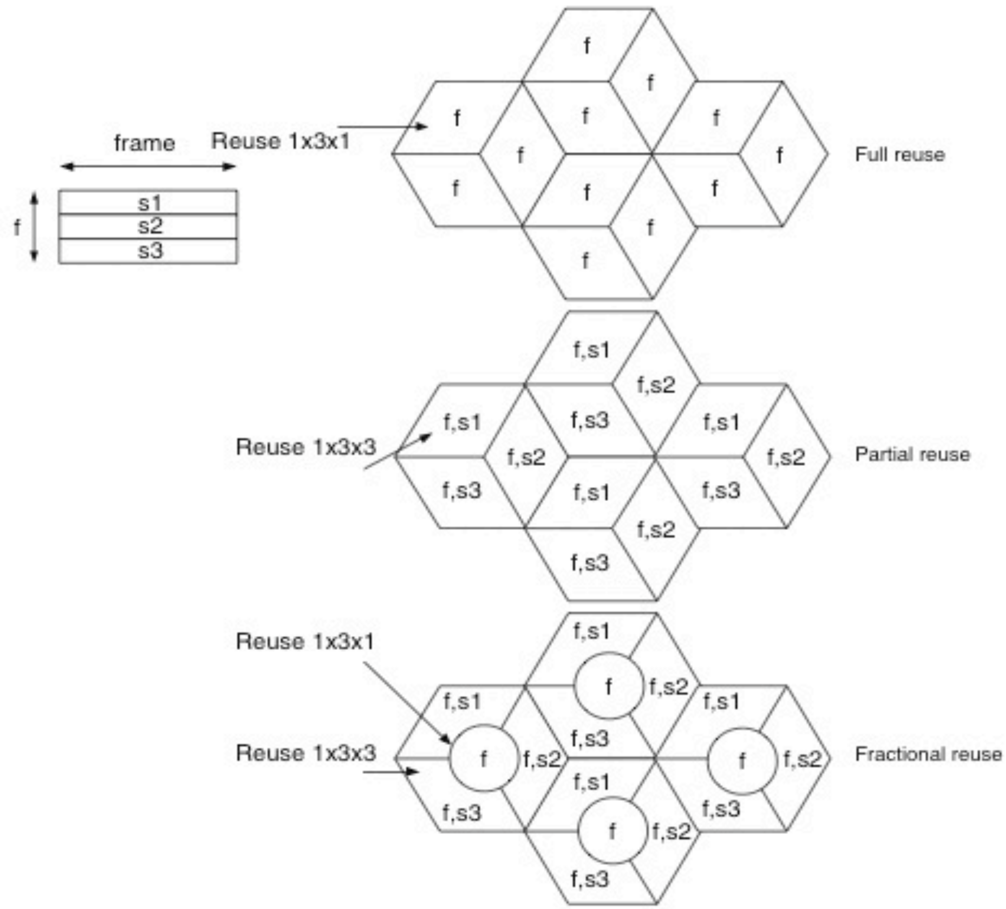


Fig. 8.14 Frequency reuse with segmentation: full reuse as in $1 \times 3 \times 1$ is not possible due to interference in the overlapping regions. Partial reuse as in $1 \times 3 \times 3$ can be increased further with fractional reuse

Multicast Broadcast Service

Multicast Broadcast Service is a broadcast service to support delivering media content. BSs participating in MBS transmit the same data at the same time and at the same location in a given frame. Stations receiving multiple transmission over the air combine them for better reception.

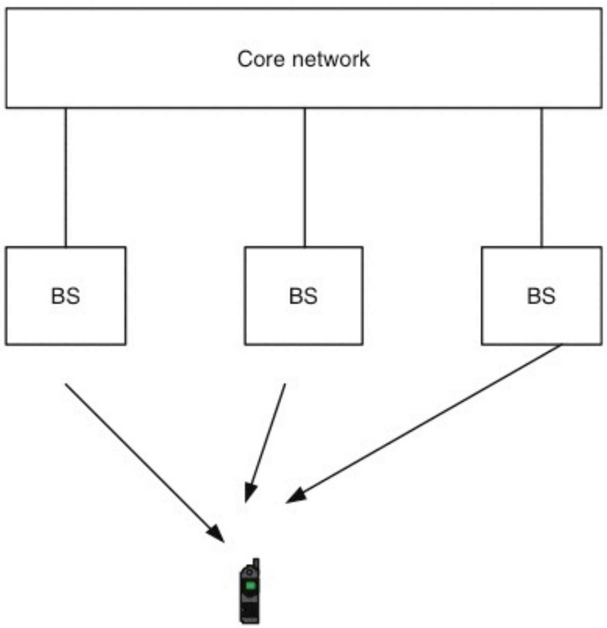


Fig. 8.16 Multicast broadcast service

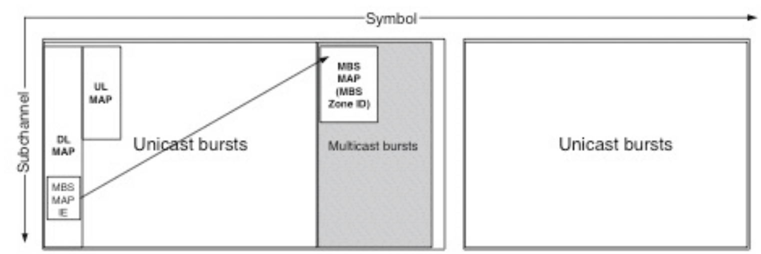


Fig. 8.17 MBS Frame Zone Layout

Control Mechanisms

- Ranging
- Power Control
- Channel Quality Measurements

Ranging

- Ranging is a collection of processes by which the MS and BS maintain the quality of the RF communication link between them. The process is based on MS transmitting a binary-coded signal and BS responding with required adjustments such as frequency, time, and power.

- Initial ranging allows an MS, joining the network, to acquire correct transmission parameters, such as time offset and transmitter power level, so that MS can communicate with the BS.

- Because of rapid changing channel, MS needs to periodically adjust uplink trans- mission. Therefore, MS performs periodic ranging to update time, frequency, and power. Also, MS may request a bandwidth from BS by performing bandwidth request ranging.

- Periodic ranging and automatic adjustment
  - Choose a random a ranging slot and a periodic ranging code (CDMA code)
  - If no response, choose a new CDMA and power level up

  to PTX_IR_MAX. BS broadcasts a ranging response <received CDMA Periodic ranging code, the ranging slot (OFDMA symbol number, subchannel)>

Power Control

- The BS provides accurate power measurements of the received burst signal to feed back to mobile station as a calibration message.
- Mobile station maintains the same power density where total transmitted power changes proportionally with the number of active subchannels assigned.
- Mobile subscriber also informs the base station about the maximum available power and normalized transmitted power to have base station select the optimum coding and modulation schemes.
- There are two types of power control: open-loop and closed-loop power control.

Power Control

- Open loop power control is the procedure where the mobile station (aka SS) adjusts its transmit power according to received signal level without explicit instruction by the BS.
- Open loop procedure is fast since it works without round-trip delay between the base station and the user terminals. The main disadvantage is the limited correlation between received power level on the uplink and downlink.
- Closed-loop power control defines a feedback mechanism for BS to measure the received signal and make adjustment procedures by sending to the mobile station to adjust output power. The delay between measurement and application is critical. Closed-loop power control utilizes periodic ranging and bandwidth request for adjustment.

Channel Quality Measurements

- There are two metrics for channel quality measurements: RSSI and CINR. MS re- ports the mean and the standard deviation of the RSSI and CINR in units of dBm.

WiMAX MAC Layer

- We introduce the medium access layer (MAC) where it defines access in two ways: point-to-multipoint (PMP) and mesh type of communication.
- PMP access is a one-hop wireless communication between a base station (BS) that has a direct connection to the network and plurality of mobile stations (MSs).
- Downlink transmission from BS to MSs is broadcast and uplink transmissions from MSs to BS are unicast.

WiMAX MAC Layer: IEEE 802.16

BS acts as the central point to facilitate downlink and uplink access for a particular mobile station. BS allocates burst regions within a frame for an MS to send or receive data.

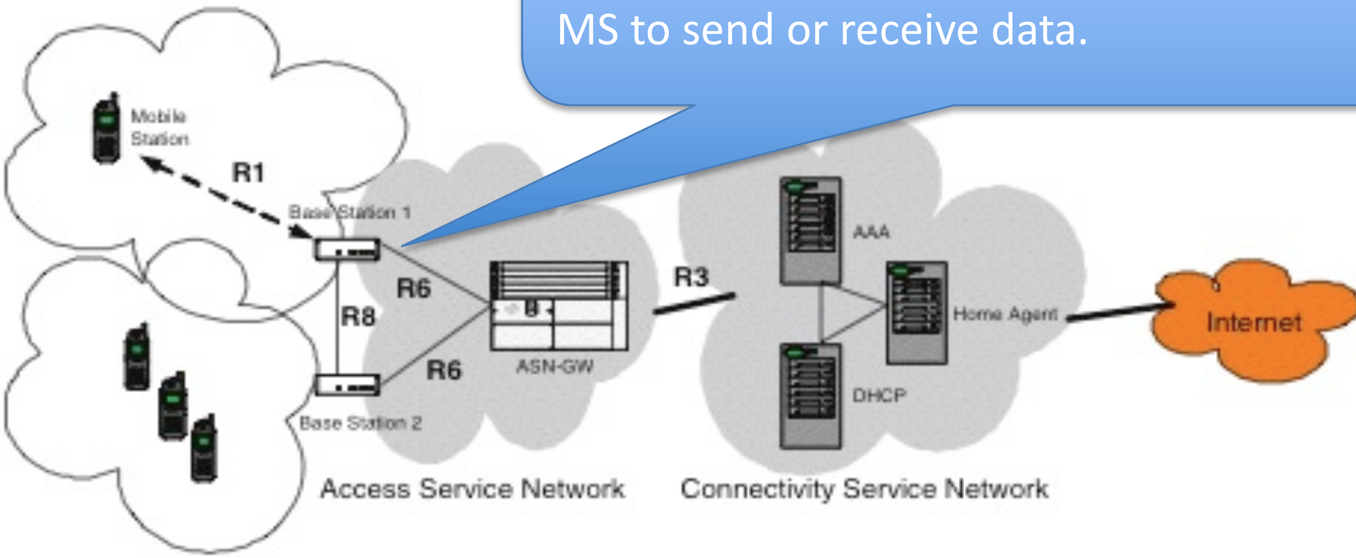


Fig. 9.1 WiMAX reference model: R1 is a reference point for WiMAX PHY; R6 is a reference point between BS and ASN Gateway; R8 is a reference point between BSs; R3 is a reference point between ASN Gateway and connectivity service network

MS knows these allocated regions by decoding the MAP portion of each frame where it can learn the burst region that is destined to it in the downlink, and to find out the dedicated region in the uplink for it to place a transmission.

MAC PDU Formats

PDU: Packet Data Unit

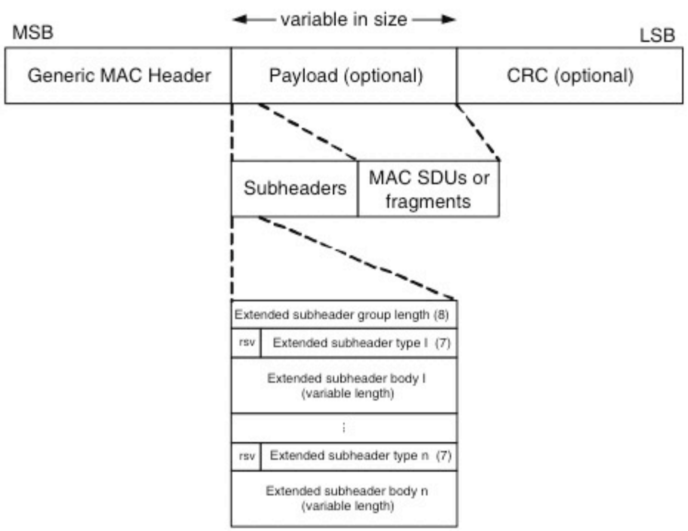
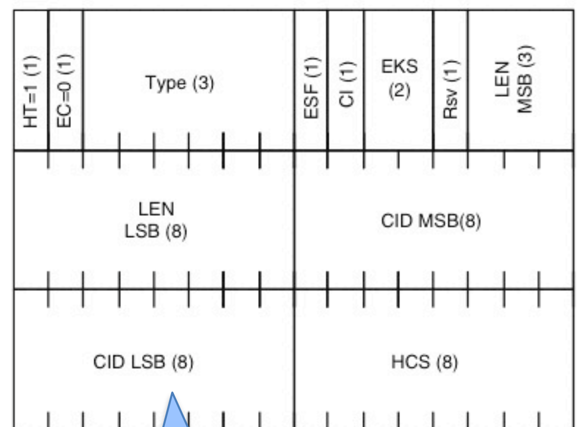


Fig. 9.3 MAC PDU formats: PDU and CRC are optional. After generic MAC header, there could be subheaders and after subheaders there could be MAC SDUs or fragments thereof. Subheader types are ordered, and extended subheader precedes the rest

Generic MAC Header



...eric MAC header format

Fig. 9.4 Generic MAC header ... header type (HT) and encryption control (EC) together determine the type field that ind... ...bheaders and special payload types. Extended subheader field (ESF) indicates the pres... ...ded subheader after the header. Extended subheaders are not encrypted. CI is CRC In... ...connection identifier; EKS is encryption key sequence, which is the index of the tra... ...(TEK) and initialization vector to be used to encrypt the payload. HCS is heade... ...d LEN is length in bytes of the MAC PDU

CID is to address a flow of subscriber.

MAC headers

Without payload

- Bandwidth request header
- Bandwidth request and UL Tx power report header
- Bandwidth request and CINR report header
- CQICH allocation request header
- PHY channel report header
- Bandwidth request and uplink sleep control header
- SN report header
- Feedback header
- MIMO channel feedback header

MAC Subheaders

- Fragmentation subheader
- Grant management subheader
- Packing subheader
- ARQ feedback subheader
- Mesh subheader
- Fast-feedback allocation subheader

MAC Management Messages

For cell or frame configuration

- UCD: Uplink channel descriptor is transmitted by the BS to inform the physical characteristic of the uplink channel. It informs if there is a change in the configuration or in the allocated regions for initial ranging and bandwidth request. [Fragmentable Broadcast]
- DCD: Downlink channel descriptor is transmitted by the BS at a periodic interval to define the characteristics of a downlink physical channel. DCD also contains downlink burst profile. [Fragmentable Broadcast]
- DL-MAP: Downlink MAP contains DL-MAP information elements (DL-MAP IEs), which basically address the portion of the frame for a particular downlink connection. [Broadcast]
- UL-MAP: Uplink MAP contains the uplink bandwidth allocations. UL-MAP message contains at least one IE that marks the end of the last allocated burst. [Broadcast]

MAC Management Messages

For network entry

- RNG-REQ/RSP: Ranging request and response are used at initialization and periodically to determine network delay and to request power and/or downlink burst profile change. [Initial Ranging or Basic]
- SBC-REQ/RSP: MS basic capabilities message is transmitted during initialization. MS sends its basic capabilities in request and BS responses with the sup- ported ones. [Basic]
- PKM-REQ/RSP: Privacy key management request and response are used at the authentication. There are several formats including authentication including PKMv2, RSA, etc. [Primary]
- REG-REQ/RSP: Registration request and response are used at the registration to exchange MAC address, IP version, CS and MS capabilities, etc. [Primary]
- TFTP-CPLT/RSP: MS receives the configuration file from the provisioning server. [Primary]

MAC Management Messages

To establish, maintain, and terminate flows.

- DSA-REQ/RSP/ACK: Dynamic service addition is used to create new service flows. It can be initiated by network as well as MS. Service flow parameters are set and Service flow ID (SFID) is assigned with CID if the connection is active by network. [Primary]
- DSC-REQ/RSP/ACK: Dynamic service change is used by an MS or BS to dy-namically change the parameters of an existing service flow. [Primary]
- DSD-REQ/RSP: Dynamic service deletion is used by an MS or BS to delete an existing service flow. [Primary]
- MCA-REQ/RSP: Multicast polling assignment messages are used to assign or remove an MS from a multicast polling group. [Primary] •
- DBPC-REQ/RSP: Downlink burst profile change messages are initiated by MS to request a change of the downlink burst profile used by the BS to transport data to the MS. [Basic]
- DSX-RVD: DSx received message is sent by BS to MS to indicate that DSx-REQ sent by MS has been received in a more timely manner than provided by the DSx-RSP message. [Primary]

MAC Management Messages

For handover, paging and idle mode.

- MOB SLP-REQ/RSP: MS sends Mobile Sleep Request message to de/activate certain Power Saving Class. Response sent by BS may contain the definition of Power Saving Class or Power Saving Class ID unique to a MS. [Basic]
- MOB TRF-IND: Traffic Indication Message is sent from BS to MS to indicate whether there has been traffic addressed to each MS that is in sleep mode. An MS that is in sleep mode, during its listening-window decodes this message to find out an indication addressed to itself. [Broadcast]
- MOB NBR ADV: Neighbor Advertisement Message is transmitted periodically by BS to identify the network and define the characteristics of neighbor BS to potential MS seeking initial network entry or handover. [Broadcast, Primary]
- MOB SCN-REQ/RSP: Scanning Interval Allocation Request may be transmitted by an MS to request a scanning interval for the purpose of seeking available BSs and determining their suitability as targets for HO. In response to request, BS transmits a response to initiate scan reporting. [Basic]

MAC Management Messages

For handover, paging and idle mode.

- MOB BSHO-REQ/RSP: BS HO Request message is sent by BS to initiate HO. BS HO Response is sent upon receiving MOB MSHO-REQ. [Basic] •
- MOB MSHO-REQ: MS HO Request message is transmitted by MS to initiate HO. [Basic]
- MOB HO-IND: HO Indication is sent by MS to indicate the final decision that it is about to perform an HO. MS may cancel or reject as well. [Basic]
- MOB SCN-REP: Scanning report is to report the scanning results to its serv- ing BS after each scanning period at the time indicated in the MOB SCN-RSP message. [Primary]
- MOB PAG-ADV: BS Broadcast Paging message is sent with Broadcast CID dur- ing the BS Paging Interval. [Broadcast]
- MBS MAP: BS may send a Multicast Broadcast Service message to describe the Multicast Broadcast Connections. MBS MAP contains MBS MAP IEs. [–]
- PMC REQ/RSP: Power control Mode Change request and response messages are to change the power control mode between the open-loop power control and closed-loop power control. [Basic]
- MOB ASC-REP: Association Result Report is used for association level 2 in which scanning report is gathered in the backbone and sent back to MS from its servicing BS. [Primary]

Transmission Scheduling

Downlink

- **UGS:** Unsolicited Grant Service is for real-time data streams with fixed-size data packets issued at periodic intervals
- **RT-VR:** Real-Time Variable Rate service is to support real-time data applica- tions with variable bit rates.
- **NRT-VR:** Nonreal-Time Variable Rate Service supports applications that require a guaranteed data rate but not sensitive delay requirements. [DL]
- **BE:** Best Effort is for data streams with no requirement on minimum ser- vice level.
- **ERT-VR:** Extended Real-Time Variable Rate Service is for applications that re- quire guaranteed data and delay such as VoIP with silence suppression.

Uplink

- **UGS**
- **rtPS:** Real-time Polling Service is for real-time data streams with variable- sized data packets that are issued at periodic intervals (MPEG video, etc.).
- **nrtPS:** Nonreal-Time Polling Service is for delay-tolerant data streams con- sisting of variable-sized data packets for which a minimum data rate is required (FTP, etc.).
- **ertPS:** Extended Real-Time Polling Service is a hybrid scheme based on UGS and rtPS.
- **BE**

Bandwidth Requests

- MSs use to indicate to the BS that they need uplink bandwidth allocation.
- Requests are in terms of number of bytes needed to carry the MAC header and payload but not the PHY overhead.
- Requests may be incremental or aggregate.

Grants

- Bandwidth grant is addressed to the MS's Basic CID, not to individual CIDs.

Polling

- Polling is bandwidth allocation for the purpose of making bandwidth requests.
- Polling is done MS basis, Bandwidth is always requested on a CID basis and bandwidth is allocated on an MS basis.
- Unicast

QoS: Service Flow

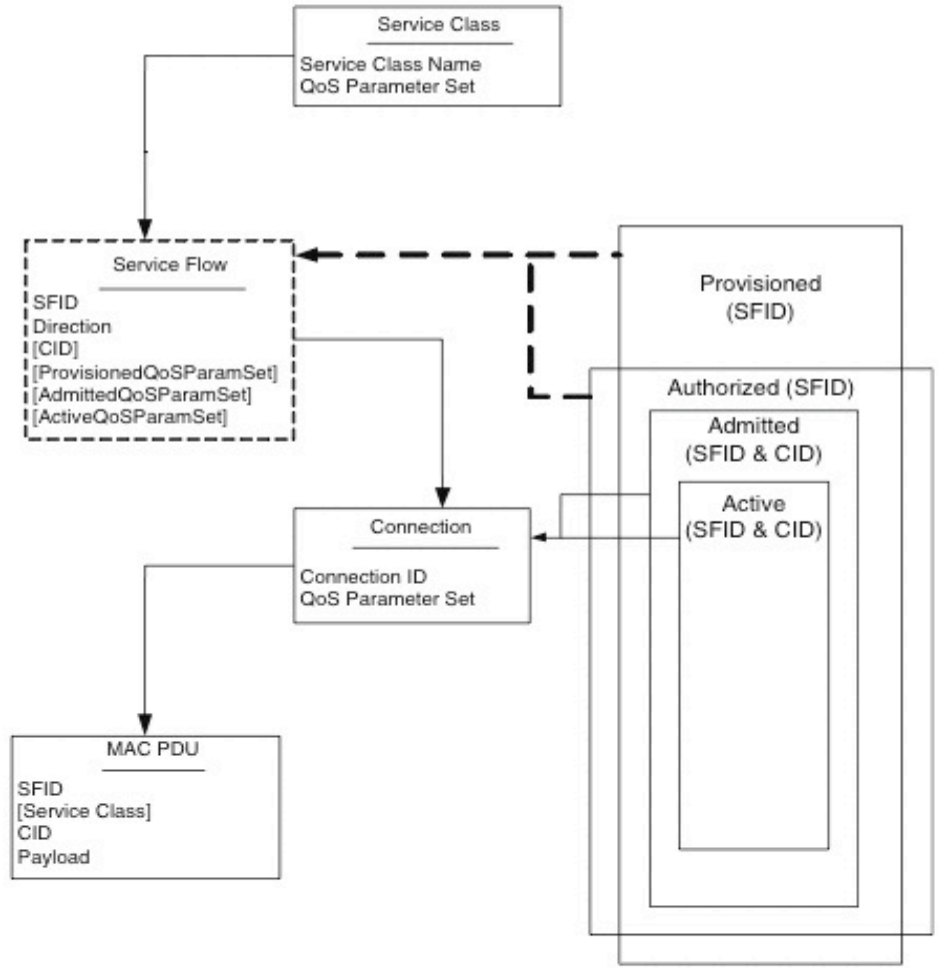


Fig. 9.10 Theory of operation and parameter sets

Network entry and Initilization

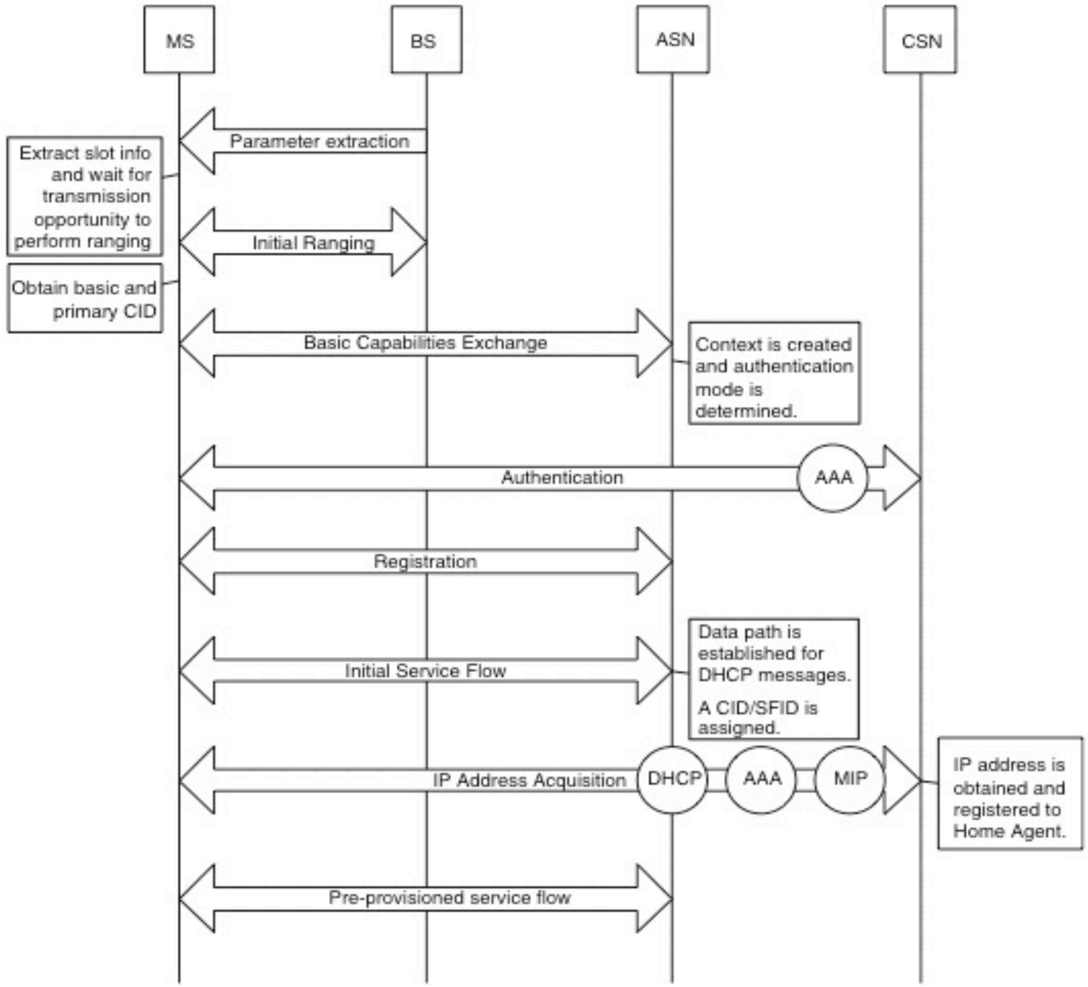


Fig. 9.9 Network entry diagram

Sleep Mode

- Sleep Mode is a state in which an MS conducts pre-negotiated periods of absence from the Serving BS air interface
- This mode is intended to minimize power and air interface resources
- BS can't send any DL traffic during this interval
- Sleep Mode support is optional for MS and mandatory for BS
- There are three types of Power Saving Classes, which differ by their parameter sets, procedures of activation/ deactivation and policies of MS availability for data transmission.
- Unavailability interval is a time interval that does not overlap with any listening window of any active Power Saving Class
- Availability interval is a time interval that does not overlap with any Unavailability interval

Sleep Mode (contd…)

- During Unavailability interval the BS shall not transmit to the MS, so the MS may power down one or more physical operation components or perform another activities that do not require communication with the BS: scanning neighbor BSs, associating with neighbor BSs etc.

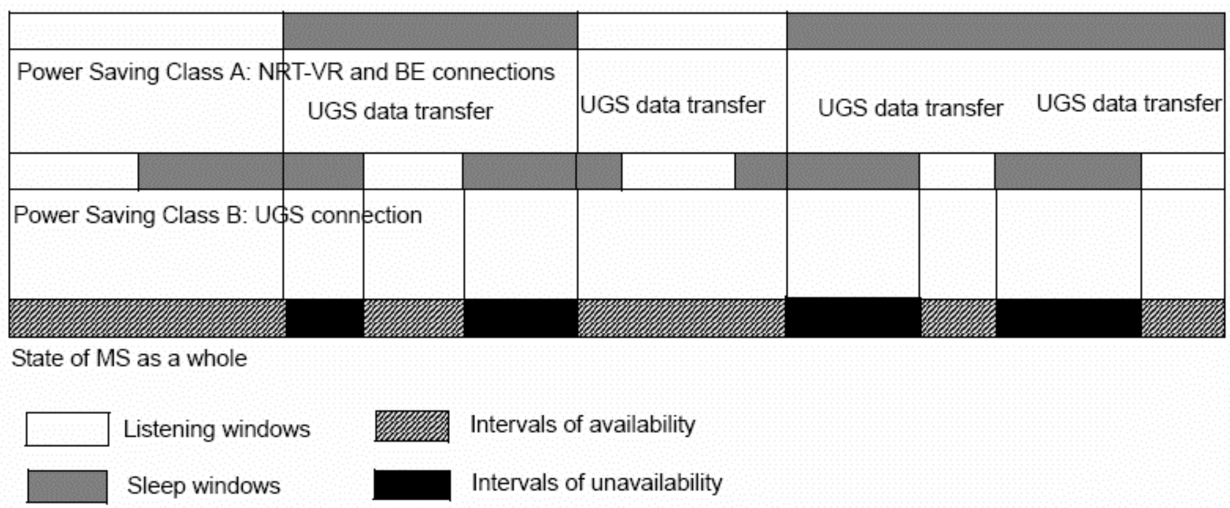


Figure 130a—Example of sleep mode operations with two power saving classes

Sleep Mode

- Sleep mode is a state in which MS conducts pre-negotiated periods of absence from the serving BS air interface.
- Minimize power usage of MS
- Decrease usage of Serving BS air interface resources.
- Implementation is optional for MS but
- Mandatory for the BS

Power Saving Class

- Availability vs Unavailability

Unavailability

No communication between MS and BS.

But perform:

Scanning neighbor BSs

Associating with Neighboring BSs

If there is a connection that is not associated with PSC then it is considered available on permanent basis

Availability

Ms receive all DL transmissions

Verify synchronization

- Algorithm of choosing Power Saving Class type for certain connections is outside of the scope of the standard.

An example

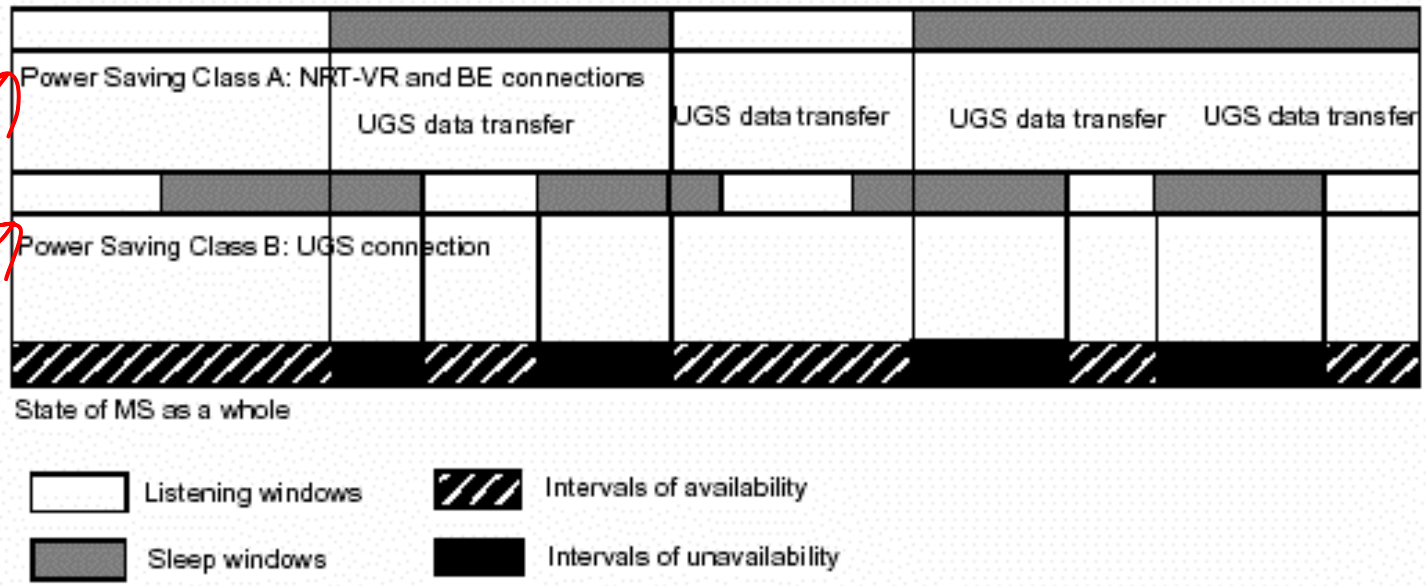


Figure 130a Example of sleep mode operations with two power saving classes

Type 1: double the sleep interval in every iteration
Type 2: fixed sleep interval
Type 3: one time sleep interval

Listening interval is fixed.

Power Saving Class of type I

- For BE and NRT-VR

$$Sleepwindow = min(2.prevSleepWin, finalSleepWinBase.2^{finalSlpWinExp}) \quad (1)$$

where

- sleepWin is sleep window
- prevSleepWin is the previous sleep window,
- finalSleepWinBase is the Final-sleep window base, and
- finalSlpWinExp is the Final-sleep window exponent

Power Saving Classes of type II

- UGS, RT-VR
  - Initial sleep window
    - MS shall not receive or transmit MAC SDU
  - Listening window
    - MS may send or receive any MAC SDU's or their fragments
  - Start frame number for first sleep window
    - Sleep windows are of the same size as initial window.
    - Sleep windows are interleaved with listening

Power Saving Classes of type III

- For multicast connections and management operations: periodic ranging, DSX operations, etc.
- Final-sleep window base
- Final-sleep window exponent
- Start-Frame number for sleep window
- After sleep window expires, PSC becomes inactive
  - For example, PSC III for the duration before periodic ranging.

Periodic Ranging in Sleep Mode

- During listening window, BS may allocate an UL transmission opportunity for periodic ranging.

Handover

- The handover decision algorithm is beyond the scope of the standard.

  - Network topology advertisement
    - BS can inform the channels of neighboring BSs
  - Scanning
    - BS can allocate time for scanning to MS
    - MS can request multiple scanning interleaved intervals

Association

- Occurs during the scanning interval
  - Records ranging parameters, service availability
- MS may associate multiple times
- BS may direct the MS to associate with recommended BSs
- Association Level 0:
  - Scan/ association without coordination
    - Serving BS allocates periodic intervals where the MS may range neighboring BSs
    - Target BS has no knowledge of ranging and provides contention-based ranging allocations.
- Association Level 1:
  - Association with coordination
    - Serving BS provides association parameters to the MS and coordinates association between

Association

- Association Level 2:
  - Network assisted association reporting
    - MS is required only to transmit the CDMA ranging code at the neighbor BS.
    - Response will be sent to the serving BS over the backbone.
    - Serving BS may aggregate into MOB_ASC_REPORT

HO Process

- MS migrates from one BS to another BS.
  - Cell reselection:
  - HO Decision and Initiation: Handover begins with a decision:
    - Decision may originate either at the MS, or the serving BS
  - Synchronization to Target BS downlink
    - If the target BS receives info from the serving BS over backbone then reserves a non-contention based Initial Ranging opportunities.
  - Ranging (Initial ranging or Handover ranging)
  - Termination of MS Context: Final step in

HO and initial network entry

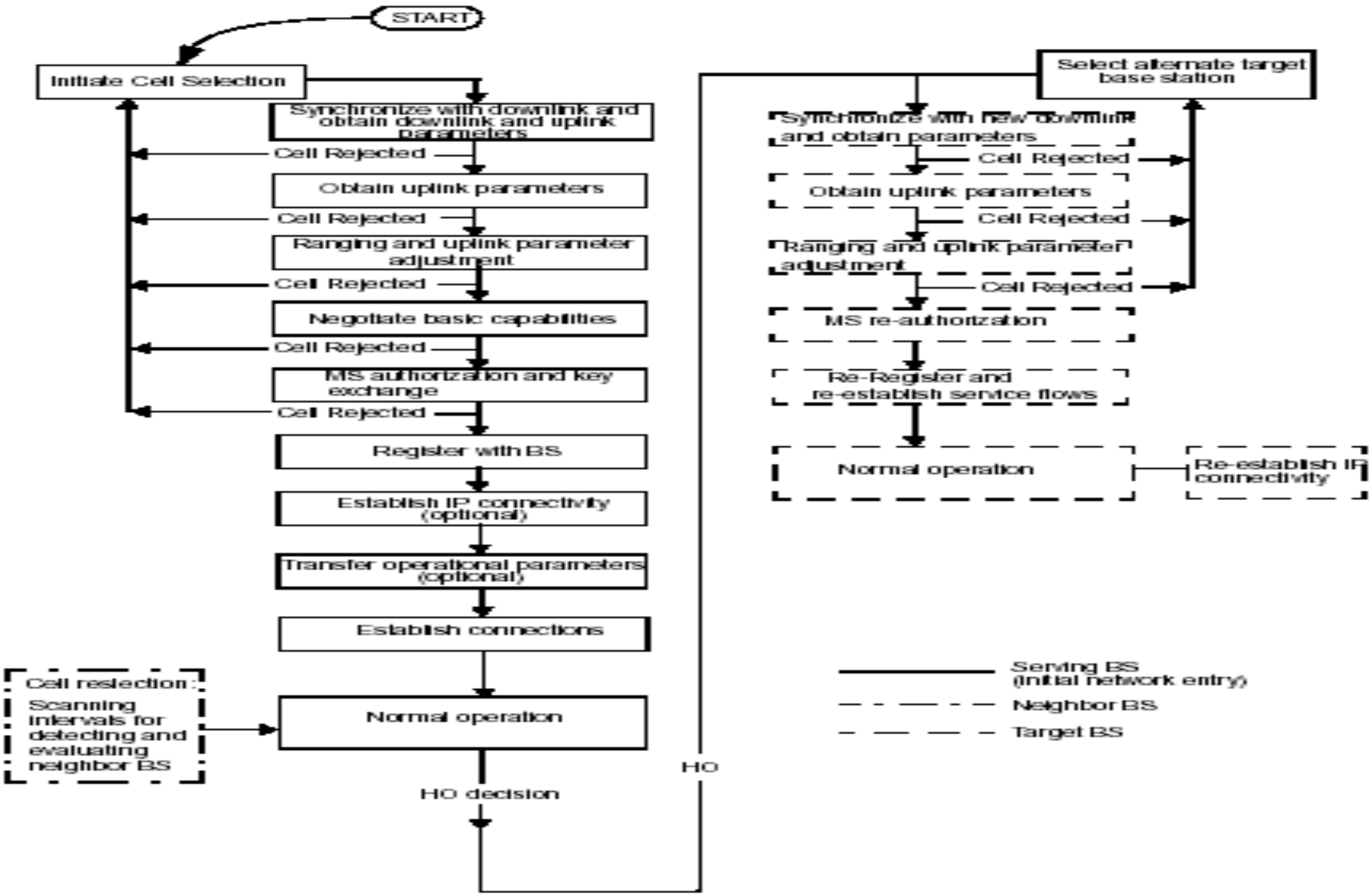


Figure 130b HO and initial network entry

HO decision and initiation

- Decision may originate either at the MS, the serving BS, or on the network.
- More than one target can be indicated in MS or BS initiated handover
- Serving BS recommends Target BS according to MS performance at potential Target BS and MS QoS requirements.
  - This information can be learned through the backbone messaging.
  - Negotiate with initial ranging transmission opportunity
- In network assisted handover, MS perform handover without notifying the serving BS
- In some instances, the BS may need to force the MS to conduct handover.
- MS may attempt to handover to a different BS than required.
- BS can talk to other BSs to expedite HO

HO Cancellation

- MS may cancel HO anytime
- They resume Normal Operation communication
- Use of Scanning and association results
- Termination with serving BS
- At some stage MS terminates service with the serving BS.

Drops during HO

- Stop communicating before HO after termination with serving BS.
- Failure:
  - Failure to demodulate downlink
  - Exceeding the RNG-REQ retries limit allowed for periodic ranging

Handover

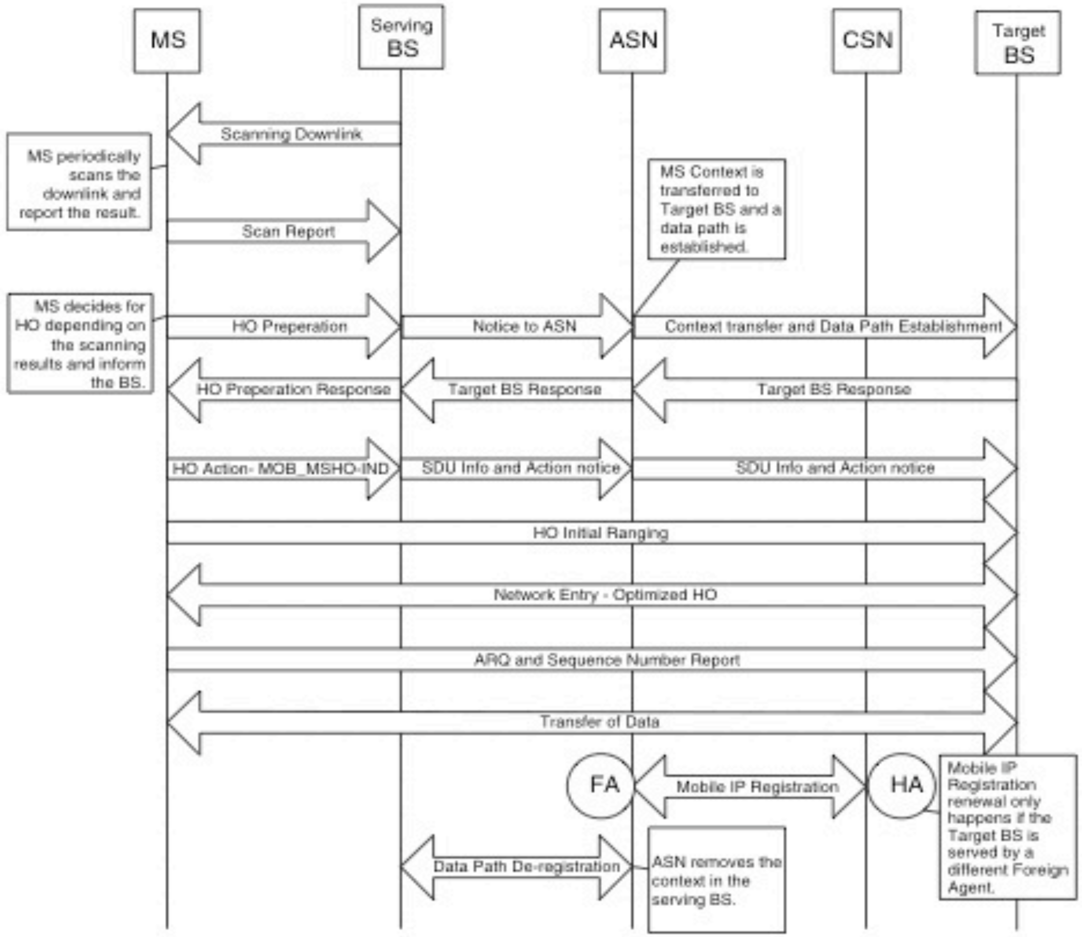


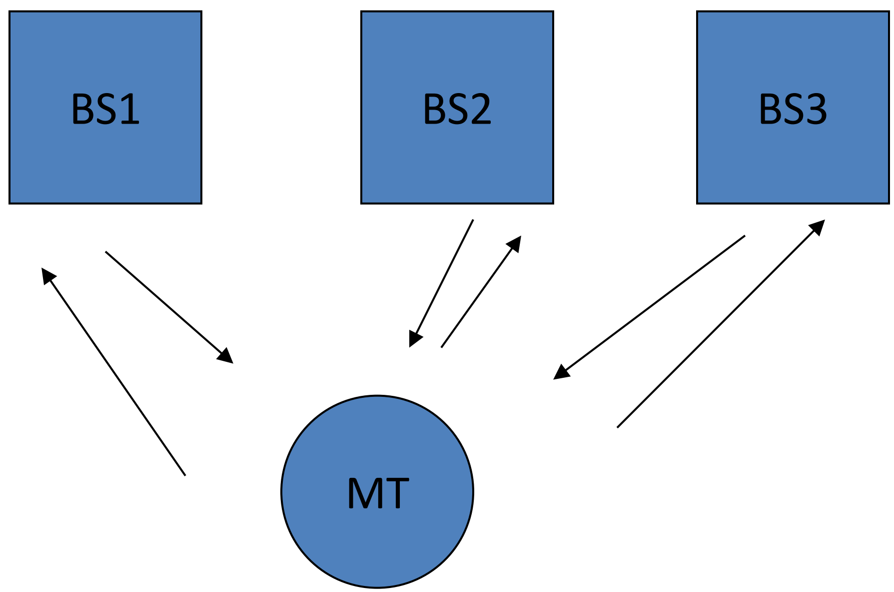
Fig. 9.12 Handover flow chart for mobile-initiated handover where handover controller resides in base station

Macro Diversity HandOver and Fast BS Switching

- MDHO Decision: MS transmit and receive from multiple BSs at the same time
- FBSS HO Decision: MS receive/transmit from/to the Anchor BS that may change within the Diversity Set.
  - Anchor BS is selected according to the signal strength among diversity set.

MDHO decision and initiation

- The list of BSs that are involved in MDHO
- When operating in MDHO, the MS communicates with all BSs in the Diversity Set for UL and DL unicast messages and traffic



Synchronized: time/frame/frequency/ CIDs

FBSS decision and initiation

- MS only communicates with the Anchor BS for UL and DL messages
- Transition from one Anchor BS to another is performed without invocation of HO procedure.

- Diversity Set update for MDHO/FBSS
  - Update the list according to signal strength measurement/propagation delay measurement/scanning/ranging/association activity.
  - Recommended BS can be based on QoS performance of MS.
  - New BS is added with ranging.
- Anchor BS update for MDHO/FBSS
  - Through HO messages or Fast Anchor BS

FBSS

MS shall transmit fast Anchor BS selection information to the current Anchor BS using Fast-feedback channel.

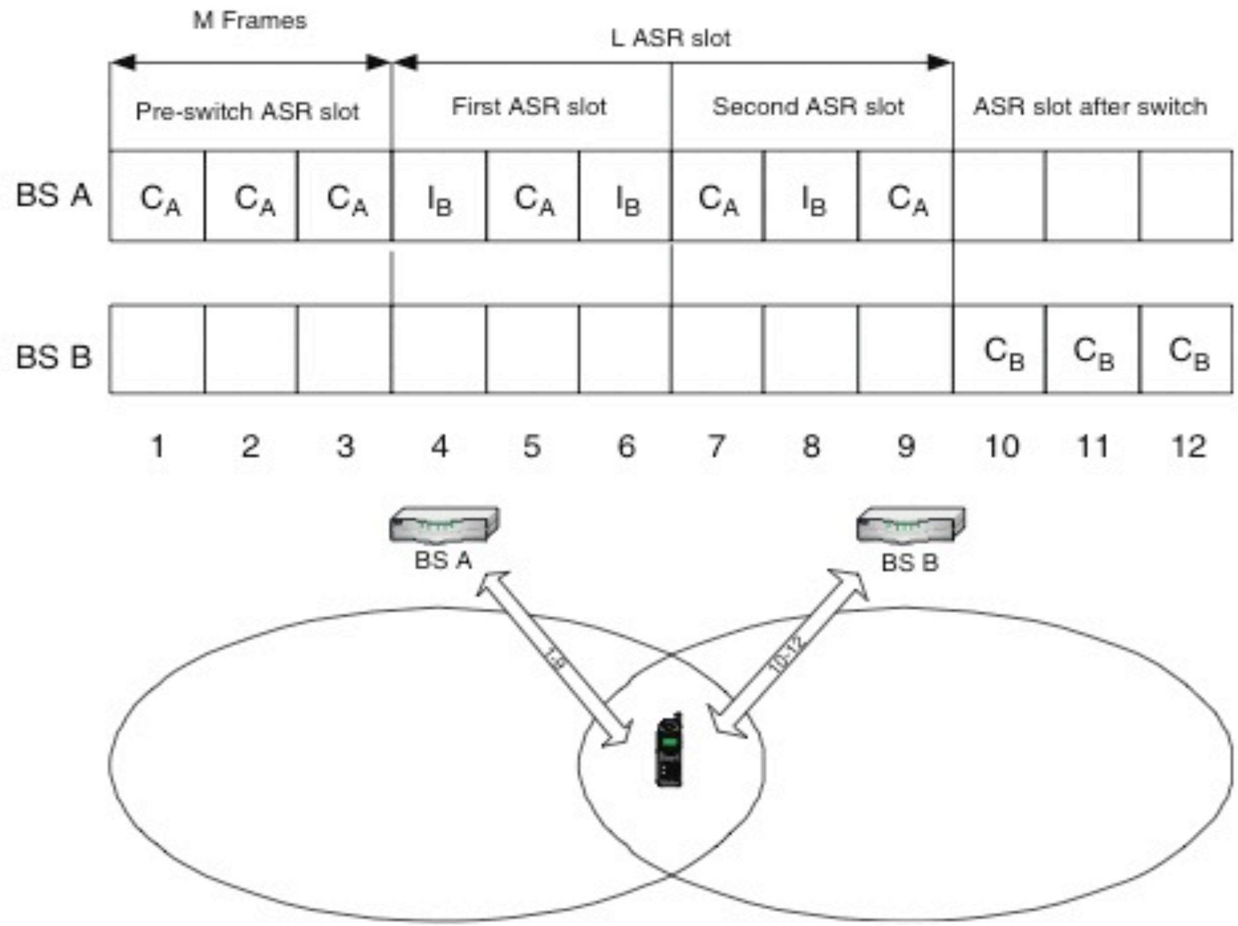


Fig. 9.13 An example of fast base station switching

WiMAX Network Layer

- Network Access Provider (NAP) owns the network and operations. – Network Service Provider (NSP) owns the subscriber and provides service. NSPs share the NAP or a NSP uses multiple NAPs. – Application Service Provider (ASP) provides application services.

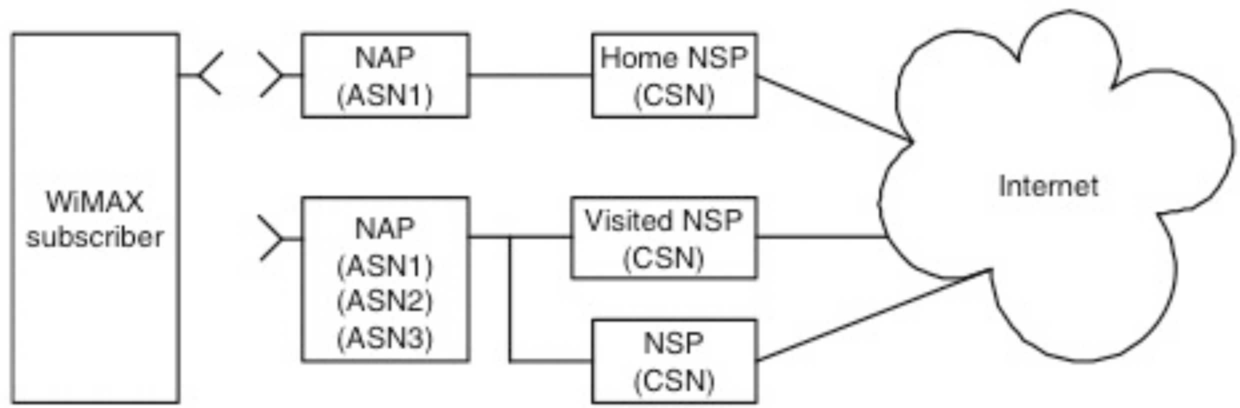


Fig. 10.2 Business relationship between WiMAX subscriber, NAP, and NSPs

WiMAX Network Reference Model

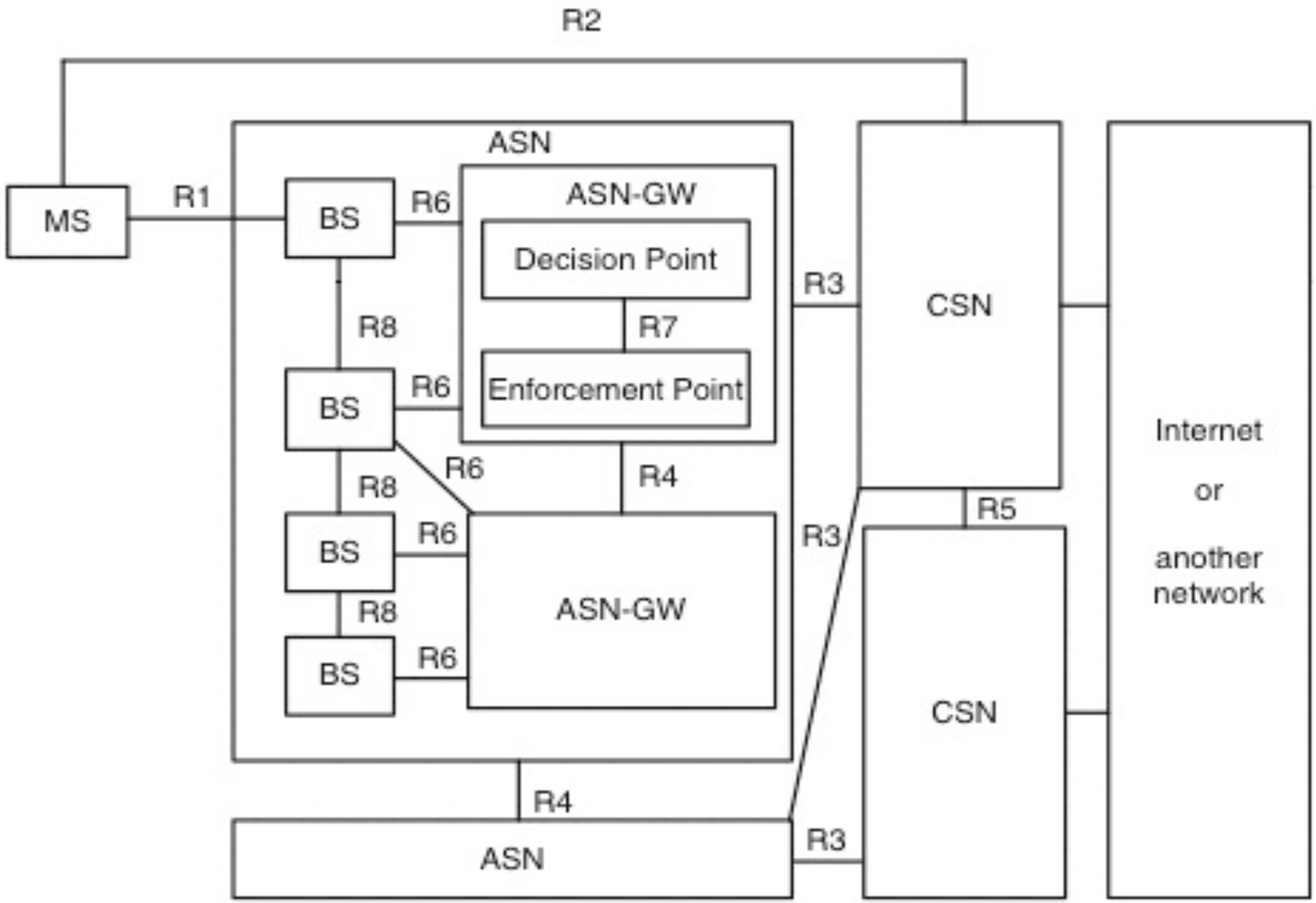


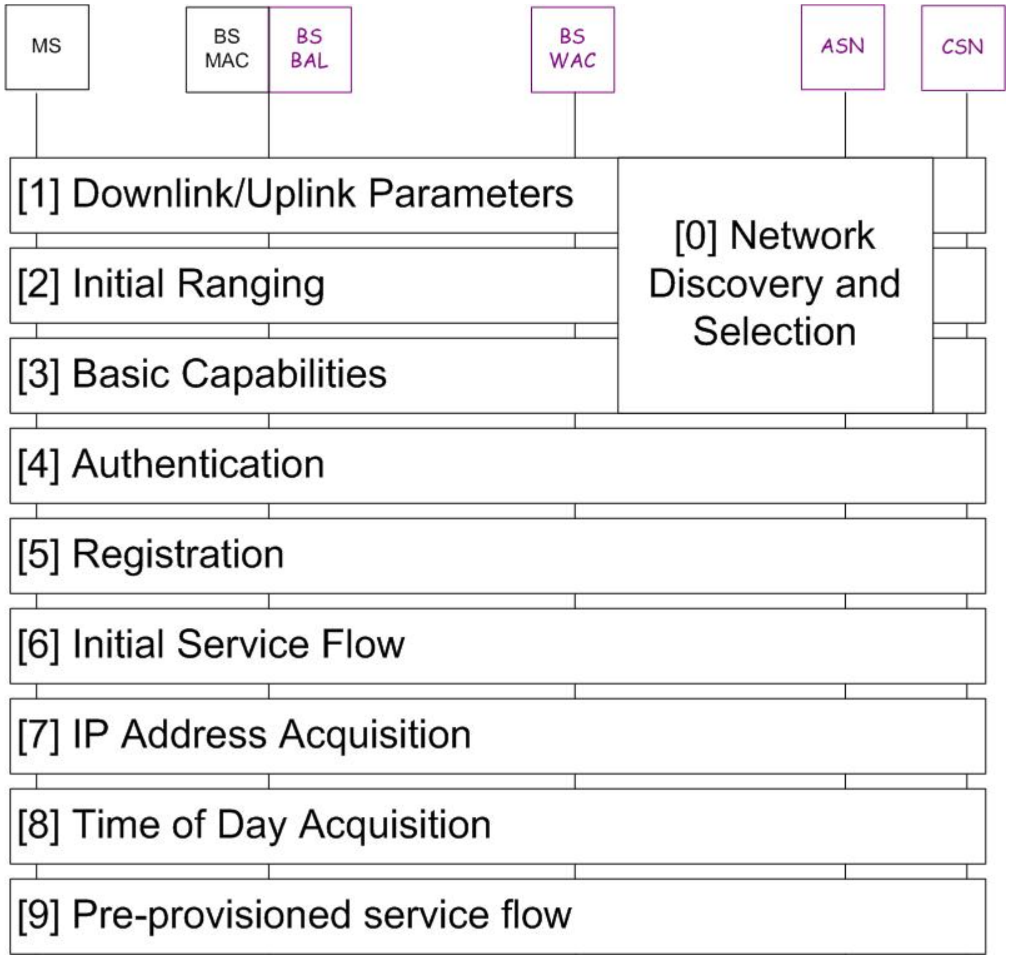
Fig. 10.1 Network reference model (© WiMAX Forum 2005–2007)

Network entry and initialization

- Initialization of MS
  - Scan for downlink channel and establish synchronization with the BS
  - Obtain transmit parameters
  - Perform ranging
  - Negotiate basic capabilities
  - Authorize SS and perform key exchange
  - Perform registration
  - Establish IP connectivity
  - Establish time of day
  - Transfer operational parameters

Optional

Initial Network Entry



Scanning and synchronization to the downlink

- SS shall acquire a downlink channel
- Try first the previous if not, look for new downlink frequency
- Once achieved synchronization, PHY indication

Obtain downlink parameters

- SS achieves MAC synchronization once it has received at least one DL-MAP message.

- SS maintains synchronization as long as it receives DL-MAP before DL-MAP Interval or

DCD before T1

Obtain uplink parameters

- After synchronization, the SS shall wait for a UCD message from the BS in order to retrieve a set of transmission parameters for a possible uplink channel.
- Extract UCD if channel is suitable otherwise search for new
- SS MAC is considered to have a valid uplink parameters as long as it continues to successfully receive the UL-MAP and UCD messages.

Initial ranging

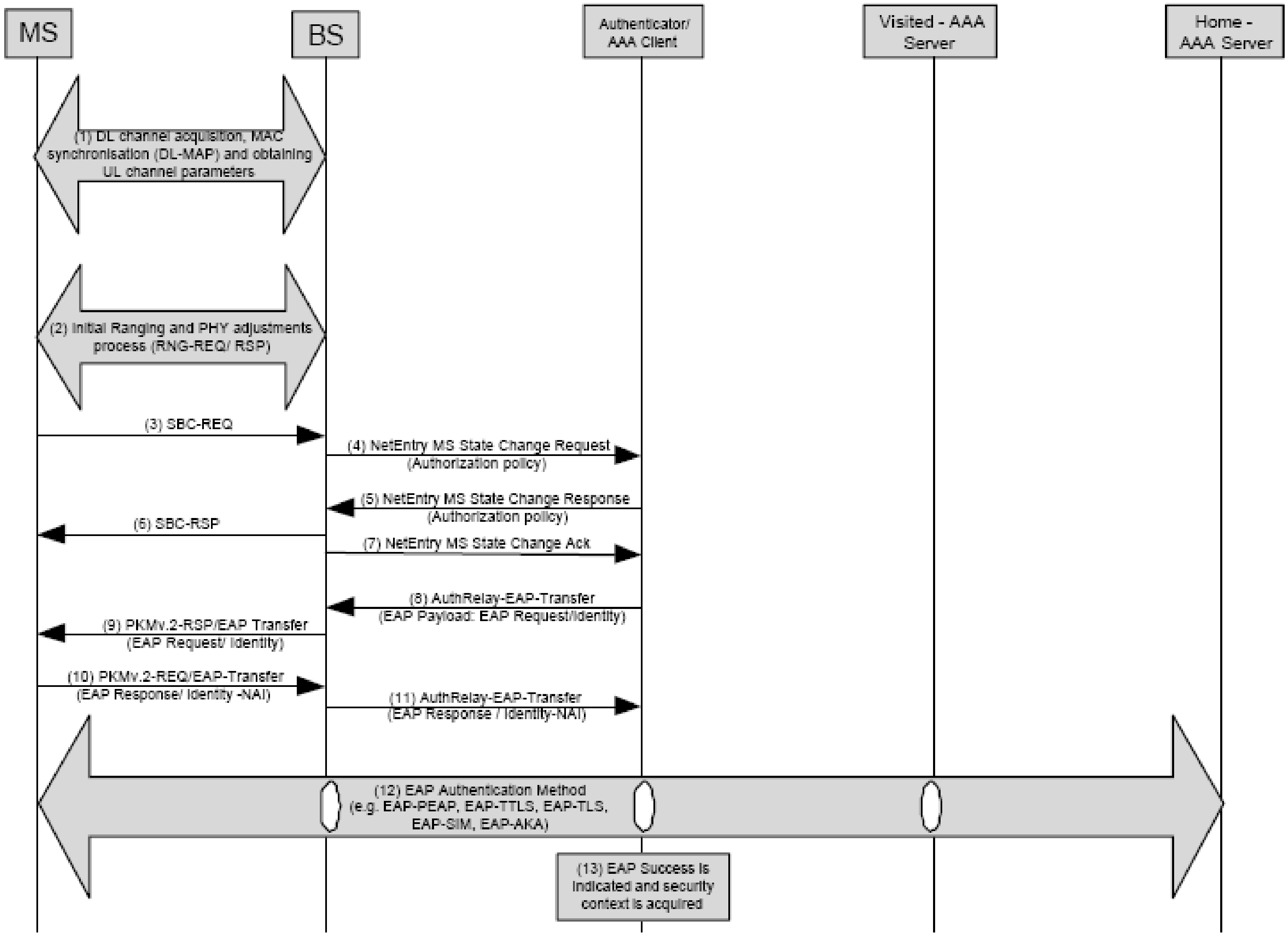
- SS shall scan the UL-MAP to find an initial ranging interval.
- For OFDMA PHY, the initial ranging process shall begin by sending initial-ranging CDMA codes on the UL allocation dedicated for that purpose.
- Ranging adjusts each SS's timing offset such that it appears to be co-located with the BS.

Obtained from DCD

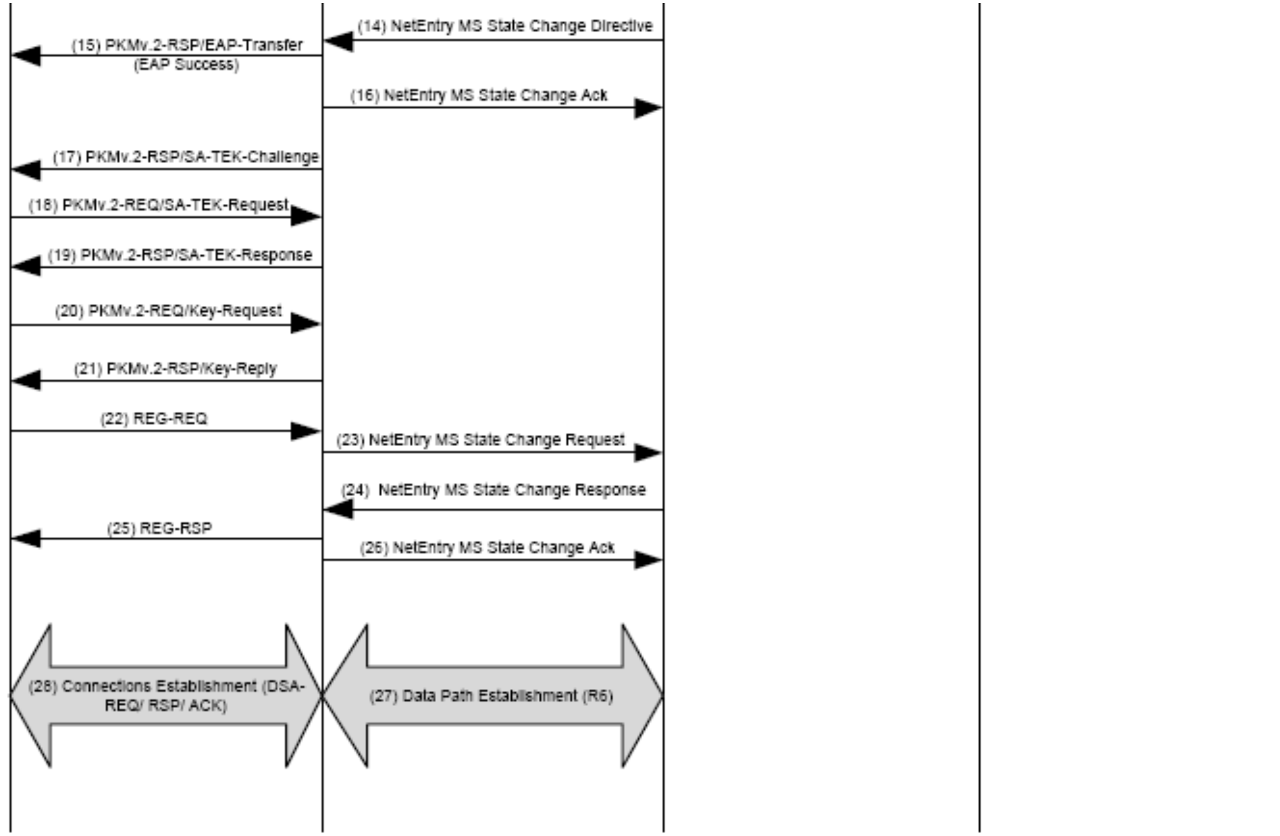
- $P_{TX_{I}R_{M}AX}=EIRxP_{IR,max}+BS_{E}IRP-RSS$

measured RSSI

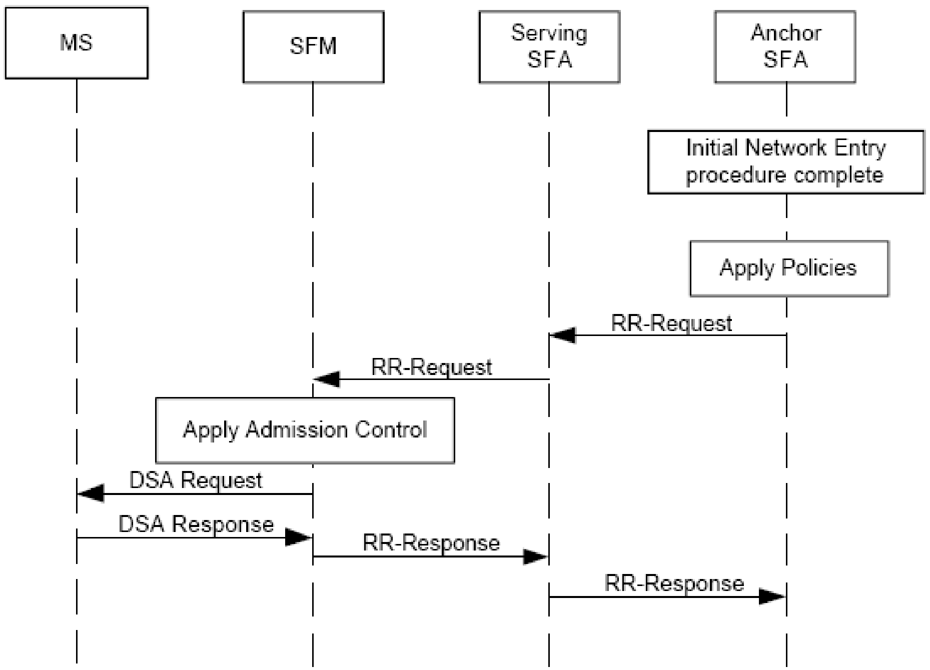
Initial Network Entry (1)



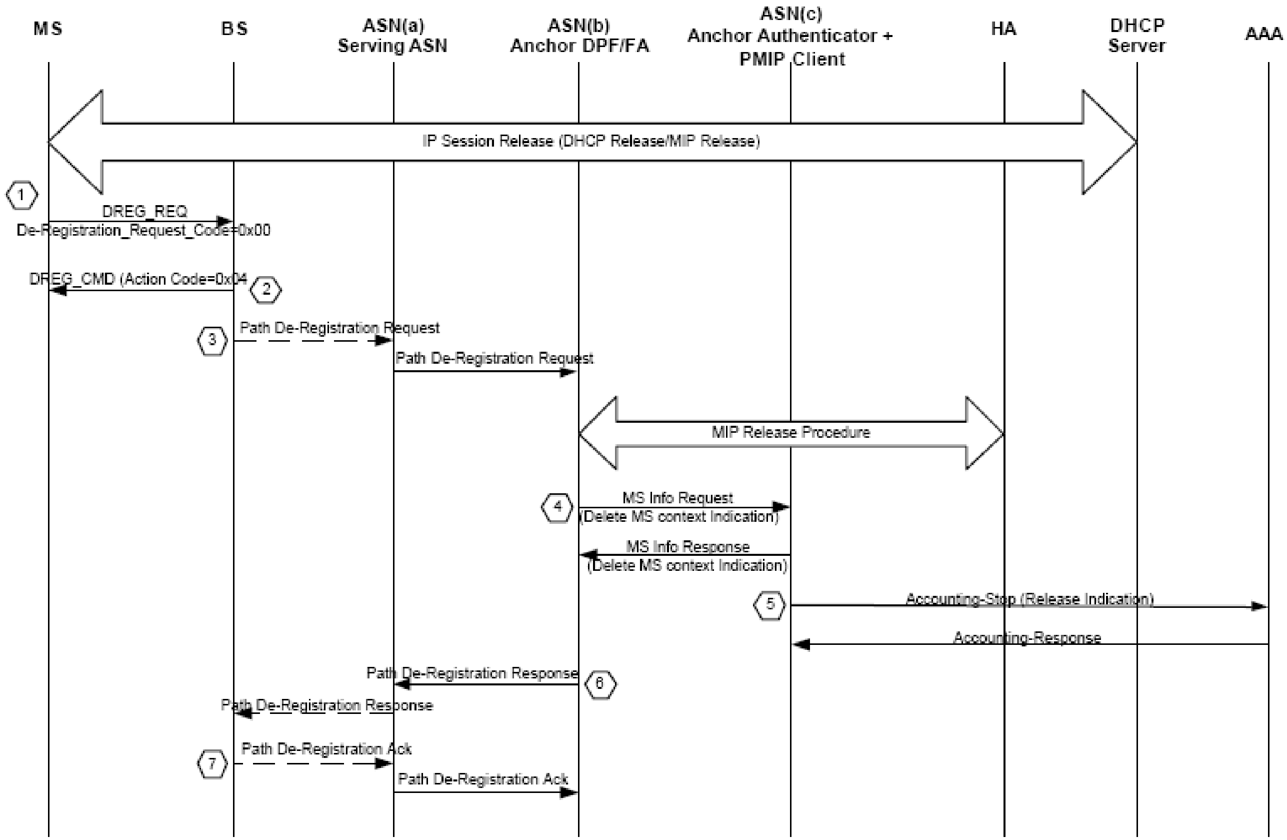
Initial Network Entry (2)



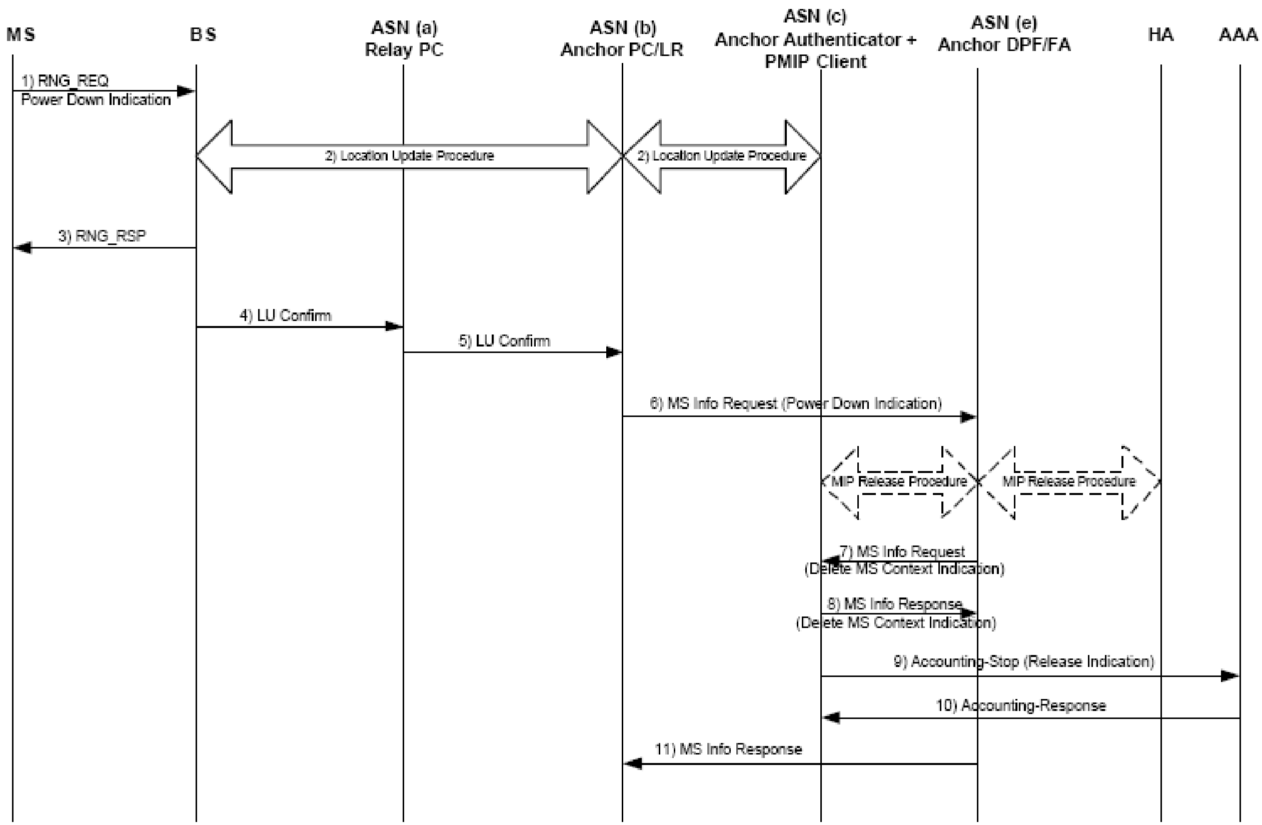
Service Flow Setup



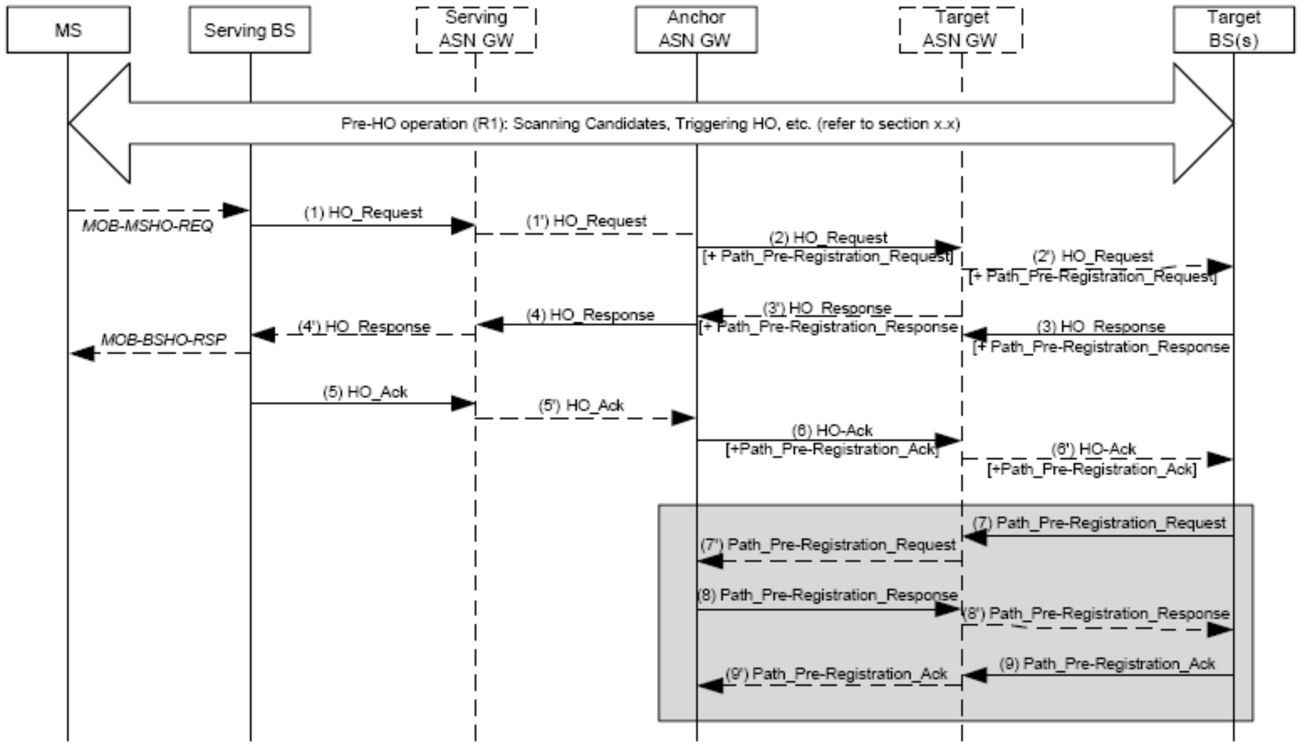
Network Exit



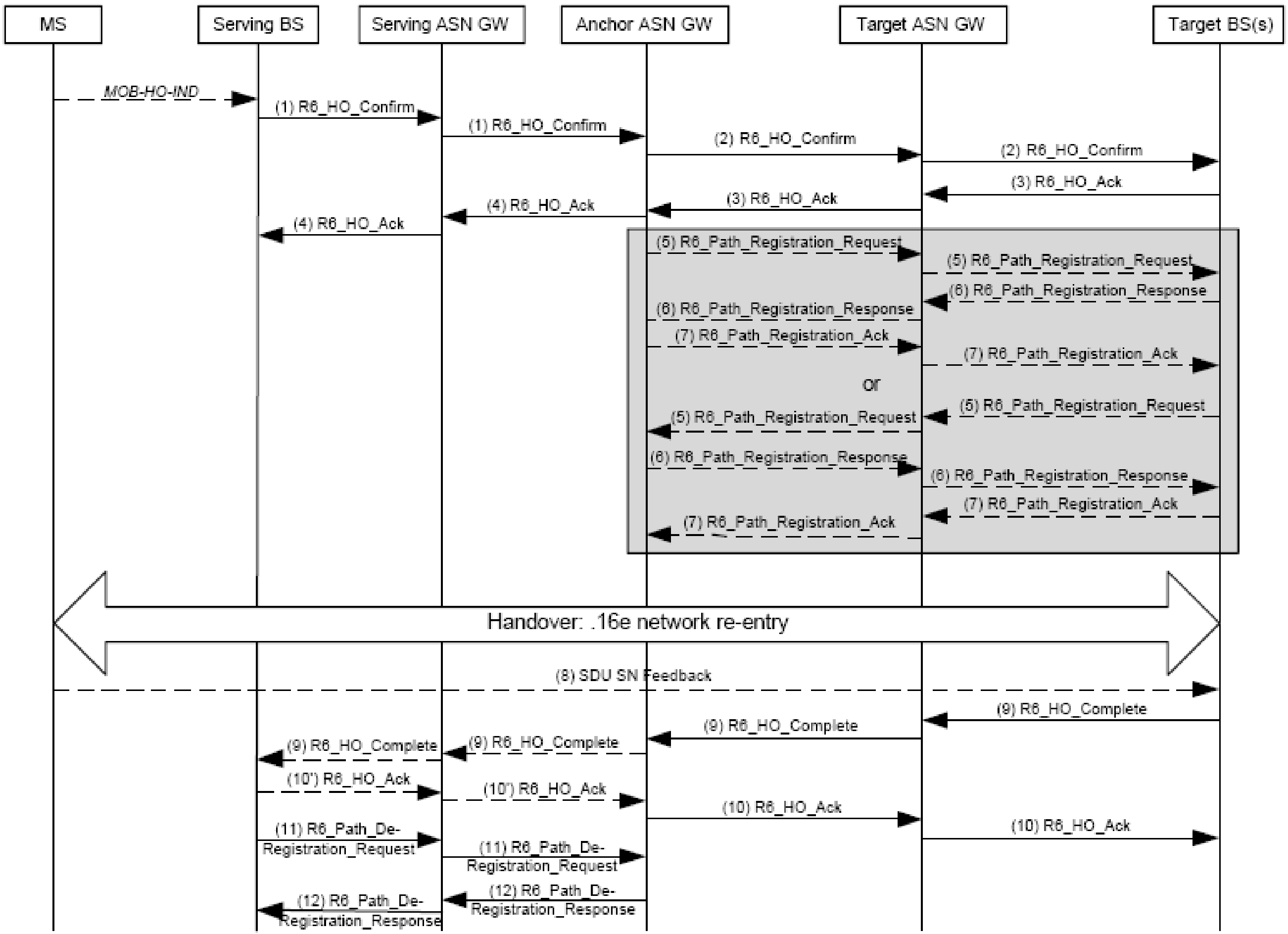
Network Exit (Idle Mode)



HO Preparation Profile A

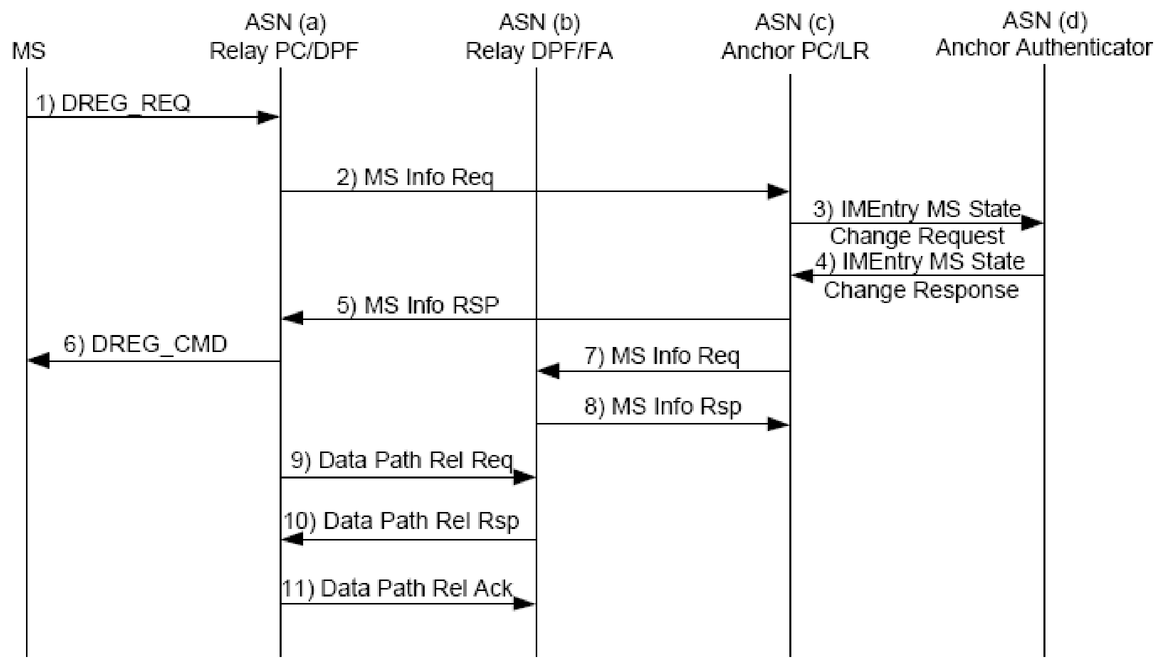


HO Execution



* Path setup transactions can be done in parallel with .16e network re-entry procedure.

Idle Mode Entry



Convergence Layer: IP-CS

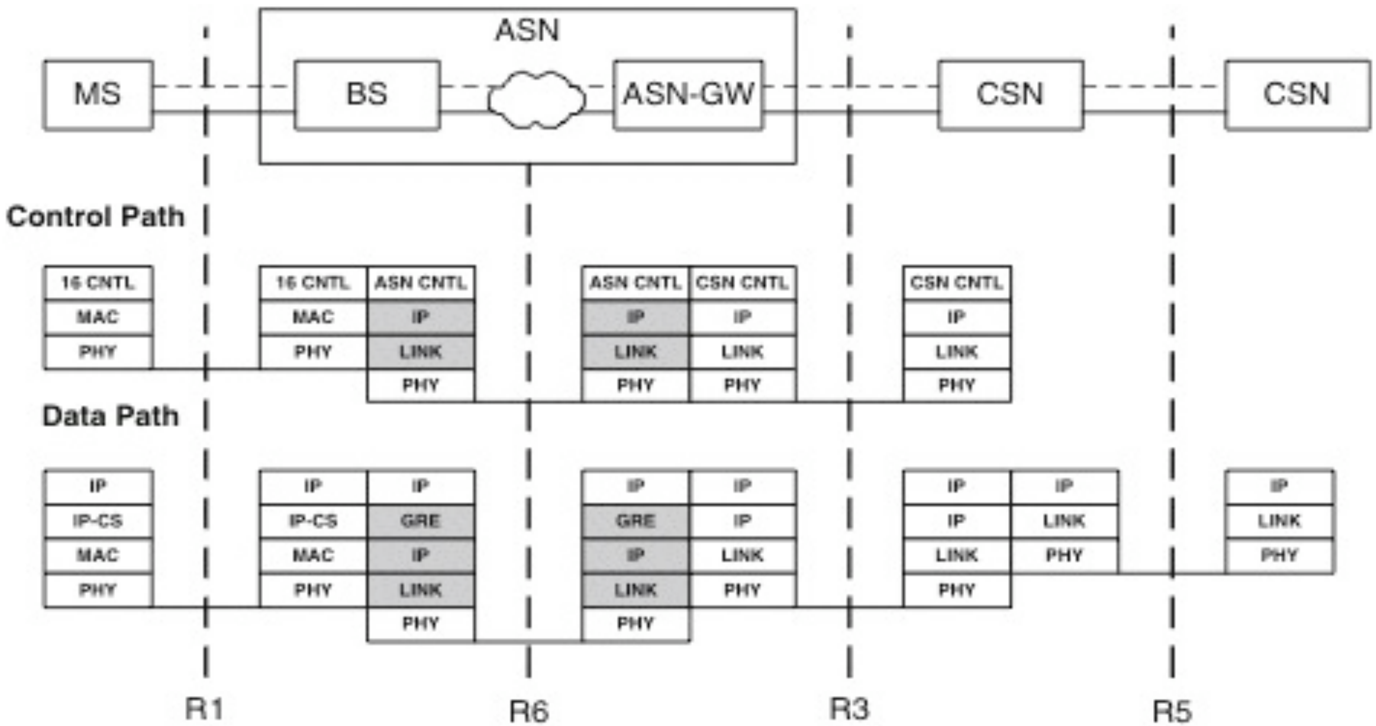


Fig. 10.4 IP-CS with routed ASN: If it is bridged ASN, then the shaded region would be replaced with an Ethernet layer (© WiMAX Forum 2005–2007)

Convergence Layer: Eth-CS

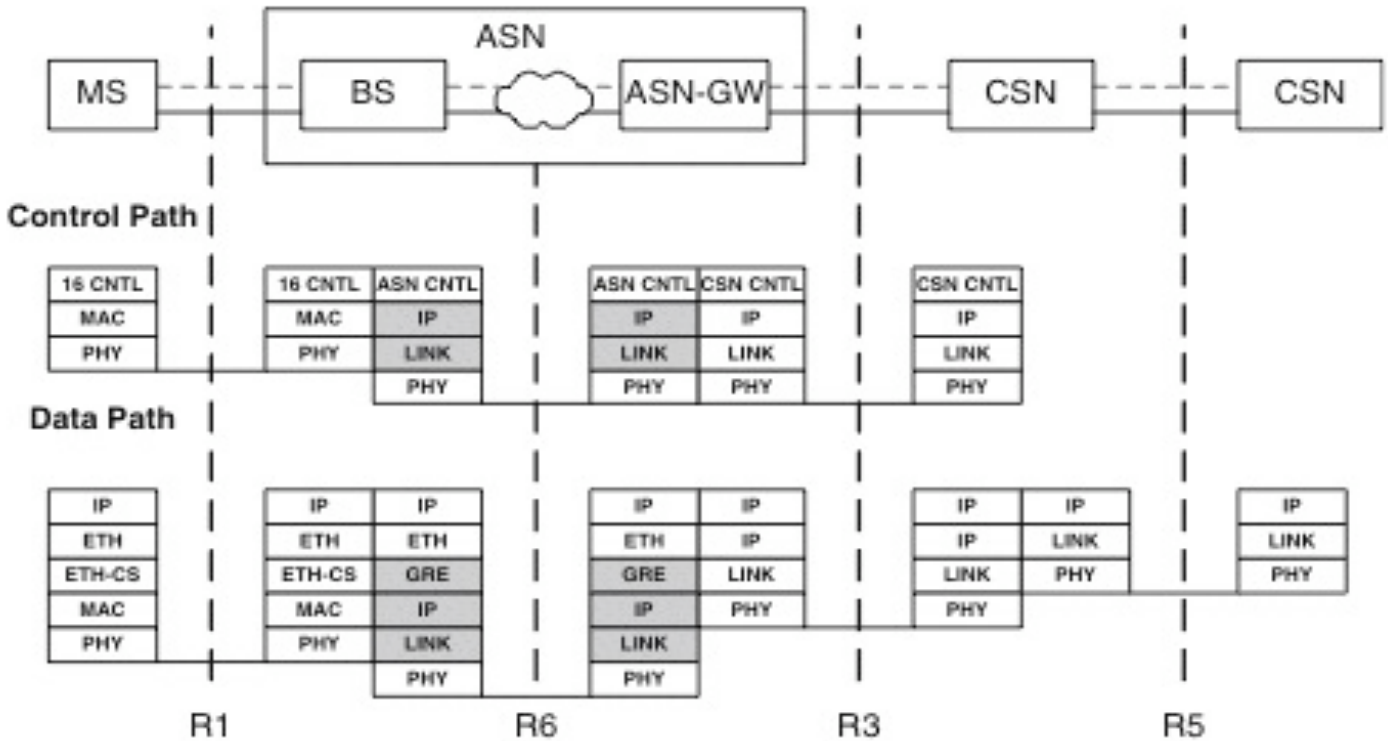


Fig. 10.5 Ethernet-CS with routed ASN: If it is bridged ASN, then shaded region would not be needed. Notice that Ethernet packets can be relayed up to CSN with another GRE tunnel between ASN-GW and CSN to enable VLAN services (© WiMAX Forum 2005–2007)

Network Discovery and Selection

- NAP Discovery: First, the subscriber needs to attach to a NAP. NAP is the owner of ASN, which basically provides the infrastructure for connection. Operator ID3 -24 bit is embedded into the Base Station ID of DL-MAP. The subscriber detects the NAPs by scanning and decoding the DL-MAPs and selects the one that broadcasts the NSP list, which the subscriber has right to access.
- NSP Discovery: Then, the subscriber needs NSP to get IP connectivity. A unique NSP ID4 -24 bit is also broadcasted. If more than one NSP uses the same NAP, then NSP list is provided to the subscriber from which the subscriber makes either an automatic or manual selection.
- NSP Enumeration and Selection: The subscriber either performs an automatic selection, which requires a dynamic information obtained within the area, or manual selection, which requires the user to exercise a provisioning procedure initially.
- ASN Attachment: After selection of NSP, the subscriber provides its identity and home NSP domain in the form of NAI (Network Access Identifier). From the realm portion of NAI, the ASN figures out the next AAA hop. The subscriber may provide a routing choice with decorated NAI as well if the home NSP is reachable through another NSP. For instance, “NSP4!user-name@NSP1.com” is a decorated NAI where NSP4 is reachable through NSP1.

AAA Framework

- **Authentication services:** AAA framework is responsible for authentication services such as device and/or user authentication.
- **Authorization services:** AAA framework is responsible for authorization services, which include delivery of information to configure the session for access, mobility, QoS, and other applications.
- **Accounting services:** AAA framework is responsible for accounting services, which include prepaid, postpaid, and hotlining activity.

Fig. 10.8 Greenfield Roaming AAA Framework (© WiMAX Forum 2005–2007)

Domains

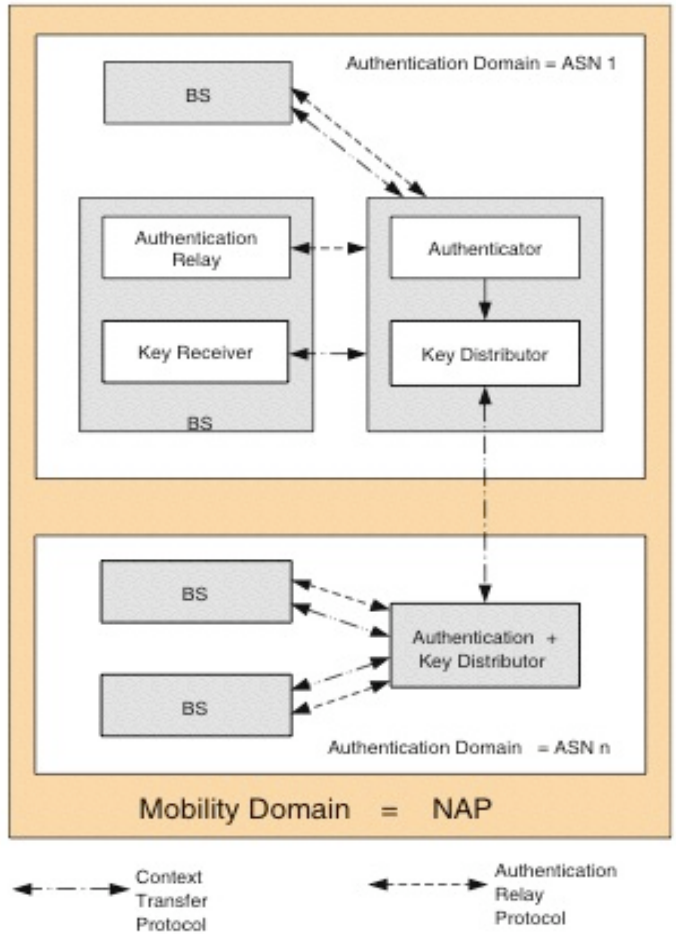


Fig. 10.10 Mobility and authenticator domains – Standalone model (© WiMAX Forum 2005–2007)

Authentication and Authorization Protocols

- PKMv2
- EAP

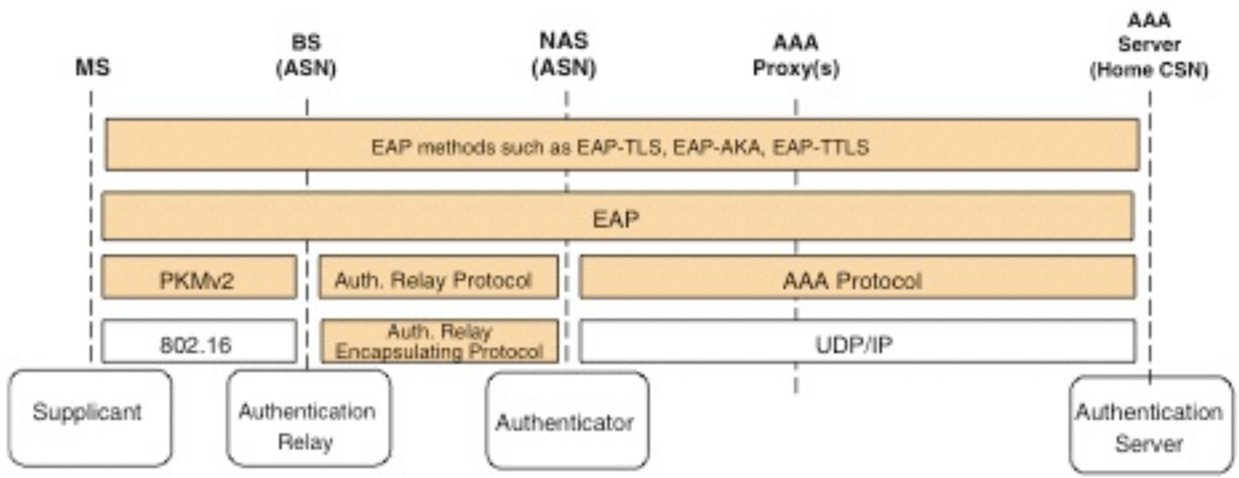


Fig. 10.9 PKMv2 User Authentication Protocols (© WiMAX Forum 2005–2007)

PKMv2 in network entry

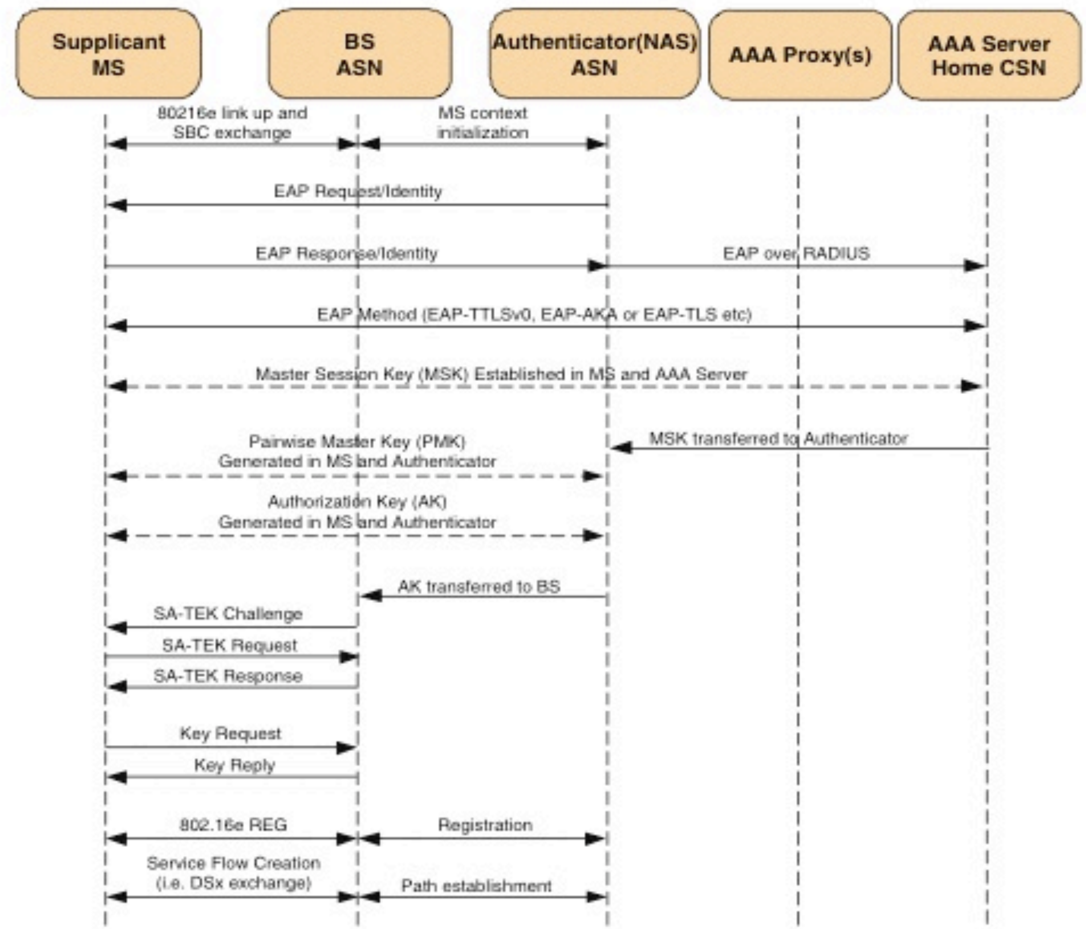


Fig. 10.11 PKMv2 procedure during network entry

Key Hierarchy

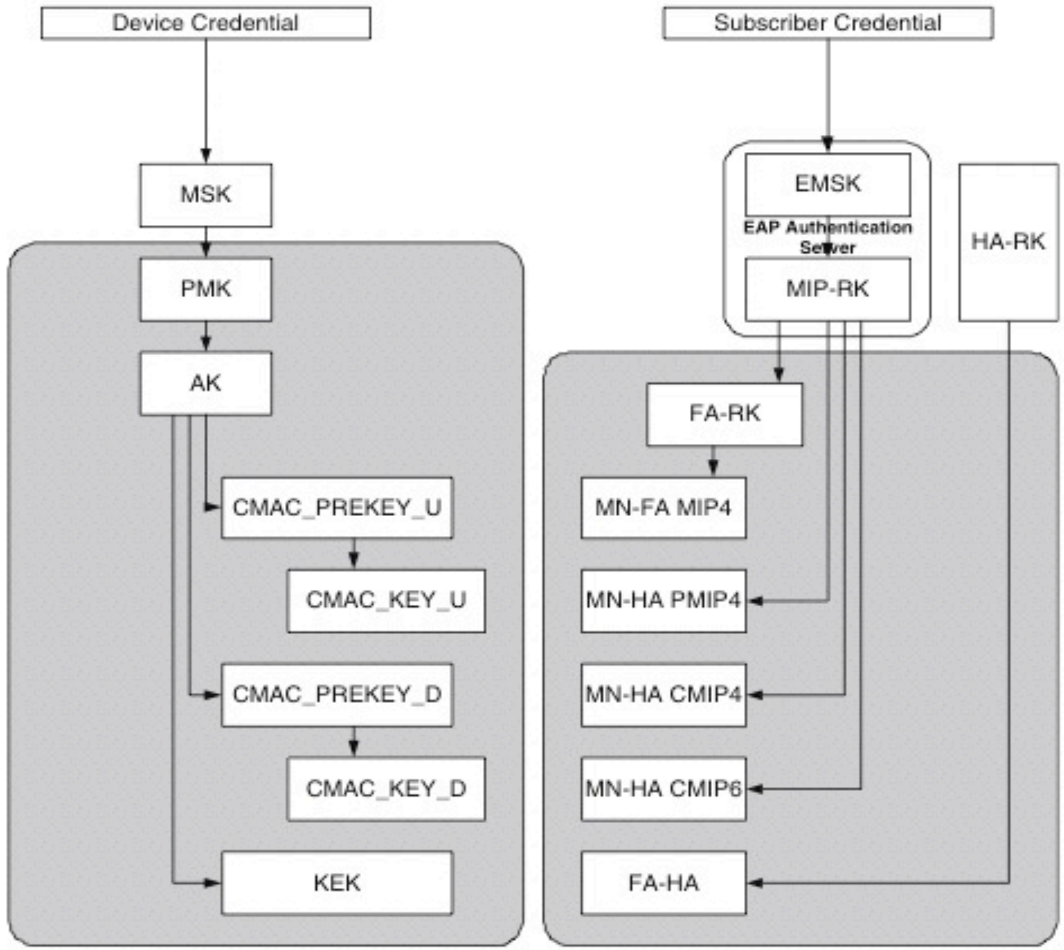


Fig. 10.12 Key hierarchy

Accounting

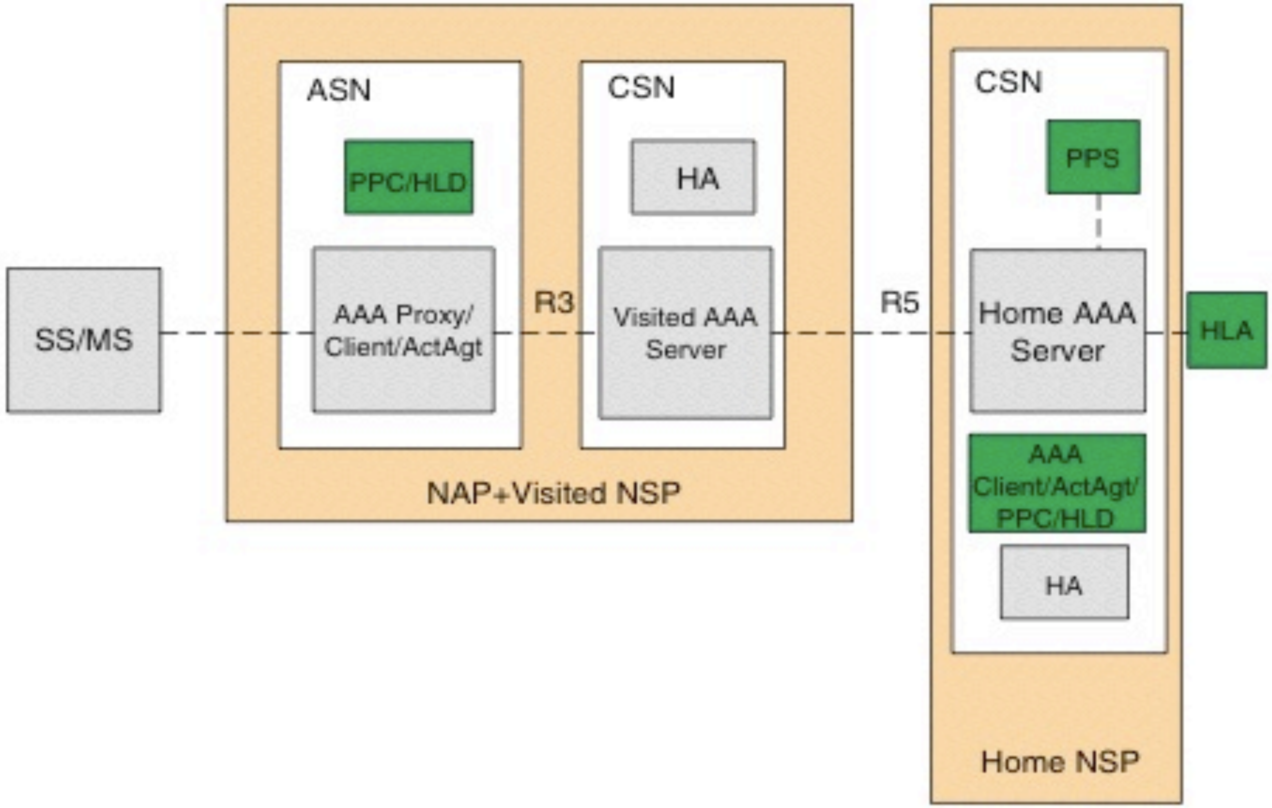


Fig. 10.13 Accounting architecture; Discarded or unsent data between MS and the account agent cause inaccurate charging; the accounting agent informs the Negative Volume count to AAA to avoid overcharging

Accounting Methods

- Offline accounting
- Online accounting
- Hotlining

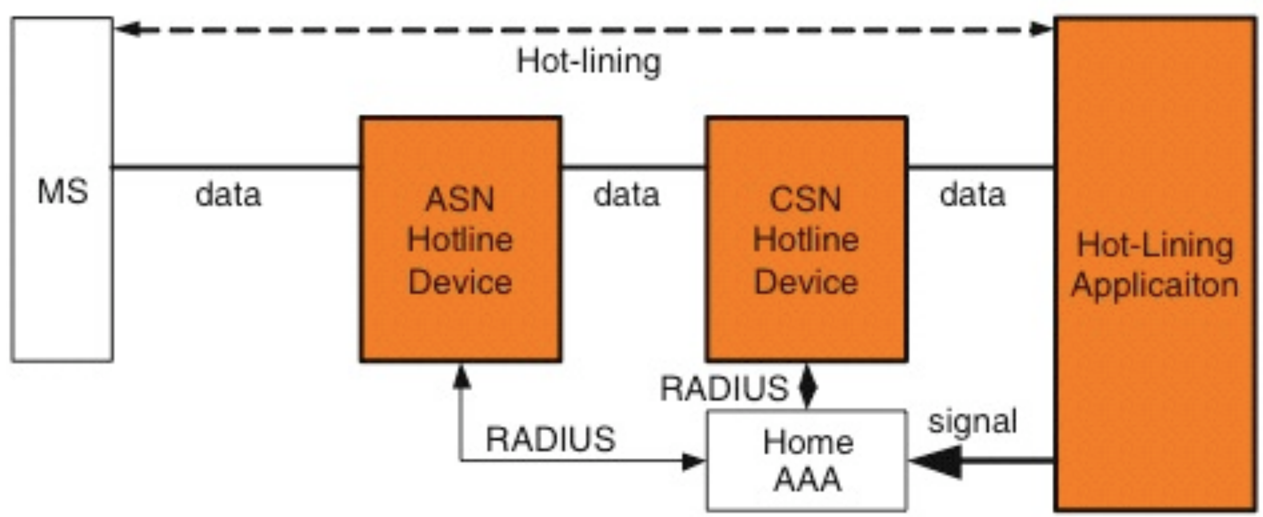


Fig. 10.14 Hot-lining

QoS Framework

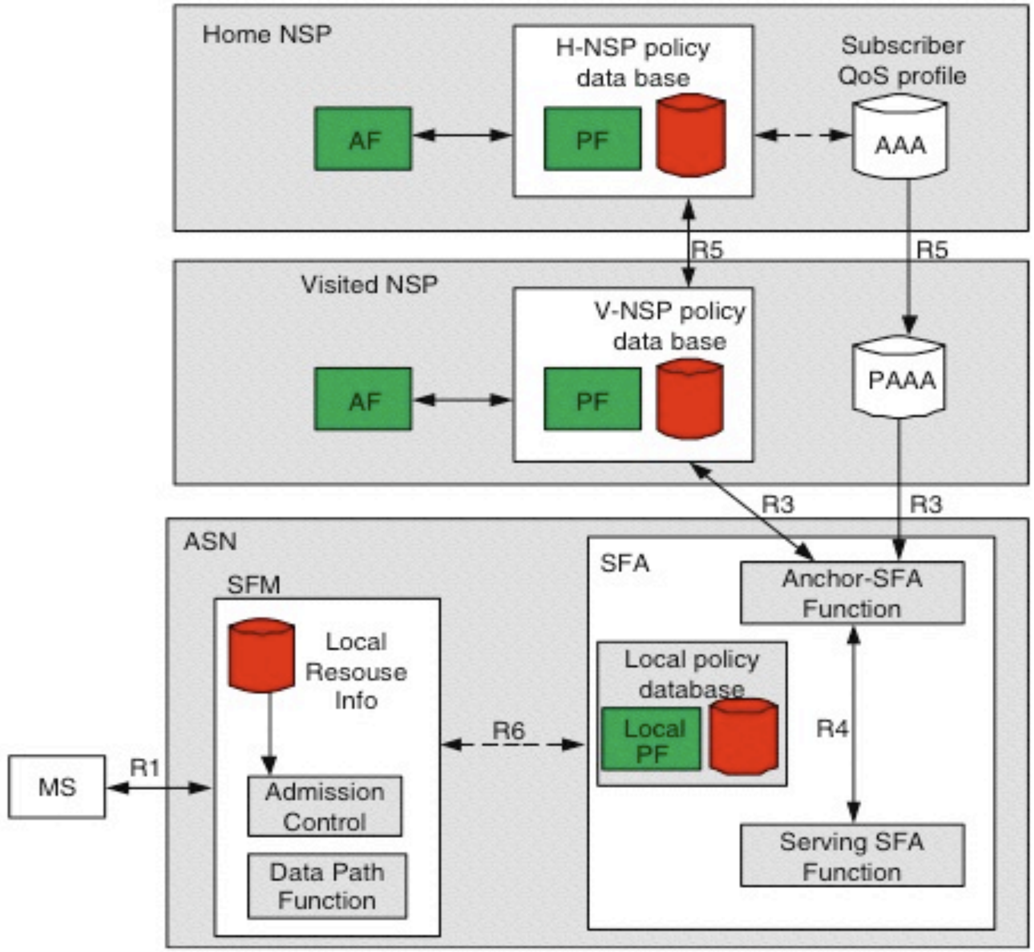


Fig. 10.15 QoS architecture (© WiMAX Forum 2005–2007)

Service Flow Creation

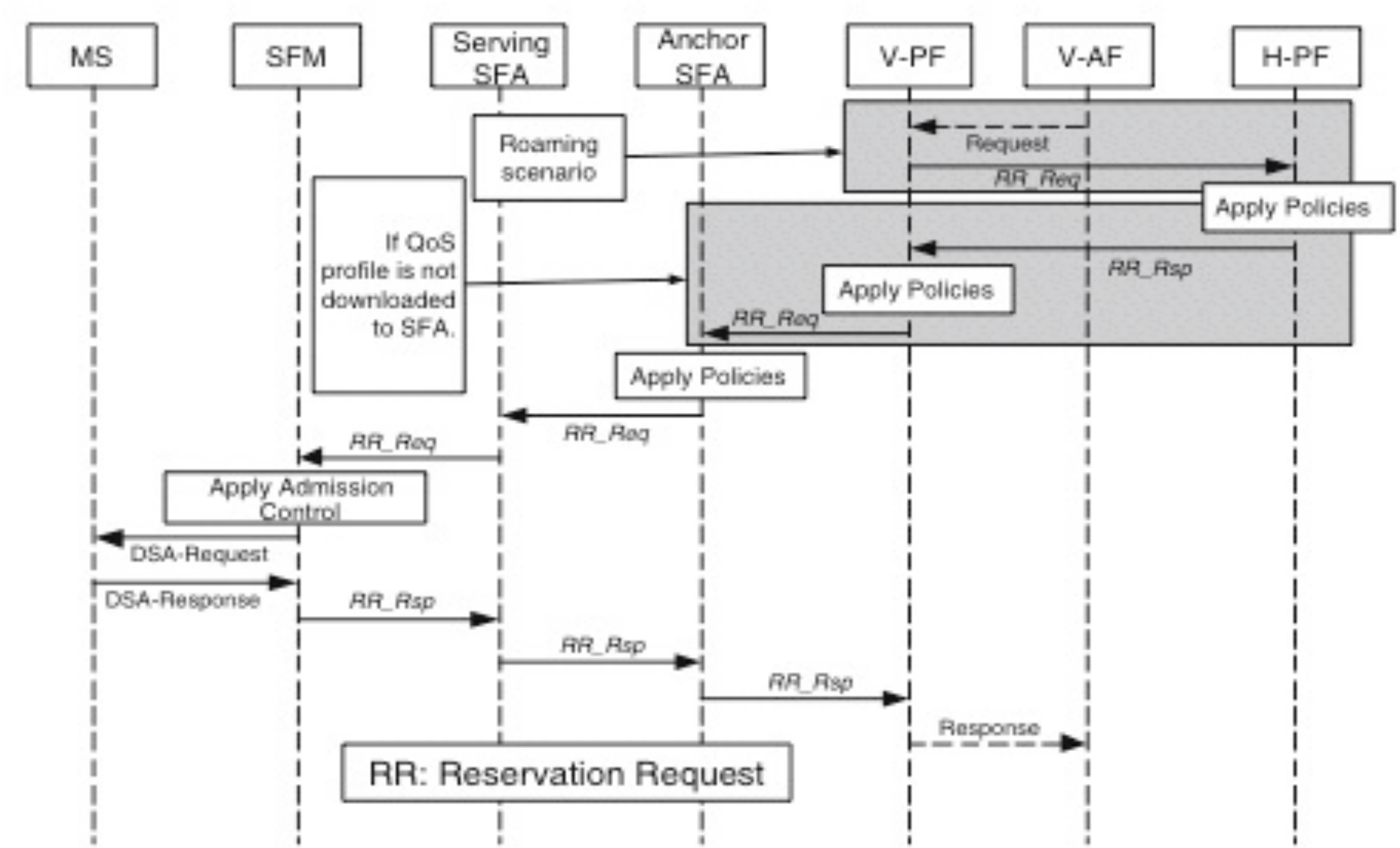


Fig. 10.16 Service flow creation triggered by the AF at the visited NSP

ASN Anchored Mobility

- Data Path (bearer) Function
- Handoff Function
- Context Function
- Data Integrity
  - Buffering
  - Bi/Multi-Casting

ASN Anchored Mobility

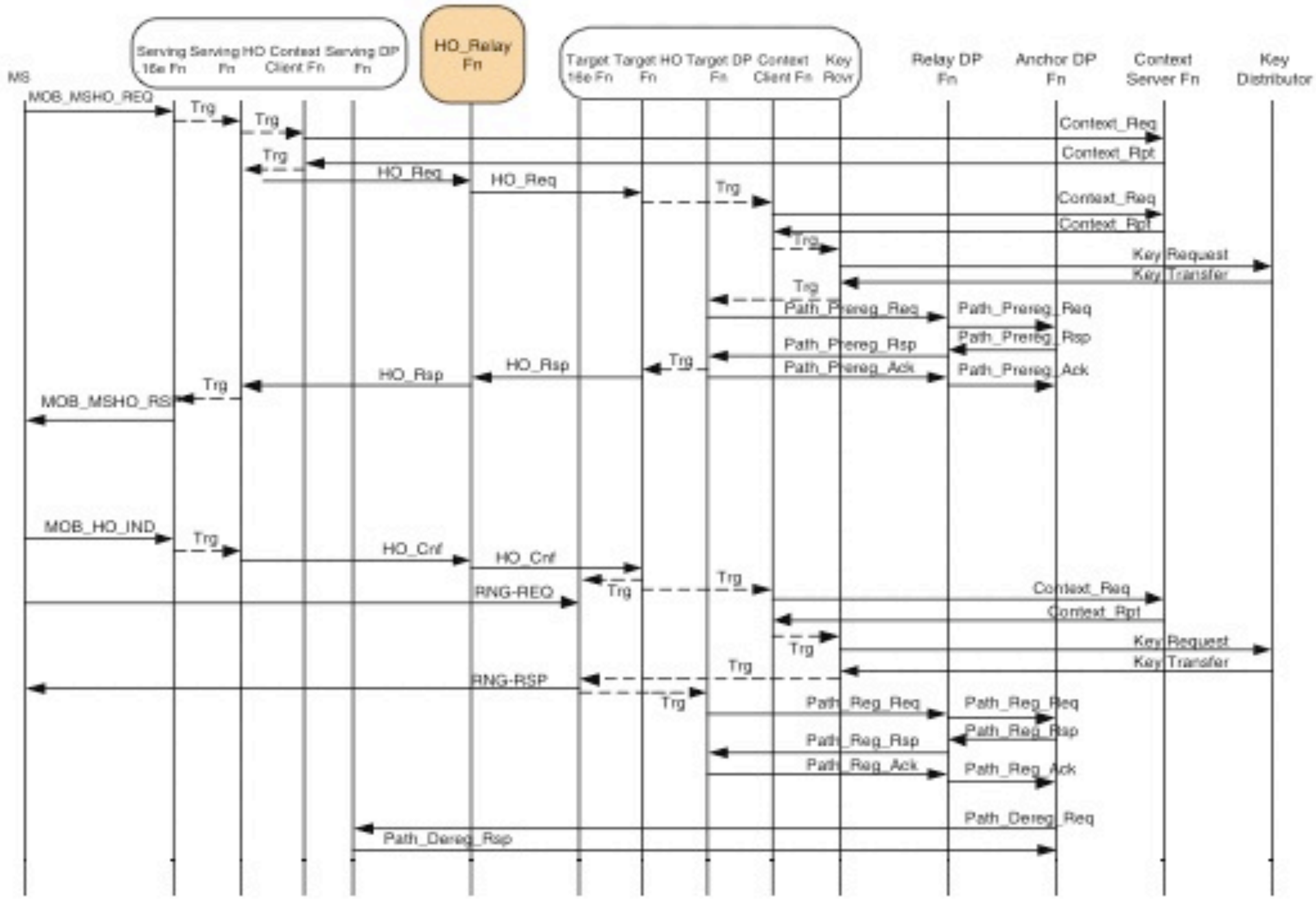


Fig. 10.17 ASN mobility functions: if BS can communicate through R8 link, then Relay HO Function is not used during R8 Handover (© WiMAX Forum 2005–2007)

CSN Anchored Mobility

- Proxy MIP

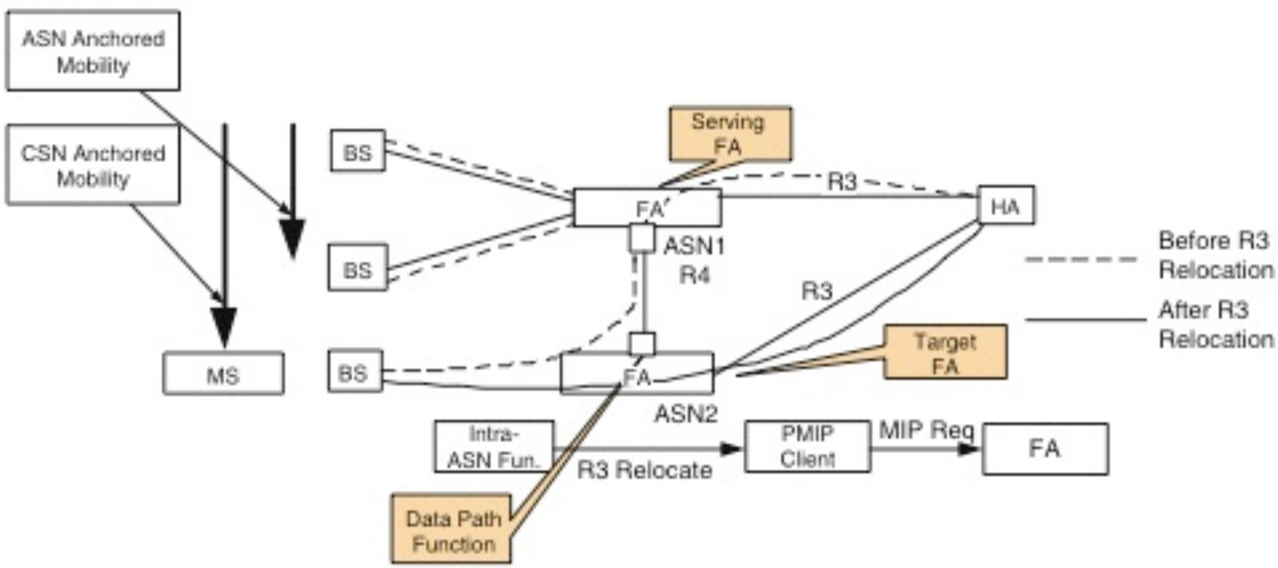


Fig. 10.18 CSN Mobility (© WiMAX Forum 2005–2007)

CSN Anchored Mobility

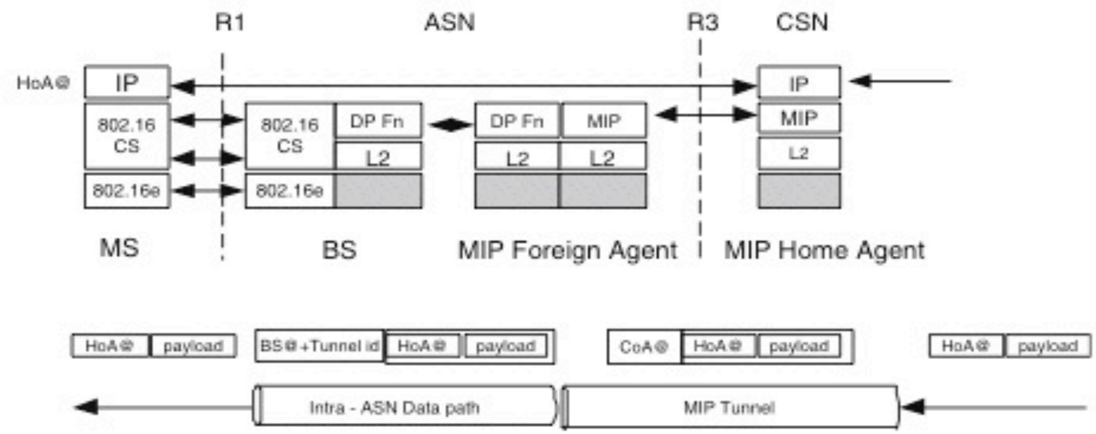


Fig. 10.19 Proxy MIP example (© WiMAX Forum 2005–2007)

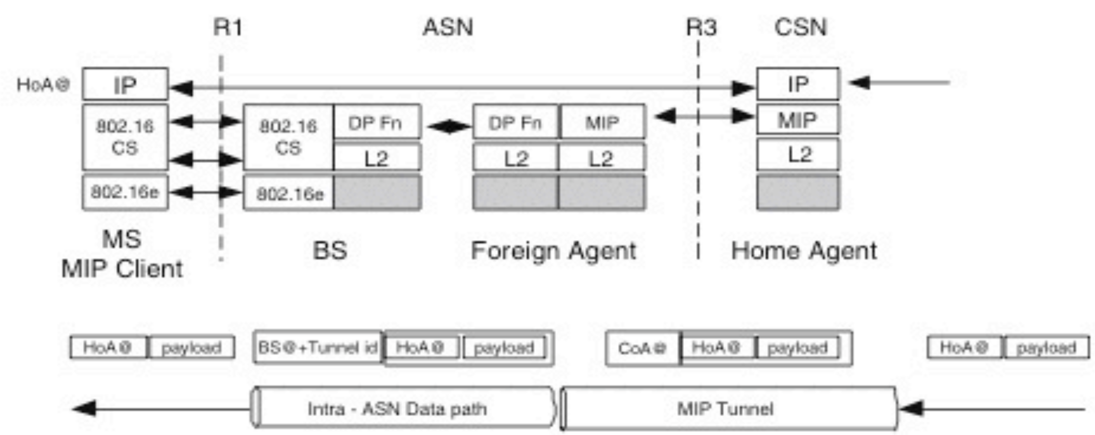


Fig. 10.20 Client MIP example (© WiMAX Forum 2005–2007)

RRM: Radio Resource Management

- RRM is responsible to utilize the radio resources efficiently. RRM function collects information about wireless link capability or available spare capacity and may assist other modules based on these aggregated information.
- RRM function comprises a Radio Resource Agent (RRA) in BS and Radio Resource Controller (RRC) in BS, ASN-GW, or a standalone server.
  - RRA is responsible to collect radio resource information of air link and relay them to the RRC. Information in RRC can be used for several purposes:
    - Admission control and connection
    - Service flow admission
    - Load control
    - Handover decision and preparation

Paging and Idle Mode

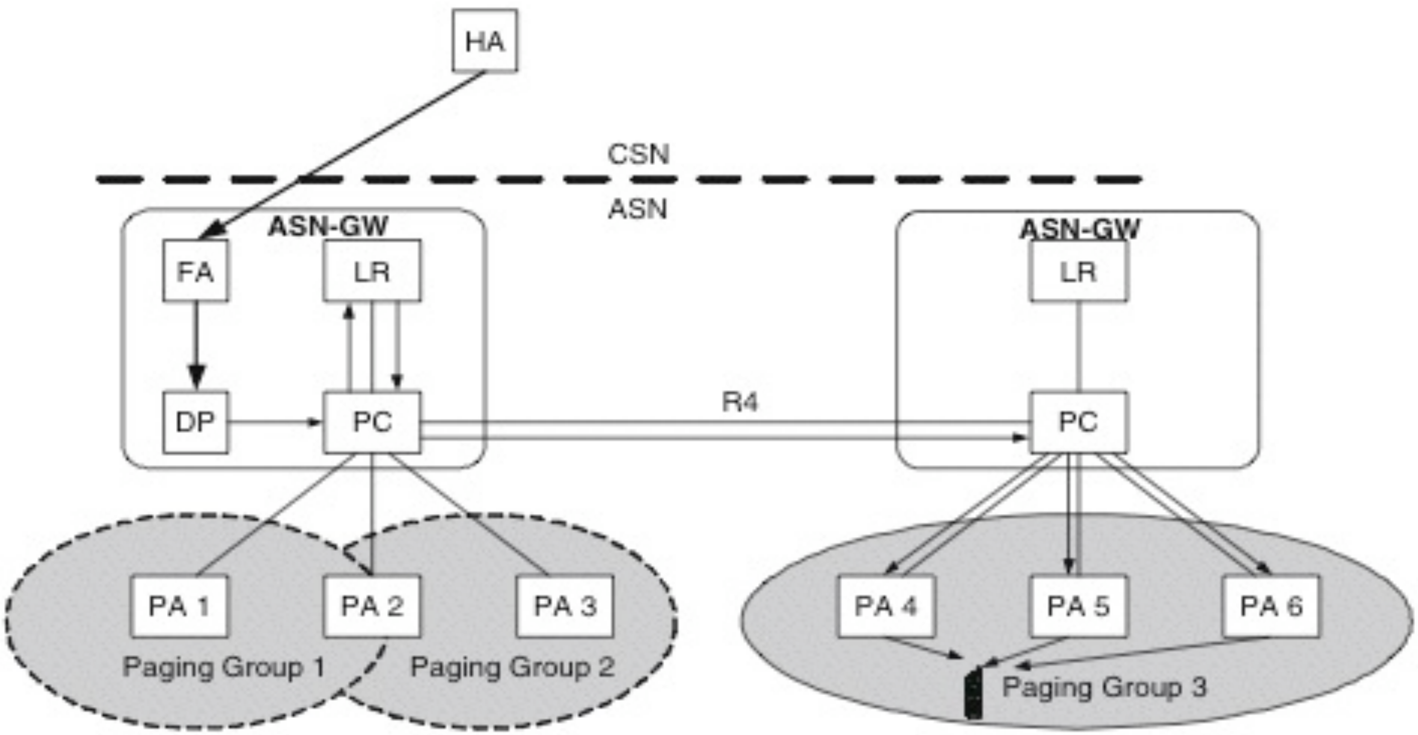
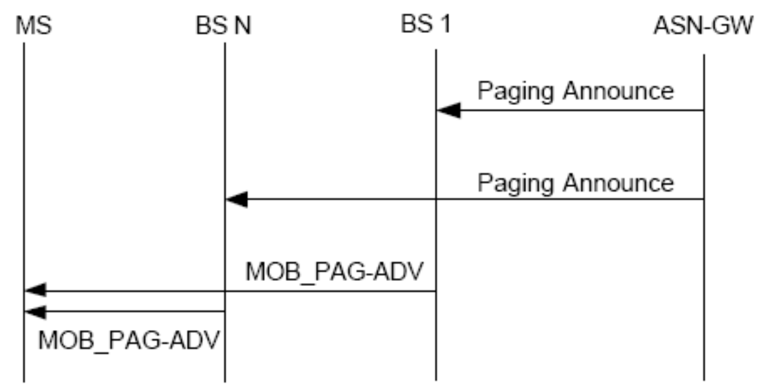


Fig. 10.21 Paging operation

Paging


MS
BS N
BS 1
ASN-GW
Paging Announce
Paging Announce
MOB_PAG-ADV
MOB_PAG-ADV

Paging

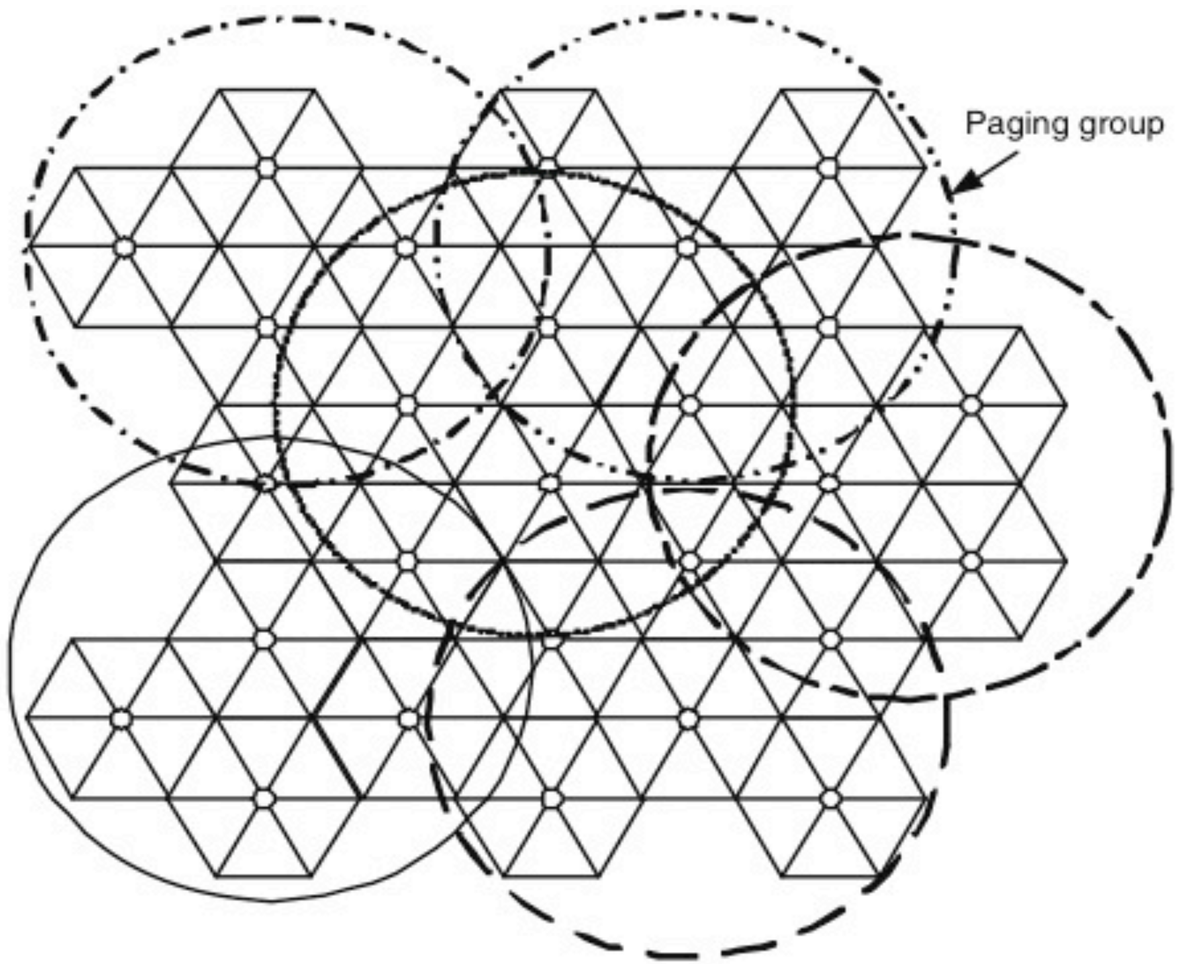


Fig. 9.14 Paging group

Release 1.5 Features

- ROHC: Robust Header Compression
- MCBCS: Multicast Broadcast Service
- LBS: Location Based Services
- ES: Emergency Services
- LI: Lawful Interception
- USI: Universal Services Interface
- OTA: Over-the-Air Provisioning

MCBCS

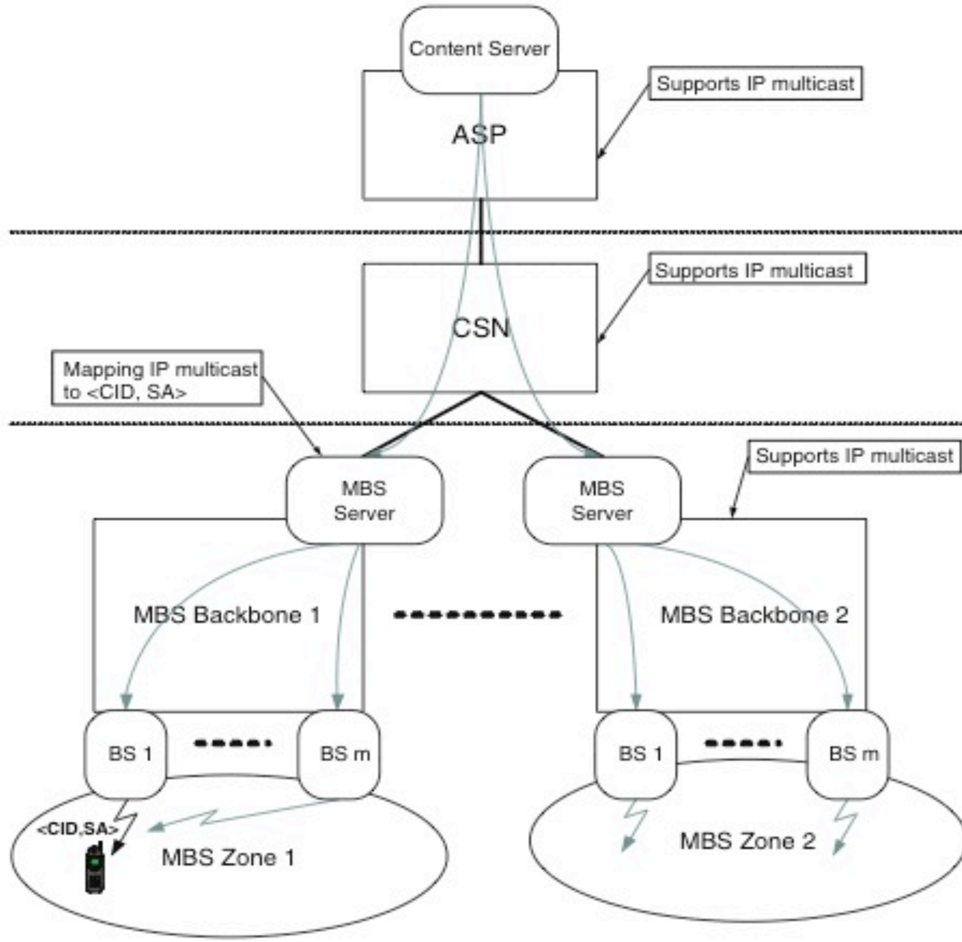


Fig. 10.25 End-to-end MCBCS scenario

LBS

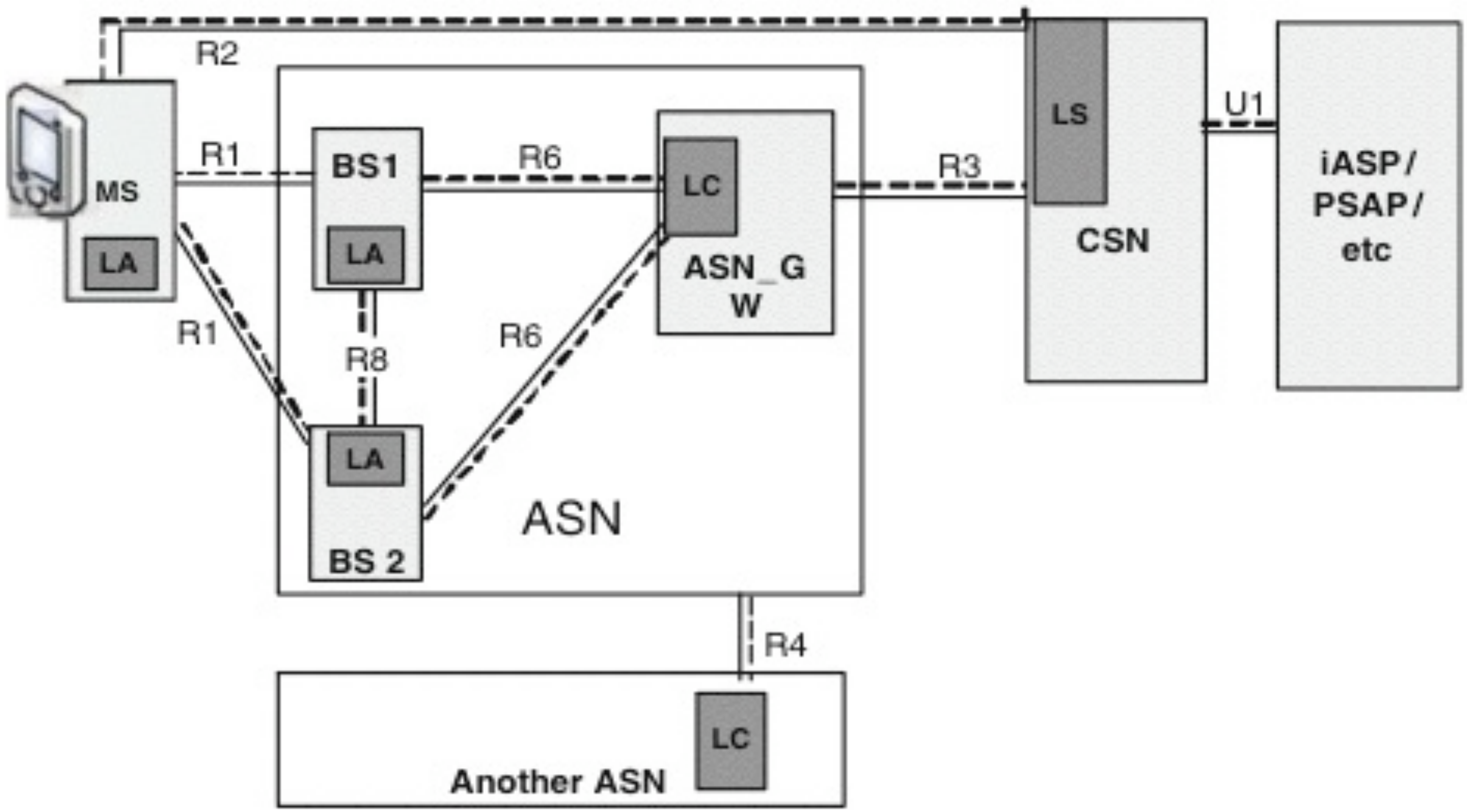


Fig. 10.26 Reference model for Location-Based Services (© WiMAX Forum 2005–2007)

LBS

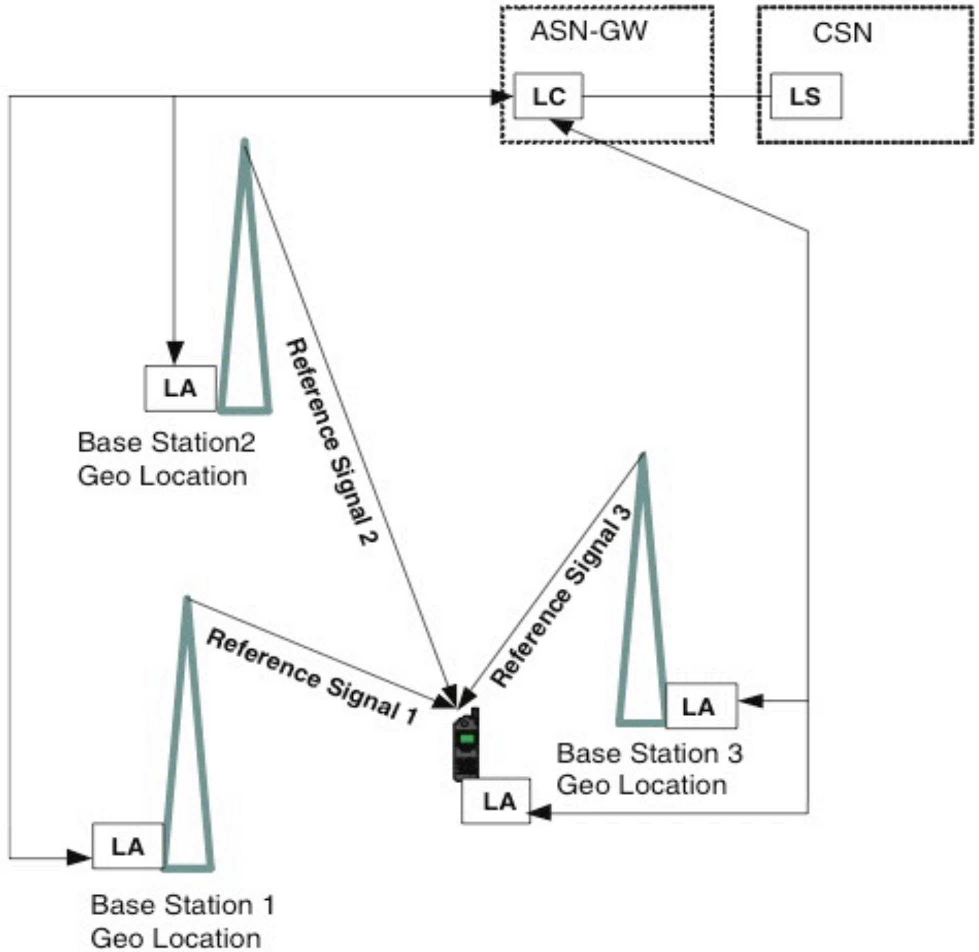


Fig. 10.27 Location determination with reference signals

ES

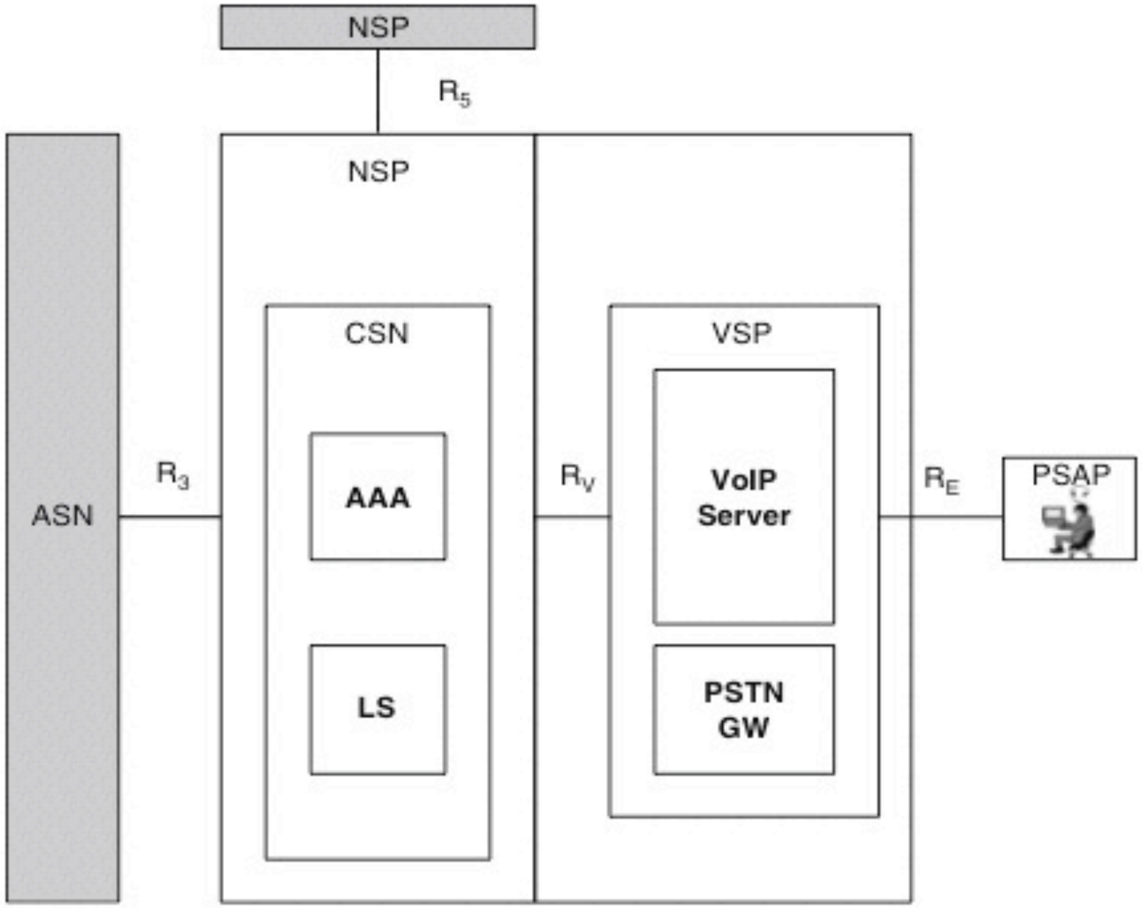


Fig. 10.28 Emergency Services (© WiMAX Forum 2005–2007)

LI

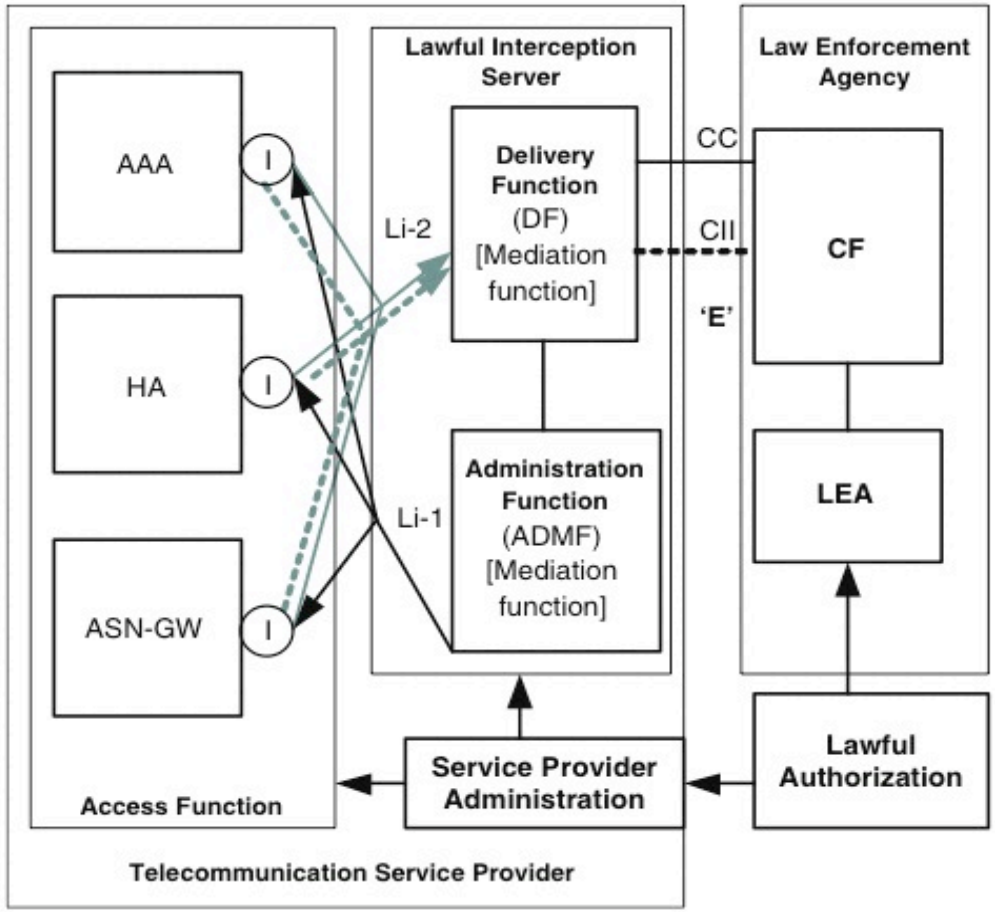


Fig. 10.29 Lawful Interception Reference Model for WiMAX: I represents IAP and TSP may represent a NAP, or NSP, or a NAP+NSP deployment case, or a "NAP Sharing" deployment case (© WiMAX Forum 2005–2007)

USI

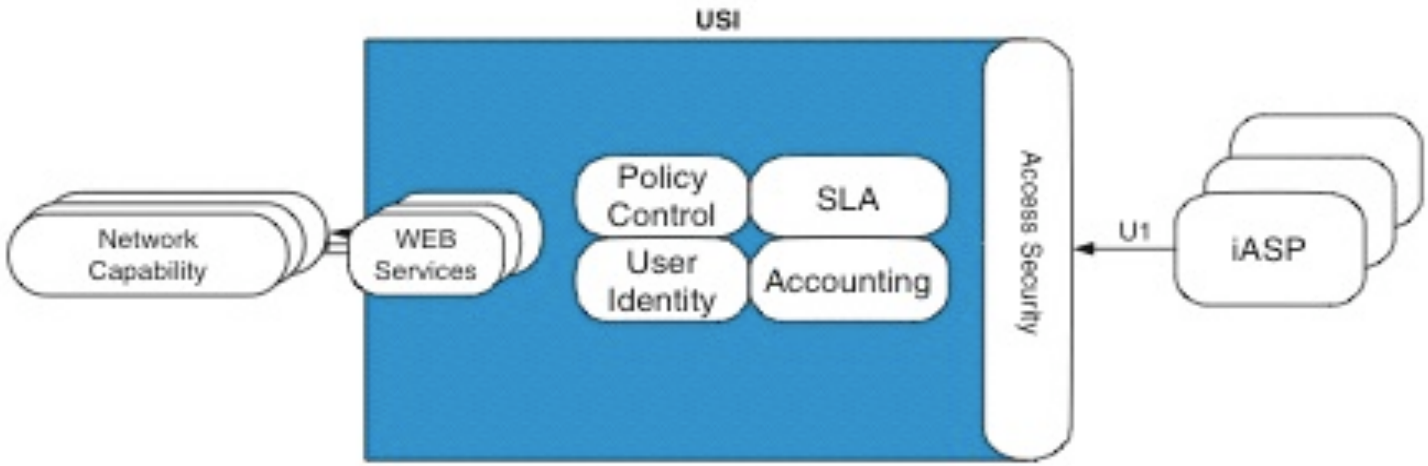


Fig. 10.30 USI module (© WiMAX Forum 2005–2007)

OTA

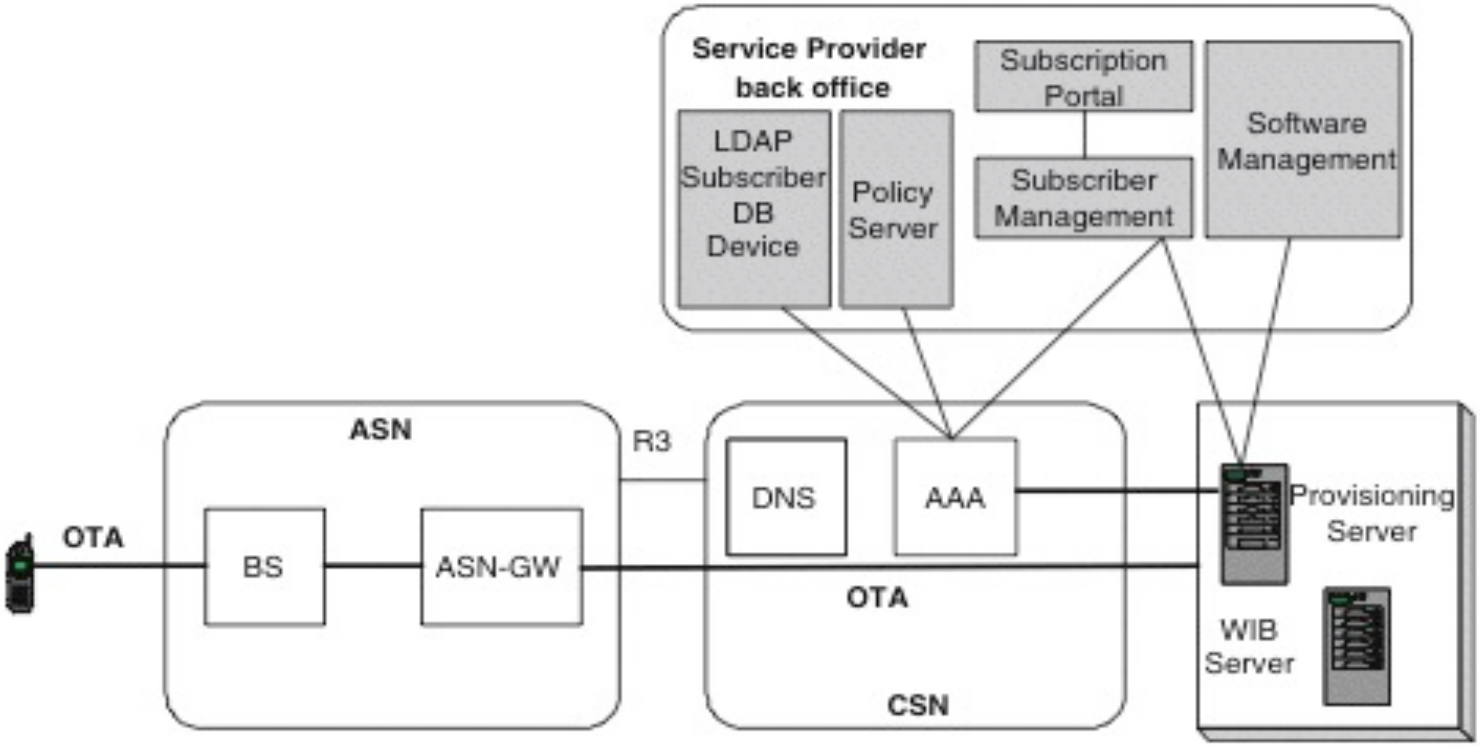


Fig. 10.31 OTA (© WiMAX Forum 2005–2007)

The ASN Gateway in 16e Networks

- ASN Gateway key part of 16e network architecture
  - Useful for Fixed, Nomadic and/or Mobile Networks
- Subscriber Management
  - Address Assignment (DCHP proxy, PMIP)
  - Authentication (EAP-based authenticator)
  - Service Flow Authorization and Creation
  - Accounting (Prepaid, Postpaid)

The ASN Gateway in 16e Networks (Contd…)

- IP Mobility
  - MIP Foreign Agent
  - Inter & Intra-ASN handovers
  - Paging/Idle Mode
- Network Optimization
  - Load Balancing
  - Seamless Handover support

Home Agent on WiMAX Networks

- The Home Agent provides an anchor point for subscriber stations, enabling inter-ASN mobility
- Works in conjunction with the Mobile IP Foreign Agent, located in the ASN Gateway, to register and track subscriber stations
- When a subscriber station moves to a different ASN, the Home Agent will intercept traffic destined for the subscriber station and tunnel that traffic to the appropriate ASN Gateway/Foreign Agent
- To ensure security, traffic from the traveling subscriber station will be tunneled back to its Home Agent for forwarding to the internet
- This enables subscriber stations to maintain their IP address as they connect to various points in the network
- The Home Agent also provides IP address assignment for subscriber stations in conjunction with the Proxy Mobile IP (PMIP) and DHCP proxy function in the ASN Gateway

Biography

- Mobile Broadband by M. Ergen